



Analysis of "Economic Comparison of White, Green, and Black Flat Roofs In the United States"

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Based on a concern that the design community, standards committees and local governments are being provided with faulty recommendations based on flawed science, the EPDM Roofing Association (ERA) assembled a group of roofing industry representatives and experts to conduct a preliminary critical review of the Lawrence Berkeley National Laboratory (LBNL) study entitled "Economic Comparison of White, Green and Black Flat Roofs in the United States" published in the March 2014, issue of *Energy and Buildings*. The following are general observations regarding the LBNL study that point to a systematic failure to comply with scientific method, resulting in potentially biased and highly uncertain conclusions and recommendations. These general observations are followed by a more detailed analysis in the second section of this document. ERA and the industry it represents (manufacturers of *both black and white roof* membranes) welcome a response and dialogue with the LBNL researchers on this matter and regret that such opportunity was not afforded during their study and prior to publication.

1. First, the economic findings indicate a favorable conclusion for black roofs. Ignoring the economic results (the stated focus of the study), the authors appeal to largely non-quantified or highly uncertain environmental and human health effects to support their conclusion that black roofs should be "phased out." This substitutionary appeal to information largely unaddressed or evaluated by the study is not the best way to conduct scientific research or support conclusions.
2. Second, the ERA review group found cases in which evidence supporting black roofs was disregarded. For example, the researchers did not take geographical climate differences into consideration, even though black roofs absorb heat and offer energy savings, environmental benefits, and human health advantages in cold climates. Instead of recognizing the pros and cons in a balanced fashion, the researchers seemingly conducted their study and analysis with a selective bias against black roofs and a corresponding support of white roofs. Such an obvious bias indicates a failure to satisfy the fundamental purpose of scientific method.
3. Third, the ERA group identified cases in which assumptions and approach were not reported in such a way that the study could be repeated. From a reporting standpoint, this indicates a failure to comply with scientific method because the study is not reproducible. The authors themselves characterized their data as "somewhat sparse" and "lamentably thin" and the report frequently relies on incomplete sources and interpretations of data. For instance, the authors made the assumption that black and white roofs have "an equal 20-year service life" when many white roof systems have not been on the market long enough to demonstrate a lifespan of 20 years, and it is not uncommon for EPDM roof systems to last for more than 35 years. Heat aging tests of in situ EPDM materials already over thirty years showed potential for a 60-year service life on 45-mil membrane. Some consultants are now regularly designing "50-year" roof systems and papers on designing 60-year EPDM roof systems have been presented at international symposia

SUPPORTING ANALYSIS:

- 1) **OVERALL APPROACH:** This study essentially follows a life-cycle costing approach. It admits to the "lamentable scarcity" of data used to establish key input data for the analysis. Under such circumstances several options should have been more carefully considered:

- a. Conduct sensitivity studies for all input parameters to determine the effect on result as recommended by ASTM E917.
- b. Abandon the study approach and spend the effort to get a better understanding of the input variables (and their uncertainties) that directly influence the analysis result.
- c. Treat the study as “exploratory” and avoid definitive and wide-sweeping conclusions that are supported only by the assumptions made and not well-supported by sound scientific method.
- d. Expand the roofing options considered such that the study meets a reasonable level of completeness in consideration of market options. For example, use of a ballasted roof with a black membrane and roof insulation levels at modern code levels was not considered. However, ballasted systems carry some of the benefits of the “green roof” and “white roof” options, with little cost premium, while also extending the service life of the black roof option. Leaving this option out of the report is incomplete at best, and misleading at worst.
- e. Furthermore, the study misses an opportunity to provide useful and practical guidance to the industry and public, instead seeming to demonize other options or useful sources of information and perspective that were not considered or deemed by their judgment to be unacceptable (e.g., “...private actors will not always make the socially optimal roofing choice. This presents a strong case for public policy to intervene by phasing out black roofs...”).
- f. As a last concern, the report does not fully disclose how the researchers treated the data and then applied that data in a life-cycle cost analysis. For example, the report refers to “emission factors” that were used to escalate the cost impact of black roofs based on evaluated energy consumption, but does not show how they were applied to the data presented. They also did not include increased energy consumption in winter for white roofs and, therefore, the emission factors tend to compound a clear and intentional bias in the report, discussed further below. They also don’t disclose how energy consumption for the various roofs was determined and what levels of roof insulation were used. Thus, the study as reported is effectively “non-repeatable” and, therefore, it fails to meet this basic principle of scientific method.
- g. With further support from the concerns detailed below, these overall concerns erode the validity of the study and cast doubt on its scientific credibility.

2) VARIOUS DETAILS, INPUTS, AND ASSUMPTIONS:

a. CASE STUDY DATA SET:

- i. The study contains a sample of only 22 buildings with very incomplete data for each, such that the sample size for various key analysis inputs is subject to significant sampling error, significantly weakening the ability to make definitive scientific conclusions. One must also question how the data that was reported for each case study was generated in those case studies. The report appears to be lacking a quality control procedure for assessing the very limited data extracted from reports by others.
- ii. The representativeness of the case studies with respect to climate zones, distribution of building stock, and other key factors was not addressed. Thus, the results have no real connection to a “national average” or “regional relevance”.
- iii. Where data was missing from the case studies (most often the case), the authors substituted median values under the assumption that this would create meaningful results. This corrupts the statistical validity of the report and further disconnects its applicability to a national average or specific region. The study is only relevant to the case studies and the manifold data manipulations done to address missing data.

- iv. Furthermore, there are clearly “outliers” in the data set that were not addressed (e.g., black roof costing \$242/m² in one case, which exceeds the cost of all of the green roof samples; this deserves an explanation).
 - v. Finally, and probably the most obvious and intentional example of the bias of the authors toward white roofs, was how they addressed the problem that none of the case studies had winter heating cost data reported. Where this occurred for other missing data, the authors provided at least some attempt to create substitute data. Instead, they chose to assume a ZERO cost penalty for white roofs during the winter merely because it was absent from the data, ignoring the known physics of white roof performance in the winter. This clearly biased the results toward selection of white roofs in the economic analyses and invalidates the study as a “national average” and especially a regional basis in climates that are mixed or heating dominated.
- b. **SOLAR REFLECTANCE ASSUMPTION AND WHITE ROOF CLEANING:** The study uses a 2-year aged value of 0.55 for white roofs and ignores the cost of cleaning to maintain this value on average over the life of the roof. Other data on aging of white roofs (LBNL/NRC paper for Cool Roofing Symposium, Atlanta, GA) indicate an average SR over the life of an uncleaned white roof to be about 0.47, not 0.55. Thus, a lower SR of 0.47 should have been considered in the study, or the cost of roof cleaning approximately every four years should have been included with the operating and maintenance cost of the white roof. This analysis shortcut taken by the authors again appears to bias the conclusion toward white roofs.
- c. **LIFE EXPECTANCY:** A 20-year life expectancy was assumed for both white and black roofs. The basis of this assumption is lacking factual support or input from industry experience. Black EPDM has been shown to last upwards of 35 years in the field, and up to 50 years in heat aging studies. There is greater uncertainty in the white roof life expectancy and at a minimum this should be accounted for in the study. This is an example where greater effort should have been put into developing sound input data for the life-cycle cost analysis so that the results of the study would carry less uncertainty based on critical comparative input variables and assumptions. Likewise, if the black roof were covered with ballast, its life expectancy would certainly be increased but, as mentioned, this viable option was not even considered in the study.
- d. **GLOBAL COOLING ECONOMIC BENEFIT COST DATA:** The researchers fail to acknowledge and account for other studies which marginalize this benefit as being very small or “within” the noise of global environmental and atmospheric modeling capability (e.g., Jacobson and Ten Hoeve, 2011). They also apply what appears to be a very aggressive cost escalation of CO₂ emission (tied to their energy use analysis for each roofing system) that goes from \$0/ton in 2005 to \$115/ton in 2060. Further study and justification is needed as this effect appears very important and yet very uncertain. Because this assumption disproportionately favors cool roofs over dark roofs, it is a potential source of bias that requires better justification in the study.
- e. **HEALTH CONCERNS:**
- i. **HEAT WAVE IMPLICATIONS:** This aspect of the study refers to anecdotal data without disclosing relevant facts associated with cause-and-effects that have significant bearing on interpretation and application of the data to the purpose of the study (e.g., the Chicago “black roof” deaths). Most of these unfortunate deaths were to elderly individuals living in aged buildings, in garden-level units where fear of gang violence or theft kept residents from opening the windows. The authors appeal to this anecdotal and unqualified data to support a hazard-based conclusion without consideration of actual risk and causes-and-effects that may better inform and re-direct their conclusion. For example, does the fact that modern buildings built to current code must have indoor air conditioning and greater roof

insulation levels have any bearing? Isn't this issue then already addressed? If these buildings were brought up to newer codes (without addition of a white roof) wouldn't this solve the problem? Thus, white roofs are not THE solution, but they may be an alternative to consider in some cases. Even so, using a white roof in Chicago without first addressing insulation and social concerns (which alone would solve this problem) carries negative consequences such as colder conditions and high energy bills in the winter: this is a countervailing risk to human health and comfort that the study does not mention or address. Because the report addresses none of these important factors, it is at best incomplete or at worst misleading on this point.

- ii. UNSUBSTANTIATED CLAIMS: "...large public health advantages of green or white roofs over black roofs..." Where is the risk-based data to support this claim? The report doesn't contain a risk assessment and appears to refer to studies that only present hazard data or unqualified statistics which may only be indirectly relevant (or nearly irrelevant when all causative factors are considered). Neither is there data to support that reflective roofing has brought the cooling of city centers; in fact, a growing body of research is documenting that reflective roofs actually raise ambient air temperatures.
- f. UNCERTAINTY: While the report is unclear on how uncertainty was determined, some estimate of uncertainty was included in the graphic, Figure 2. In particular the 1-sigma error bar on the White-Black roof shows a significant probability that the black roof could be more cost effective than the white (even with all the biases mentioned above which in some cases intentionally biased the analysis against black roofs). The authors fail to give this issue appropriate consideration in the report, particularly in regard to tempering their conclusions. They do not give a confidence level on the estimated savings upon which they base their conclusions. However, even if this were included, the fundamental data used for the study would question how well the uncertainty is known and it is unlikely that all sources of uncertainty associated with each study variable could be quantified and included in the study. In such circumstances and as mentioned previously, ASTM E917 standard for Life Cycle Costing recommends doing a sensitivity study with plausible ranges of the variables considered for individual impact and also with all simultaneously set to one extreme or the other such that a range of the total result is quantified. This was not done. As a result, the findings appear much more definitive than they would if the study had been conducted in a more academically neutral manner.
- g. SIGNIFICANT LOGICAL ERRORS IN APPLYING THE FINDINGS: In Section 3.2.1, the researchers demonstrate their findings in the order of relative cost effectiveness: White>Black>Green. At the end of Section 1.2, they revealed that the purpose of their study was to "investigate whether white and green roofs offer purely economic advantages over black roofs." Yet, later in Section 5, they strongly recommend either green or white roofs over black. Why? Because of factors not fully considered in the economic analysis and which are not quantified following scientific method in their report. These factors that they rely on to support the main assertion of their report (which is counter to the stated purpose and scope of the study to analyze the roofs on a purely cost effectiveness basis) include the following relative disadvantages they associate with black roofs: (1) building energy costs, (2) summer heat island effects, and (3) global warming. In response to these actual reasons that reach beyond the cost-benefit analysis basis of the report, the following points should have been considered and evaluated in the study but were not:
 - i. (1) Building energy costs can be addressed in a variety of ways that have nothing to do with roof color or type. The study fails to address viable alternatives such as insulating roofs to modern codes, adding more insulation, using ballasted roofs,

etc. Thus, this reason is insufficient to make broad claims regarding public policy to phase out black roofs as stated in Section 4.2 of the report.

- ii. (2) Summer heat island effect must be balanced with countervailing risks or impacts that trend with climate zone. Further, the heat island effect is a very localized, urban issue – not applicable in non-urban areas which cover the vast majority of the continent. In effect, this is a localized issue most relevant to warm climate zones and highly populated urban areas. Thus, it is hardly a reason to make broad claims regarding public policy to indiscriminately phase out black roofs (Section 4.2).
- iii. (3) The global warming connection to white vs. black roofs has significant uncertainty with researchers indicating in some cases that the impact is within the noise of all other factors that affect global warming and, therefore, is likely an ineffective approach toward mitigating global warming. While the jury is perhaps still out on quantifying the real impact, it is likely very small or inconsequential in the big picture of all factors affecting global warming and the report lacks information to help form an unbiased and informed perspective on this matter. Thus, this reason is perhaps interesting and deserves further study, but falls well short of providing compelling evidence to support a claim directing policymakers to phase out (or begin to ban) the use of black roofs.

3) CONCLUSION:

In conclusion, the group of roofing industry representatives and experts assembled by the EPDM Roofing Association (manufacturers of both dark and reflective roofing membranes) found that systematic failure to comply with scientific method in the study resulted in potentially biased and highly uncertain conclusions and recommendations. ERA welcomes a response and dialogue with the LBNL researchers on this matter and regret that such opportunity was not afforded during their study and prior to publication.