



# Economic comparison of white, green, and black flat roofs in the United States



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## ABSTRACT

White and “green” (vegetated) roofs have begun replacing conventional black (dark-colored) roofs to mitigate the adverse effects of dark impervious urban surfaces. This paper presents an economic perspective on roof color choice using a 50-year life-cycle cost analysis (LCCA). We find that relative to black roofs, white roofs provide a 50-year net savings (NS) of \$25/m<sup>2</sup> (\$2.40/ft<sup>2</sup>) and green roofs have a negative NS of \$71/m<sup>2</sup> (\$6.60/ft<sup>2</sup>). Despite lasting at least twice as long as white or black roofs, green roofs cannot compensate for their installation cost premium. However, while the 50-year NS of white roofs compared to green roofs is \$96/m<sup>2</sup> (\$8.90/ft<sup>2</sup>), the annualized cost premium is just \$3.20/m<sup>2</sup>-year (\$0.30/ft<sup>2</sup>-year). This annual difference is sufficiently small that the choice between a white and green roof should be based on preferences of the building owner. Owners concerned with global warming should choose white roofs, which are three times more effective than green roofs at cooling the globe. Owners concerned with local environmental benefits should choose green roofs, which offer built-in stormwater management and a “natural” urban landscape esthetic. We strongly recommend building code policies that phase out dark-colored roofs in warm climates to protect against their adverse public health externalities.

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## 1. Introduction

### 1.1. Background

Rapid urbanization in the United States (U.S.) during the 20th century converted much of the nation’s vegetation into urban areas, made up largely of buildings and pavements. According to the Statistical Abstract of the United States, nearly 75% of the U.S. population lives in large metropolitan areas [1]. In addition, U.S. buildings consume about 39% of total U.S. energy use, and contribute 40% of U.S. CO<sub>2</sub> emissions [2]. As global warming sets in, excess urban heat will exacerbate summer urban

*Abbreviations:* A/C, air-conditioning; BMP, best management practice; BUR, built-up bituminous roofing; CO<sub>2</sub>, carbon dioxide; CSO, combined sewer overflow; GHG, greenhouse gas; GSA, General Services Administration; LBNL, Lawrence Berkeley National Laboratory; LCCA, life-cycle cost analysis; LID, low-impact development; NO<sub>x</sub>, nitrogen oxides; NS, net savings; O&P, overhead & profit; SO<sub>2</sub>, sulphur dioxide; SR, solar reflectance; TPO, thermoplastic elastomers; UV, ultra-violet; VOC, volatile organic compound.

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heat islands and lead to more heat-related deaths, respiratory illness, increased peak electricity use, and other ecologically adverse impacts.

These detrimental impacts of urbanization on society and the environment are partly attributable to the conventional use of black and dark-colored roofs on buildings throughout the U.S. The majority of the building sector in the U.S. is made up of impervious black or dark-colored roofs that absorb roughly 80% of incoming sunlight [3]. The sunlight that is absorbed heats the roof, which increases cooling costs in air-conditioned buildings, increases discomfort in unconditioned buildings, increases mortality during heat waves, and pollutes local and regional air. To mitigate the public health hazards associated with dark-colored roofs [4,5],<sup>1</sup> the construction industry has begun replacing them in recent years with two roofing alternatives—white and “green” (vegetated) roofs—that are much more beneficial to society and the urban environment.

<sup>1</sup> Excess deaths during the 2003 European heat wave were estimated to be over 50,000 [4]; analysis of the 1995 Chicago heat wave identified as a critical risk factor living on the top floor of a building (beneath a black roof) [5].

**Table 1**  
Solar reflectance summary for white and green roofs.

		Aged white roof	Green roof
1	Solar reflectance (SR)	0.55	0.20
2	Ratio of SR (white/green)	2.75 (rounded to 3)	1
3	One-time emitted CO <sub>2</sub> offset (tons CO <sub>2</sub> e/100 m <sup>2</sup> )	10	~3
4	Row 3 converted to an annual rate over a 20-year roof service life (tons/year)	0.5	0.15
5	Global potential for cool roofs relative to black roofs, one-time CO <sub>2</sub> offset (Gt)	24	8
6	Row 5 converted to annual rate over a 20 yr. roof service life (Gt/year)	1.2	0.4

As first estimated by Akbari et al. [6], converting 100 m<sup>2</sup> of dark roof to white offsets the emission of ~10 tons of CO<sub>2</sub>. Therefore, according to the (2.75 ± 0.5):1 ratio of the SR of white and green roofs, 100 m<sup>2</sup> of green roof has a one-time global warming offset potential of 3–4 tons of CO<sub>2</sub> equivalent.

## 1.2. White and green roofs are displacing black roofs

For flat “cool roofs,” white is the most effective color. A white roof reflects 55–80%<sup>2</sup> of incident sunlight [3], keeping its surface cool on a clear summer day. This reduces heat transfer through the roof and makes the space below the roof more comfortable in unconditioned buildings. White roofs on air-conditioned buildings in hot climates can cut cooling energy use by 10–20% on the floor of the building immediately beneath the roof [6]. Cooler roof surfaces also mitigate the urban heat island effect, which improves air quality, reduces GHG emissions from power plants, and increases grid reliability during the summer (see supplementary data in the online version for more information on types of white roofs).

Moreover, increasing the solar reflectance (SR) of roof surfaces reduces the amount of heat absorbed at earth’s surface and transferred into the atmosphere. This “albedo effect”<sup>3</sup> counters global warming; studies estimate that converting 100 m<sup>2</sup> (roughly 1000 ft<sup>2</sup>) of dark roof to white offsets the emission of 10 tons of CO<sub>2</sub> equivalent over the lifetime of the roof [6,7]. Akbari et al. [6] also estimate the global cooling potential for cool roofs (mainly flat white roofs) in cities with hot summers to have a one-time offset potential of 24 GtCO<sub>2</sub>e. Assuming that the world’s average car emits 4 tons of CO<sub>2</sub> per year, this offset is roughly equivalent to taking half of the world’s approximately 600 million cars off the road for 20 years.

Relative to white roofs, green roofs are less reflective of incoming sunlight and therefore have lower global cooling potential. Figure 4 of Gaffin et al. [8] indicates that average July SR of an extensive green roof is 0.20. We assume that an aged white roof has an SR of 0.55, which can be rounded to three times the green roof SR owing to the uncertainty in both SR estimates. This threefold difference in solar reflectance corresponds to a threefold difference in global cooling potential, which is a distinction no studies have made to date. Applied to the above greenhouse gas offsetting estimates from Akbari et al. [6], this suggests that replacing 100 m<sup>2</sup> of dark roof with a green roof offsets the emission of 3–4 tons of CO<sub>2</sub> equivalent over the lifetime of the roof (see Table 1 for a comparison of global cooling potentials between white and green roofs). Thus white roofs, which offset 10 tons of CO<sub>2</sub> equivalent for every 100 m<sup>2</sup> of roof area, more effectively help to cool the world and mimic high-albedo land surfaces such as disappearing glaciers or Arctic sea ice<sup>4</sup> [9–11].

“Green” (vegetated) roofs vary in size, weight and vegetation, but they all shade the roof and protect it from water, UV damage, thermal cycling (expansion and contraction), and roof punctures. Vegetation and soil cool the roof’s surface and the nearby air in two major ways: (1) they provide additional insulation and thermal mass to the roof, which reduces the transfer of heat into the space below; (2) evapotranspiration transforms sensible heat into latent heat of vaporization. However, it should be noted that while this lowers the city air temperature, it does not influence global temperatures.<sup>5</sup> On a sunny summer day, these factors reduce electricity use in air-conditioned buildings and improve comfort in non-air-conditioned buildings. By reducing electricity demand in cities, green roofs reduce the emission of air pollutants and GHGs from power plants, which in turn mitigates global warming and improves urban air quality.

Unlike white or black roofs, green roofs can be part of a building stormwater management plan. In wet weather, green roofs can reduce peak runoff by up to 65% and extend by 3 h the time it takes for water to leave a site. “Extensive” green roofs (described more in Section 1.3.2 and in detail in the supplementary data in the online version) intercept and retain the first 1–2 cm (0.5–0.8 in) of rainfall, preventing it from running off. In cities that require stormwater management plans, green roofs can save building owners money on both avoided stormwater fees and the costs of upgrading stormwater infrastructure [12]. This is particularly helpful in older cities that have undersized combined sewer systems.<sup>6</sup> Additionally, green roofs can create natural habitats, limit noise pollution, and increase property values.

Relative to black roofs that increase urban climate vulnerability, white and green roofs confer social benefits that make cities more comfortable. However, because there is no standard protocol for quantifying these urban heat island-related externalities, comparisons among these three roofing strategies are limited. To date there have been a number of published case studies that compare green roofs to black roofs [12–16] and white roofs to black roofs [17–20]. However, we could not find a comprehensive comparison of green and white roofs.

This paper presents a 50-year LCCA<sup>7</sup> for white, green, and black roofs using data collected from 22 flat roof projects or studies in the U.S. Even without accounting for important heat island-related externalities, we investigate whether white and green roofs offer purely economic advantages over black roofs. We seek to determine

<sup>2</sup> Reflectance degrades as the white roof ages—a solar reflectance of 0.80 is typical of a new white roof, and a solar reflectance of 0.55 is typical after 1–2 years.

<sup>3</sup> “Albedo” is a Greek term meaning “whiteness” and is used interchangeably with the term “solar reflectance.”

<sup>4</sup> This analysis relies solely upon comparing differences in albedo, and does not consider the resulting changes in upward fluxes of sensible and latent heat [9,10]. Nor does it consider any climate feedbacks, such as cloud formation and precipitation, that can result from changes in roof albedo [11]. We take these to be

second-order effects on which no consensus currently exists, but we acknowledge their ability to affect our results.

<sup>5</sup> Wind transfers cool moist air away from the city, where it condenses as rain. The heat released during condensation exactly cancels the evaporative cooling, so there is no net global cooling effect.

<sup>6</sup> These cities may experience CSOs (combined sewer overflow), which result in the discharge of untreated wastewater and stormwater from a combined sewer system directly into a river, stream, lake, or ocean.

<sup>7</sup> We refer to our analysis as an LCCA, whereas GSA [12] refers to its analysis as a cost-benefit analysis. We view these terms as interchangeable.

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