A Case Study on the

Impact of Solar Reflectance Attenuation and Roof Cleaning on a Cool Roof Return on Investment

by

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ABSTRACT

Research has shown roofing systems with high solar reflectance and thermal emissivity lead to less heat absorption, a consequential reduction in cooling load demand, and a resultant reduction on energy expenditure. Studies on energy savings from cool roof coatings have been conducted for decades and when compared to more traditional roofing systems have demonstrated energy savings ranging from 2-40%, with average savings estimated at 20%. The 20% average is widely used by cool roof industry professionals, designers, and contractors to market and sell the technology in the commercial sector to owners and owner representatives researching new roofs. While the 20% energy savings is a documented average, unfortunately there is no average roof. Each roof is unique considering size, materials, and location to name a few. In addition, the ability of the cool roof to maintain the original solar reflectance is integral to realizing energy savings. The case study calculated project payback for a 20-year cool roof design using both 30% and 20% estimated annual energy savings. In addition, building material specifications and solar reflectance attenuation in respect to reductions in cooling energy were projected into the payback calculations. Lastly, the cost impact of cleaning maintenance was added to the calculations to provide an analysis on affect to anticipated payback schedules. The results showed cleaning costs only added 1 year to project paybacks and saved over 262,244 kWh over 20 years.

DEDICATION

To my wife, who encouraged and inspired me to continue my education and to my parents, who ensured their children would receive the education they never had.

ACKNOWLEDGMENTS

This work would not have been possible without the support from my advisor Dr. Sullivan, and my employer, the U.S. Naval Research Laboratory at Stennis Space Center and Director Dr. Herbert Eppert, Jr.

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TABLE OF CONTENTS

CHAPTER Page

LIST OF TABLES

Table Page

LIST OF FIGURES

GLOSSARY OF TERMS

Albedo: The percentage of solar energy striking a surface that is reflected in the full spectrum (Gernetzke 2016).

Solar Reflectance: The fraction of the incident solar radiation in the visible spectrum reflected by the surface compared to the amount of light striking the surface. A higher number means more energy is reflected rather than absorbed (Gernetzke 2016). Values range from 0 to 1.0 where 0 indicates total absorption while 1.0 indicates total reflectance.

Thermal Emissivity: The relative ability of a surface to absorb and radiate or emit absorbed long-wave infrared (heat). The higher the number, the faster the surface sheds the heat it has absorbed. Thermal emissivity and solar reflectance are both measured in values of 0-1 (Gernetzke 2016).

Solar Reflectance Index (SRI): A measure of the constructed surface's ability to stay cool in the sun by reflecting solar radiation and emitting thermal radiation. It is defined such that a standard black surface (initial solar reflectance 0.05, initial thermal emittance 0.90) has an initial SRI of 0, and a standard white surface (initial solar reflectance 0.80, initial thermal emittance 0.90) has an initial SRI of 100. To calculate the SRI for a given material, obtain its solar reflectance and thermal emittance via the Cool Roof Rating Council Standard (CRRC-1). SRI is calculated according to ASTM E 1980. Calculation of the aged SRI is based on the aged tested values of solar reflectance and thermal emittance (U.S. Green Building Council, 2016).

CHAPTER 1

INTRODUCTION

Solar reflectance and thermal emittance are the two most important properties affecting the temperature of a surface (Mastrapostoli et al., 2016). Roofing material or roof coatings that provide both a high solar reflectance and high thermal emittance tend to stay cool in the sun and are therefore identified as cool roofs (Levinson, Akbari, Konopacki, & Bretz, 2005; Mastrapostoli et al., 2016). The higher the reflectance and/or emittance of the roofing material, the lower the resulting surface temperature. As the surface temperature of the roof decreases, so does the amount of heat penetrating the building, resulting in less energy required to condition the space below. Cool roof studies have shown average energy reductions of 20% (Levinson et al., 2005).

The building material under the cool roof is also influential. Research involving numerous buildings has shown that annual reduction in cooling load is a linear function of changes in both roof solar reflectance and U-value of the roofing material (Synnefa et al., 2007). While a roof's U-value and thermal emissivity remain relatively constant over time (Levinson et al., 2005), the solar reflectance of roof coatings is more dynamic as it is reduced by the soiling accumulation on the surface after exposure to natural weathering (Dornelles, Caram, & Sichieri, 1994; Berdahl, Akbari, Levinson, & Miller, 2008). Studies have shown solar reflectance attenuation due to soiling to be the most important factor in evaluating the long-term performance of the cool white roof coatings (Xue, et al., 2015). Losses in energy savings due to soiling have been estimated at 10-20% (Bretz & Akbar, 1994; Revel et al., 2013).

In order to realize the full potential of energy savings, the roof coatings must maintain the high solar reflectance for the service life of the coatings (Mastrapostoli et al., 2016).

Maintenance to clean a cool roof has been shown to restore initial reflectance up to 90% of initial value, thus restoring the majority of reflective benefits. While cleaning is effective, the restoration of full energy savings is only temporary as soiling is ongoing. The most important consideration is cleaning labor costs, which can be significant in comparison to energy savings returns (Bretz & Akbar, 1994). However, it has been shown that cleaning maintenance is necessary in order to meet the potential of the cool roof's energy efficiency (Mastrapostoli et al., 2016). Many cool roofing manufacturers recommend cleaning every 3-4 years. While this cyclical maintenance requirement will vary depending on numerous factors such as building characteristics, location, and specific roof coating, the need for cleaning will be a constant, but variable cycle.

The energy savings potentials of a cool roof are clearly marketed. In interviews with 3 facility management professionals who had installed cool roofs in the last 3 years, all three were told to anticipate 20-30% energy reductions. Only 1 in 3 had considered the potential impact of soiling, and none had factored in cleaning maintenance into their project return on investment (ROI) calculations. In addition, none had considered their roof insulation as potentially impactful to anticipated energy savings.

In order to calculate the most accurate ROI for a cool roof, one must consider both the impact of roofing insulation to energy savings and the cleaning costs necessary to maintain solar reflectance.

CHAPTER 2

LITERATURE REVIEW

COOL ROOF SCIENCE

When being subjected to solar radiation, a material will emit, transmit, or reflect that radiation through any one or combination of the three. The most basic explanation of how cool roofs work is because of both high visible and Near Infrared (NIR) reflectance along with high thermal emittance, leaving little radiation to be transmitted into the building (Levinson et al., 2005). A roof that reflects or emits a large portion of the overall solar radiation instead of transmitting it will keep the building underneath cooler, leading to a reduction in cooling costs (Gernetzke 2016).

In optimal solar conditions for an insulated surface and minimal wind, the temperature of a black surface with a solar reflectance of 0.05 is about 122°F higher than ambient air temperature while a white surface with solar reflectance of 0.8 has a temperature of only about 50°F higher than ambient (Synnefa et al., 2007).

While a roof coating color can play a significant role in impacts to thermal behavior, a roof coating is not required to be white in order to be a cool material (Alchapar & Correa, 2016). There are cool non-white coatings which absorb in the visible range, in order to appear having a specific color. Combined with high emissivity and high reflectivity in the NIR spectrum will result in a cool material. Ability of a material to reflect the NIR spectrum can still maintain a high overall solar reflectance. Consideration for the NIR spectrum is important as about half of all solar power arrives in this form of radiation (Mastrapostoli et al., 2016).

Regardless of the spectrum, radiation that is not reflected can be emitted. Studies have shown that energy reductions due to solar reflection and thermal emissivity are variable with climate. While reduced emissivity will increase energy use in hot climates and decrease energy use in cold climates, it provides no significant change in temperate climates (Muraya, 2007). In regards to solar reflectance, it has been shown that the same increases produce greater cooling load reduction in hotter climates (Synnefa et al., 2007). In the temperate climates, medium solar reflectance and low thermal emissivity are a better combination for energy savings, while in mountain or subarctic climates, both low solar reflectance and low emissivity is best as more radiation can be absorbed and transmitted into the building providing an energy benefit during the longer heating season (Shi & Zhang, 2011).

The solar reflectance and thermal emissivity is what allows a cool roof to have passive cooling, active cooling is also an important factor to consider. Active cooling is due to the change in thermal roof characteristics in relation to the change in the thermal environment of the surrounding air. This results in a beneficial impact to heat pump energy efficiency of roof top units as a result of a decrease in outdoor temperature providing an increase in the coefficient of heat pump performance (Pisello, Santamouris, & Cotana, 2013).

Pisello (2013) explains the benefit further:

> The active cool roof effect consists of the cool roof capability to decrease the suction air temperature of the heat pumps external units and then to decrease also the temperature lift between the source and the output air of the heat pump in

cooling mode, when these units are located over the roof. For this reason, the energy efficiency of the heat pump increases in summer.

Research by Pisello showed an overall cool roof benefit of 34% of energy saving during the day and nighttime energy savings of 47% and demonstrated the reduction in energy requirement for cooling is produced by a combination of both the passive and active cooling effect (Pisello et al., 2013).

COOL ROOF CLASSIFICATION

In order to quantify a material's ability to reflect and emit radiation and therefore be considered a cool material, the Cool Roof Rating Council (CRRC) assigns ratings based on testing. These ratings are provided in the Solar Reflectance Index (SRI), which is calculated by both solar reflectance and thermal emissivity. For a low-sloped roof, the minimum basis for cool roof requirements is a solar reflectance of 0.55 and a thermal emittance of 0.75 for an SRI of 64 (U.S. Department of Energy, 2010). While this is a minimum, SRI values of high-performance roofs can reach over 100. The Lawrence Berkeley National Laboratory defines a perfect SRI as roughly 122, but is not attainable in real world conditions. Most cool roof manufacturers will provide an aged SRI value to show how the product will perform after 3 years of weathering based on field-testing (Gernetzke 2016).

For contrast, a black EPDM product reflects little solar energy and has a reflectance of 0.06 and an emittance of 0.88 (Gernetzke 2016). This provides an SRI of 0. Stone ballasted roofing and aggregate surfacing generally has a reflectivity of around 0.30, however this can vary significantly depending on the surface (Gernetzke 2016). The solar reflectance of a conventional roof typically ranges between 0.2 and 0.4 (Mastrapostoli et al., 2016).

SAVINGS POTENTIAL

A 2012 report by the U.S. Energy Information Administration shows that electricity accounts for 61% of all energy consumed in commercial buildings. Electricity usage has increased by 19% since 2003 while electricity for cooling has increased 4% since 2003. Cooling accounts on average for 9% of electricity costs and could be more depending on building conditions and geography (U.S. Energy Information Administration, 2016). Geography plays a major factor as research has demonstrated that building in regions with long cooling seasons and short heating seasons provide the greatest savings (Levinson et al., 2005). It is in these climates where the high solar reflectance and the high thermal emissivity of cool materials are more impactful in providing energy savings to the building (Shi & Zhang, 2011).

When considering savings in terms of percentage, Levinson showed that while cool roofs typically resulted in summertime air-conditioning savings of 10 to 30%, the potential range is large as values were as low as 2% and as high as 40% (Levinson et al., 2005). Use of cool roofs in Florida provided similar results as data showed savings from 10-40% (Parker & Barkaszi, 1997). These results are not annual net results and do not account for the shorter heating season however. Research shows a 40% decrease in the annual cooling load along with a corresponding heating penalty, or increase of the heating load, by 10% (Synnefa, Saliari, & Santamouris, 2012).

Studies have shown that increasing the solar reflectance by 0.75 from a base case of 0.2, can provide between 19% and 65% in cooling load savings with higher increases in reflectance providing as much as 93% reductions (Synnefa et al., 2007).

Upon investigation of actual cool roof units of energy savings data rather than percent reductions in energy costs, the energy efficiency potential for cooling was shown to range between 2.5 and 10 kWh/m^2 per year of cool roof surface (Mastrapostoli et al., 2016). Other studies have shown how a 0.69 increase in roof solar reflectance is able to reduce cooling loads for an insulated building of 1 kWh/m^2 and represents a net gain of 0.3 kWh/m^2 after considering heating load increase (Synnefa et al., 2012). For all the locations researched by Synnefa in 2007, the heating penalty of 0.2-17 kWh/m^2 per year was less significant than the 9-48 kWh/m^2 per year reduction of cooling load reduction (Synnefa et al., 2007).

To put this data into perspective of actual dollars saved, research in 2005 on a commercial building in California has shown that replacing a roof with a solar reflectance 0.20 with a one with a solar reflectance 0.55 can provide a net energy savings ranging from \$1 to \$7/m^2 (10.76 ft^2) of roof area (Levinson et al., 2005).

The potential for energy savings from cool roofs is demonstrated. However, it is important to remember that energy savings are directly correlated to preserving the reflecting properties over time, which is a significant consideration when determining if the initial investment of a cool roof can be paid back by the yearly cooling energy saving (Revel et al., 2013).

SOILING

The ability of a roof to reflect solar radiation is dependent upon maintaining the initial surface characteristics. The largest obstacles to solar reflection preservation is due to it sole purpose for being, outdoor exposure. Effects of exposure include sunlight, temperature, wind, moisture, atmospheric gases and pollutants, and biological growth all act to degrade roof coatings (Berdahl et al., 2008; Dornelles et al., 1994). It has been proposed that resultant degradation may actually modify the solar reflectance permanently via resulting chemical change of the material (Dornelles et al., 1994).

While the impacts to roof coatings from exposure are numerous, solar reflectance is diminished by two main factors-the soiling and weathering processes over time (Berdahl et al., 2013). Zang reported that while outdoor exposure includes both natural soiling (deposition and growth) and natural weathering (exposure to sunlight, moisture, and variations in temperature), separating these two effects is extremely difficult (Zhang, et al., 2013). So while this paper will focus primarily on the effects of soiling, it is acknowledged that weathering also plays a role in solar reflectance attenuation.

Soiling results from the deposition and accumulation of atmospheric particulate matter as well as the presence and growth of microorganisms, both of which absorb sunlight (Berdahl et al., 2013). The effect of atmospheric pollution such as soot and hydrocarbons from exhaust on a cool roof's aging is considerable. As mentioned before, while cleaning can reclaim a majority of a roof's reflectance, the reapplication of the roof coating is a necessity in areas with increased air pollution (Dornelles et al., 1994).

Soiling as a result of biological growth (e.g. cyanobacteria, fungi, algae) are common on roofing in humid areas such as the southeastern and northwestern parts of the

United States and can be a major agent of roof soiling in humid climates (Berdahl et al., 2013; Berdahl et al., 2008). The build up of the dead colonies of these microorganisms during the aging process can be significant and be evident as dark stains on white cool roofing, impacting aesthetics as well as solar reflectance (Berdahl et al., 2008).

The aging effect of soiling and weathering on cool roofs has been shown to reduce initial albedo by almost 25% within 3-4 years (Mastrapostoli et al., 2016). Data from another study indicated the majority of albedo attenuation happened within the first year, with 70% of one year's albedo degradation occurred in the first two months on one roof. Degradation slowed after the first year with only small losses in albedo after year two (Bretz & Akbar, 1994). Studies have shown that the attenuation of solar reflectance was more apparent for roofs with lighter colors with the highest reductions in reflectance on high albedo white roof coatings (Dornelles et al., 1994). As reported by Paolini in a three-site study over 3 years conducted on materials with an initial solar reflectance greater than 0.80, the average loss of solar reflectance was 0.16, with a maximum of 0.24 in Florida and a minimum of 0.08 in Arizona (Paolini, Zinzi, Poli, Carnielo, & Mainini, 2014). While testing showed changes marked changes in solar reflectance, thermal emittance variations for products with an initial emittance greater than 0.85 were within ±0.05 after the three year experiment, demonstrating how material reflectance is more variable than emissivity (Paolini et al., 2014).

Testing and researchers is vital in determining the real world affect of exposure on cool roof materials. A study at an outdoor test facility in Tennessee over three and a half years of exposure resulted in the reduction of average solar reflectance of white PVC roofing membranes to 0.49 from 0.86 (Levinson, Berdahl, Asefawberhe, & Akbari, 2005).

While the best way to predict how a material will react to outside conditions for a period of time is to actually place the material outside and wait, this is obviously not always a practical method. Fortunately, the Cool Roof Rating Council (CRRC), created in 1998 during the rise of cool materials, has test farms or exposure sites in different climates around the US. It lists the initial and 3 year solar reflectance, thermal emittance, and subsequent SRI of more than 2500 roofing products (Cool Roof Rating Council, 2016).

Artificial testing methods are also being used to simulate the exposure process in more condensed time frames more suitable for research. To prove the effectiveness of artificial testing, a test was conducted on a cool white roof with initial solar reflectance of 0.82 for 400 hours. Resulting data indicated an average of over 11% attenuation in solar reflectance, which corresponded to actual 3 year testing of the same material (Xue, et al., 2015).

All testing has limitations however, despite its methodology. For example, microbial growth on roofing materials exposed in hot and humid climates, such as those in Mississippi, can be so extreme as to greatly alter the roof material's appearance and albedo in ways that are incapable of being reproduced (Berdahl et al., 2013). In other words, it is nearly impossible to develop accelerated methods to mimic aging effects in regards to potential biological growth in extreme humid climates.

In addition, knowledge of the impact of exposure to material may not be a true representation once the material is installed and part of a roofing system. Each roofing system has a unique albedo, with variations in the roughness, the substrate, and coating thickness. As a result, the change in albedo will inconsistently vary over time between roofs depending on a variety of factors such as climate, the roof slope, coating roughness and resistance to dirt, substrate, pollution, and adjacent sources of dirt and debris (Bretz & Akbar, 1994).

As a result, it is impossible to simulate all of these possible effects on the performance of every product (Berdahl et al., 2013). Therefore, for those individuals who may be investigating a cool roof, the best method for predicting material exposure may come from investigating real world installations of like materials in adjacent areas.

SOILING IMPACT TO SAVINGS

It has been shown that in order for roof coatings to maximize energy savings, they should have high solar reflectance in both visible and NIR spectrum, have high thermal emittance, and be able to maintain these properties throughout life of the coating (Bretz & Akbar, 1994). However, it has been demonstrated that exposure will degrade the solar reflectance, significantly impacting cool material performance and as a result, energy savings (Revel et al., 2013). This leaves to question what the impact of exposure actually means in terms of energy reduction losses and ultimately money.

Experimental data has shown that a roof's solar reflectance can decrease due to dust load, ultraviolet radiation, microbial growth, moisture, wind, and biomass accumulation (Mastrapostoli et al., 2016). The combined effects can decrease the reflectance of cool materials by as much as 0.15, mostly within only the first year of service (Bretz & Akbar, 1994). Another study in Arizona reported a solar reflectance decrease of almost 0.20 was measured from weathering conditions after three years of exposure (Mastrapostoli et al., 2016). A 3-year exposure study in Rome and Milan cites a reduction of 20-34% the cooling load savings that could be achieved compared to a new white membrane (Paolini et al., 2014).

Based on the findings above, assuming an initial 20% savings and a 30% decrease in energy reduction over time would result in a loss of 6% savings and actual energy savings of only 14%.

IMPACTS OF BUILDING MATERIALS

It has been discussed how cool roofs works by reflecting or emitting solar radiation, leaving only remaining absorbed radiation to be transmitted as heat into the building below, providing a corresponding reduction of energy requirement for cooling (Pisello et al., 2013). The performance of cool roofs and resulting energy reductions can be influenced by several variables, such as the ceiling insulation level, the attic configuration, climate conditions, and occupancy schedules (Pisello et al., 2013). However, it has been shown that the impact of an increase in solar reflectance and resulting surface temperatures on the roof coating is extremely reliant upon the level of insulation (Paolini et al., 2014). One study indicated the two main factors affecting the energy savings resulting from cool roofs were the climate and the U-value of the roof deck (Synnefa et al., 2007).

The ability of the heat to transmit into the thermal zone of the building is dependent upon the overall heat transfer coefficient, or U-value of the components that lie between the roof coating and the building itself. These components typically consist of the roof decking and insulation. If the roof is well insulated and the U-value is small, the resulting heat transfer between the roof coating and the building interior is small and therefore the impact on the energy use is less important (Synnefa et al., 2007). This is not to say that highly insulated buildings are incapable of reaping the benefits of a cool roof. In fact, in climates dominated by long cooling seasons, energy savings can be significant even for roofs with high levels of insulation (Synnefa et al., 2007).

Studies on cool roof savings that include both insulated and non-insulated buildings, have demonstrated the energy benefits even with highly insulated buildings. Data from these studies have shown a 35% decrease in cooling load for an insulated building, with a corresponding heating penalty of 4% resulting in a net gain (Synnefa et al., 2012).

A 2007 study on numerous buildings with varying solar reflectance levels and U-values found that the annual reduction in cooling load was a linear function of changes in solar reflectance and roofing system U-value (Synnefa et al., 2007). The importance of this finding is that it provides the ability to more accurately calculate cooling load savings for applications of varying levels of solar reflectance and insulation, regardless of the assumptions of the original study (Synnefa et al., 2007).

In summary, the U-value of the roofing system plays an important role in affecting cooling load energy reductions from a cool roof. However, roofs with high levels of insulation can still see significant savings.

MAINTENANCE

As discussed before, the energy savings from a cool roof are dependent upon, solar reflectance, thermal emittance, and maintaining condition of the roof. It has also been demonstrated that exposure and resultant soiling have significant impact to solar reflectance, but only negligible effect to thermal emittance. Thus, maintaining the roof is mainly about retaining the solar reflectance and resulting contribution to energy savings. Research has shown how weathering and soiling may strongly affect a roof coating's solar reflectance (Paolini et al., 2014). A roofing company interviewed for this paper reported that roof slope greatly affects biological build up and ponding on roofs further compounds this issue. Studies have indicated that about 26% of the energy savings can be lost through exposure and soiling of the roof coating (Bretz & Akbar, 1994). However, cleaning the cool roof coating can increase solar reflectance to near initial levels and have shown to decrease annual energy consumption by 18.8% (Mastrapostoli et al., 2016).

In attempts to quantify specific solar reflectance to change energy reductions, a two year study was done on membranes with an initial solar reflectance greater than 0.80 which resulted in decreased annual cooling load savings of 4.1-7.1 MJ/m^2 (0.106 kWh/ft^2 – 0.183 kWh/ft^2) per year, per 0.1 loss in solar reflectance (Paolini et al., 2014).

A cleaning regimen to retain initial solar reflectance of 0.70 has been shown to increase the net energy savings by over 40%, which equated to \$0.5 to \$3/m^2 in one study (Levinson et al., 2005). Any cleaning regimen should consider that studies have shown that the greatest losses in reflectance occurred during the first winter (Paolini et al., 2014). Thus, best practice for maintenance would be to perform cleaning in the Spring, after the soiling effects of Winter and before the on coming cooling loads of summer in order to maximize returns on investment.

Thomas Gernetzke, Project Manager for Facility Engineering, Inc., which specializes in roofing and waterproofing systems questions the thought process of owners who specify a cool roof but have no interest in keeping it clean. Gernetzke stated, “If you know your building will attract a lot of grime and you let it build up instead of just addressing minor dirt deposits during regular maintenance, a cool roof may not be for you” (Gernetzke 2016).

SUMMARY

The literature covering cool roofs has made the following case: 1) Energy savings from cooling load reductions due to both passive and active benefits are real, 2) The application of a cool roof and it’s energy reductions are best realized in climates with longer cooling seasons, 3) Soiling from exposure can significantly effect the full energy savings potential, and 4) These effects can be mitigated by maintenance.

For a facility manager, an average 20% decrease in energy consumption is significant regardless of the energy bill. However, based on the above evidence, realized energy reductions to cooling load will vary based on climate, cool material properties, building envelope U-values, location in respect to exposure to air pollution and soiling from dirt and debris source, and location energy costs. Despite these variations, it is still possible to consider these factors and make an informed estimate of energy savings that will be more representative of likely energy reductions in comparison to assuming reductions will be an average percentage for the entire life cycle of the cool roof. Doing so will provide the facility manager a more accurate estimate of project payback.

The fact that energy savings are related to the ability of a cool roof to stay clean is an important consideration. While some research contends the return on investment is not worth the increase in savings, this again is based on average conditions and can vary. During project planning, the facility manager needs to account for cleaning by either dismissing it entirely and adjusting energy reductions, or programming cyclical cleaning costs throughout the roof life cycle to provide a realistic project payback.

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CHAPTER 3

METHODOLOGY

The purpose of this study is to conduct a quantitative case study. The study will compare and contrast different cool roof project payback (or ROI) calculation. Each scenario, or iteration, will represent either an “informed” ROI or an “uninformed” ROI. “Informed” will represent accounting for predicted variables that have been shown to reduce cool roof energy reduction. “Uninformed” scenarios will assume only cool roof industry projected energy reductions of both 20 and 30%.

CASE STUDY DESCRIPTION

The case study is for a building where cool roof project planning began in September of 2014. The cool roof installation is scheduled to begin in October of 2016.

The single story building is located at Stennis Space Center, MS within 13 miles of the Gulf of Mexico (Figure 1). The facility was constructed in 1983 and currently houses laboratory and office spaces. Average annual kWh usage over a 3 year period from 2013 through 2015 provided an average annual electricity usage of 2,473,922kWh. Present electricity costs were \$0.088/kWh. The existing roof is 65,313ft^2 and consists of loose-laid EPDM with stone ballast (Figure 2) and subject to areas of considerable debris and resultant soiling due to adjacent trees (Figure 3). Based on reviewed literature, the solar reflectance of the roof was estimated to be 0.30.

The roof decking is a reinforced concrete waffle slab. Dimensions of the slab thickness range from 3 to 17” based on measurement location due to waffling. Roof insulation consists of polyisocyanurate (ISO) roofing boards 3.75” thick. The roofing system has a total U-value of 0.05 (R-20).

Figure 1.

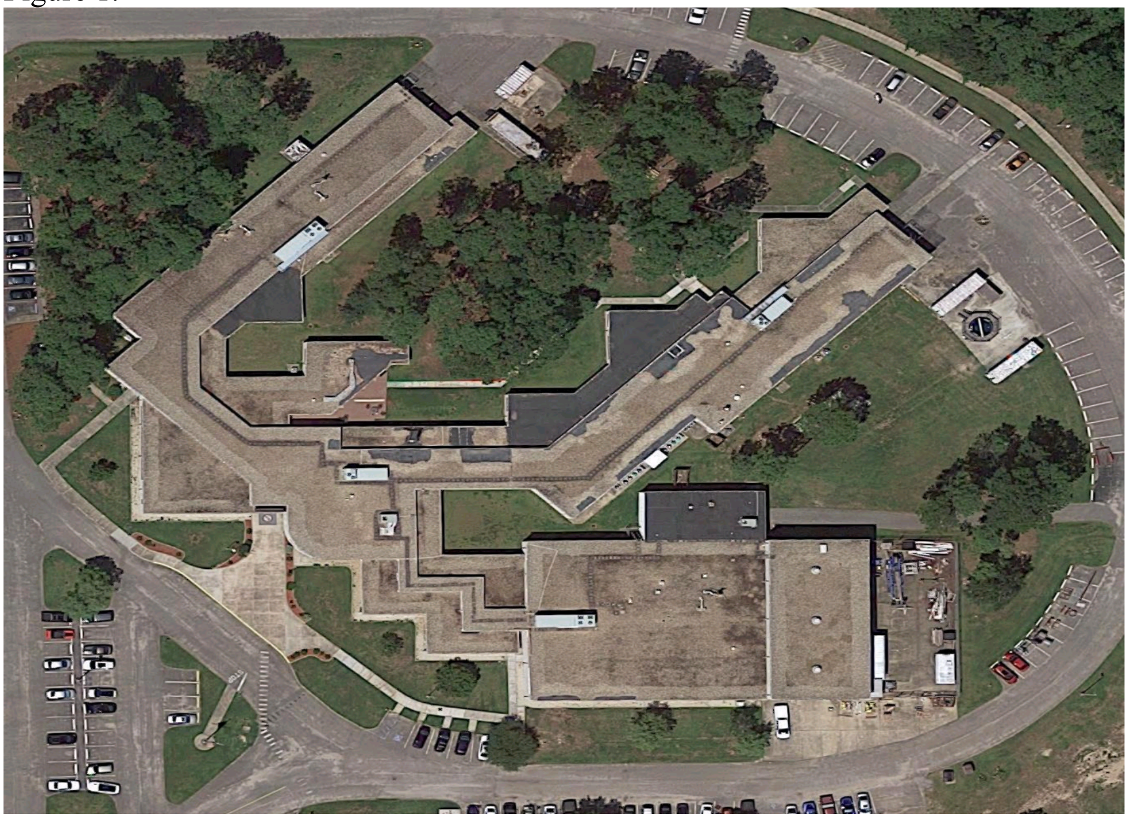


Figure 2.

Figure 3.

CASE STUDY DETAILS

With informed knowledge of the existing roofing material properties, the next step was to gather details regarding the specific roof coating. Technical specifications listed the following: Initial Solar Reflectance 0.87, Initial Thermal Emittance 0.87, and SRI 110. Research about the same product on CRRC listed the same initial values in addition to the following 3-year values: Solar Reflectance 0.77, Thermal Emittance 0.86, and SRI 95. The roof coating product is a fluoropolymer based coating that, according to product field representative, resists biological build up through a combination of both chemical ingredients in the compound as well as the Teflon like coating which greatly mitigates the ability of soiling to adhere to the surface. See Table 1 for roof data summary.

Despite the claimed resistance to soiling, the product representative in addition to an independent roofing contractor recommended cleaning every 3-4 years with spot cleaning that may need to be done every 1 to 2 years. Cleaning is done with a particular manufacturer approved product. The cleaning product is a non-TSP detergent and when diluted to the correct concentration, a 5-gallon bucket will cover 10,000ft^2 and cost $288.60 per bucket. The product is sprayed on the roof coating and should sit for approximately 10 minutes. This is followed by a pressure washing at 3000 psi using a 25° spray nozzle. Labor cost estimate from a contractor to perform the work was $0.17/ft^2. See Table 2 for estimated cleaning costs.

Table 1. Roof Data Summary

	Existing Roof	Cool Roof	
		Initial	3-year
Solar Reflectance	0.30	0.87	0.77
Thermal Emittance	Unknown*	0.87	0.86
SRI	NA	110.00	95
U-Value	0.05	0.05 (no change)	
Cleaning Frequency	None	every 4 years	
Cleaning Costs	$0.00	$12,834.93	
* Study shows this will be insignificant compared to solar reflectance value			

Table 2. Roof Cleaning Cost Estimate

ESTIMATE							
Project:	COOL ROOF CLEANING COSTS			Stennis Space Center, MS			
				Date:	9/19/2016		
Item Description	Quantity	Unit	Material		Labor		
			Unit Cost	Total Matl.	Unit Cost	Ttl. Labor	Total Cost
CLEANING PRODUCT	6	5 GAL	$288.62	$1,731.72	$0.00	$0.00	$1,731.72
LABOR	65313	SF	$0.00	$0.00	$0.17	$11,103.21	$11,103.21
Subtotal				$1,731.72		$11,103.21	$12,834.93
Total for Page							$12,834.93

CHAPTER 4

ANALYSIS

COOL ROOF INSTALLATION AND CLEANING ANALYSIS

As mentioned, at the time of this study the building was currently contracted to have a cool roof installed. All preparation work to install the new roof would consist of removal and disposal of the existing stone ballast and necessary surface preparations per cool roof product specifications to facilitate a clean and thorough installation of the new roof. The total contract price for this work was $854,947.17, which was used to calculate payback.

The estimated cleaning costs of $12,843.93 performed every 4 years was divided by 4 and factored into annual costs for service. This resulted in approximately $3,208.73 per year and reflected into the project payback. Utility research on cost per kWh showed approximately a 1% average annual inflation rate, which was used as part of the payback equation.

COOL ROOF SOILING AND BUILDING MATERIALS ANALYSIS

Analysis concentrated on the reduction of solar reflectance as literature had shown the reduction in thermal emissivity was negligible. In order to begin the analysis soiling and building materials analysis, the parameters of how to use the data had to be determined and assumptions made based on either field conditions or correlations of the case study locale and condition to previous studies.

While there are numerous studies on the impact of exposure solar reflectance to materials and resulting energy savings reductions, the fact of the matter is it is impossible to exactly predict the exact effect of exposure on a specific coating. The only assumption that can be made is that solar reflectance will without doubt decline with time. In order to analyze the impact, assumptions, albeit informed ones, had to be made regarding solar attenuation.

To estimate solar attenuation, established research on quantifying specific solar reflectance to the change in energy reductions was used. This is of particular importance as the study provided annual cooling reductions for both un-insulated and highly insulated buildings. Since the building in question is considered highly insulated (R-20, U-0.05), the savings can be calculated based on the findings from highly insulated data. The study showed a reduction in annual cooling load savings of 4.1-7.1 MJ/m^2 (0.106 kWh/ft^2 – 0.183 kWh/ft^2) per year, per 0.1 loss in solar reflectance (Paolini et al., 2014; Pisello et al., 2013). In order to specifically quantify a fixed reduction number within this range to use for calculations, 0.168 kWh/ft^2 was estimated based on the 80^{th} percentile of this range due to the apparent and extreme soiling and exposure as demonstrated by locale.

The initial solar reflectance of the roof coating was previously reported as 0.87, with the 3-year solar reflectance as 0.77. This provides total attenuation for the 3-year period of 0.10. In order to get an annual energy reduction cost, annual solar reflectance attenuation was needed.

Since cleaning was actually calculated on a 4-year cycle, 4-year attenuation was needed. Therefore, the 4-year solar reflectance attenuation was estimated to be 0.12, again due to locale.

Based on the literature, exposure effects are greatest in the first year. Therefore a solar reflectance loss of 0.03 will be used for the first year, and every subsequent year following cleaning, while losses of 0.02 will be used in years 2, 3, and 4.

For the analysis where cleaning will not be performed, a bottom line solar reflectance was needed to be estimated as literature has shown that the solar reflectance reduction will eventually stabilize.

To account for maximum solar reflectance attenuation, Paolini's research was again taken into account. The findings in Florida were of important consideration as the climate is very similar to coastal Mississippi. In the study, data showed a maximum solar reflectance reduction of 0.24 (Paolini et al., 2014). The study was for a 3-year period, however when compared to 3 years reduction for the specific coating by the CRRC, this maximum solar reflectance loss was a valid estimate for maximum loss. Estimating an average annual solar reflection loss of 0.02, it would take 12 years to reach maximum soiling. This maximum value will then be carried forward for the remaining years for the 20-year roof.

Based on the above information, the energy reductions formula was calculated to be 1.68 kWh/ft^2 per loss in solar reflectance. This was used to calculate the energy losses per solar reflectance loss per year as well as calculate a maximum loss.

Table #3 lists the data for the cost of solar reflectance loss on annual cooling energy reduction without a cleaning maintenance schedule. As contrast, Table #4 list the same data energy reduction calculated with a 4-year cyclical cleaning maintenance schedule. Figure #4 compares the aforementioned data in a graph.

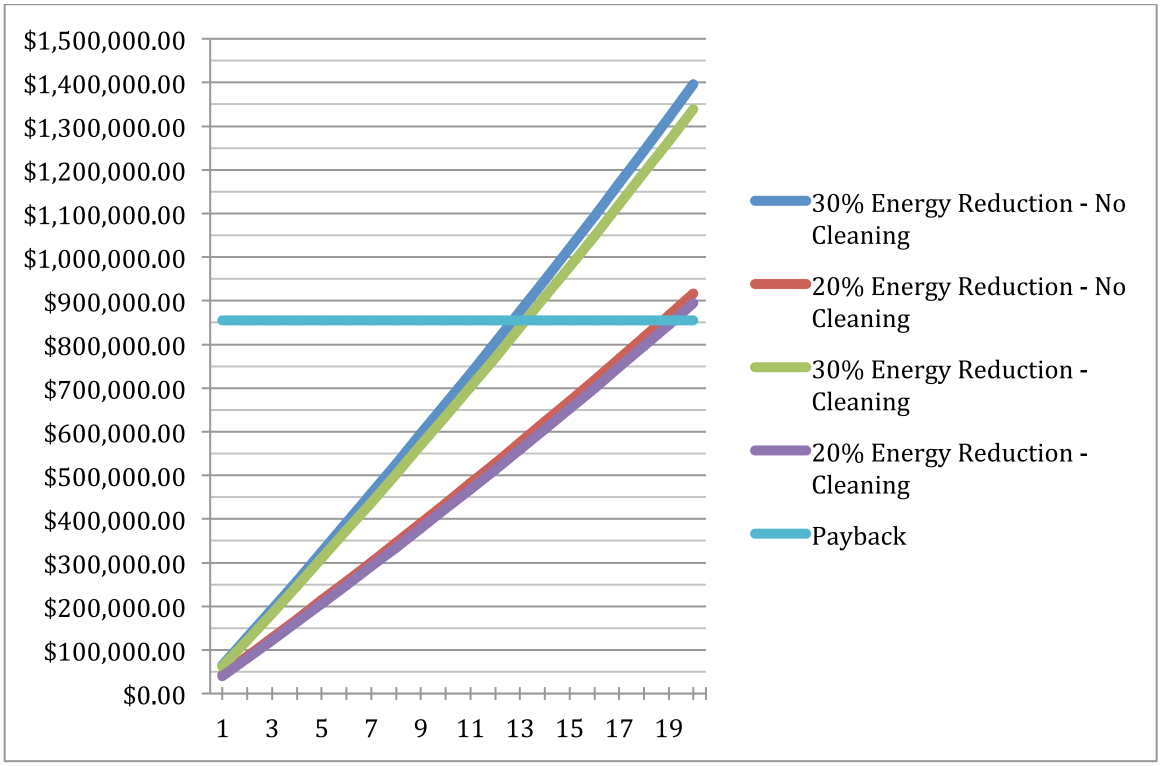
Table 3.

Cost of Solar Reflectance Loss on Annual Cooling Energy Reduction Without Cleaning									
Year	Solar Reflectance (SR) Loss/Year	Running Total Solar Reflectance (SR) Loss	Total per 0.1 Solar Reflectance (SR) Loss	Annual Energy loss per area per solar reflectance kWh/ft^2/YR/0.1 SR	Energy loss per area kWh/ft^2	Area ft^2	Energy Loss kWh	Electricity Cost $/kWh	Annual Cost $
1	0.1	0.1	1		0.1450		9,470.4	$0.0880	$833.39
2	0.07	0.17	1.7		0.2465		16,099.7	$0.0889	$1,430.94
3	0.07	0.24	2.4		0.3480		22,728.9	$0.0898	$2,040.35
4	0	0.24	2.4		0.3480		22,728.9	$0.0907	$2,060.75
5	0	0.24	2.4		0.3480		22,728.9	$0.0916	$2,081.36
6	0	0.24	2.4		0.3480		22,728.9	$0.0925	$2,102.17
7	0	0.24	2.4		0.3480		22,728.9	$0.0934	$2,123.19
8	0	0.24	2.4		0.3480		22,728.9	$0.0943	$2,144.43
9	0	0.24	2.4		0.3480		22,728.9	$0.0953	$2,165.87
10	0	0.24	2.4	0.145	0.3480	65,313	22,728.9	$0.0962	$2,187.53
11	0	0.24	2.4		0.3480		22,728.9	$0.0972	$2,209.40
12	0	0.24	2.4		0.3480		22,728.9	$0.0982	$2,231.50
13	0	0.24	2.4		0.3480		22,728.9	$0.0992	$2,253.81
14	0	0.24	2.4		0.3480		22,728.9	$0.1002	$2,276.35
15	0	0.24	2.4		0.3480		22,728.9	$0.1012	$2,299.12
16	0	0.24	2.4		0.3480		22,728.9	$0.1022	$2,322.11
17	0	0.24	2.4		0.3480		22,728.9	$0.1032	$2,345.33
18	0	0.24	2.4		0.3480		22,728.9	$0.1042	$2,368.78
19	0	0.24	2.4		0.3480		22,728.9	$0.1053	$2,392.47
20	0	0.24	2.4		0.3480		22,728.9	$0.1063	$2,416.39
								TOTAL	$42,285.25

Table 4.

Cost of Solar Reflectance Loss on Annual Cooling Energy Reduction - Cleaning									
Year	Solar Reflectance (SR) Loss/Year	Running Total Solar Reflectance (SR) Loss	Total per 0.1 Solar Reflectance (SR) Loss	Annual Energy loss per area per solar reflectance kWh/ft^2/YR/0.1 SR	Energy loss per area kWh/ft^2	Area ft^2	Energy Loss kWh	Electricity Cost $/kWh	Annual Cost $
1	0.1	0.1	1		0.1450		9,470.4	$0.0880	$833.39
2	0.07	0.17	1.7		0.2465		16,099.7	$0.0889	$1,430.94
3	0.07	0.24	2.4		0.3480		22,728.9	$0.0898	$2,040.35
4	0	0.24	2.4		0.3480		22,728.9	$0.0907	$2,060.75
5	0.1	0.1	1		0.1450		9,470.4	$0.0916	$867.23
6	0.07	0.17	1.7		0.2465		16,099.7	$0.0925	$1,489.04
7	0.07	0.24	2.4		0.3480		22,728.9	$0.0934	$2,123.19
8	0	0.24	2.4		0.3480		22,728.9	$0.0943	$2,144.43
9	0.1	0.1	1		0.1450		9,470.4	$0.0953	$902.45
10	0.07	0.17	1.7	0.145	0.2465	65,313	16,099.7	$0.0962	$1,549.50
11	0.07	0.24	2.4		0.3480		22,728.9	$0.0972	$2,209.40
12	0	0.24	2.4		0.3480		22,728.9	$0.0982	$2,231.50
13	0.1	0.1	1		0.1450		9,470.4	$0.0992	$939.09
14	0.07	0.17	1.7		0.2465		16,099.7	$0.1002	$1,612.42
15	0.07	0.24	2.4		0.3480		22,728.9	$0.1012	$2,299.12
16	0	0.24	2.4		0.3480		22,728.9	$0.1022	$2,322.11
17	0.1	0.1	1		0.1450		9,470.4	$0.1032	$977.22
18	0.07	0.17	1.7		0.2465		16,099.7	$0.1042	$1,677.89
19	0.07	0.24	2.4		0.3480		22,728.9	$0.1053	$2,392.47
20	0	0.24	2.4		0.3480		22,728.9	$0.1063	$2,416.39
								TOTAL	$34,518.87

Figure 4. Payback Comparison



CHAPTER 5

RESULTS

A total of four ROI's scenarios were calculated based on the data collected and calculated. These include:

ROI #1: Used industry standard 30% annual energy reduction only (Table 5).

ROI #2: Used industry standard 20% annual energy reduction only (Table 6).

ROI #3: Accounted for solar reflectance attenuation change to original 30% savings assumption (Table 7).

ROI #4: Accounted for solar reflectance attenuation change to original 20% savings assumption (Table 8).

ROI #5: Accounted for solar reflectance attenuation change to 30% savings assumption AND cleaning performed every 4 years (Table 9).

ROI #6: Accounted for solar reflectance attenuation change to 20% savings assumption AND cleaning performed every 4 years (Table 10).

ROI #1 showed a project payback in year 13, while ROI #2 at just barely 19 years. Both scenarios appear to provide total payback well within the 20-year life cycle of the new cool roof.

ROI #3 showed that the loss in energy reduction was not enough to affect the calculated project payback of 13 years. While ROI #4 showed that the solar reflectance attenuation indeed had a larger affect, the projected payback of 19 years remained unchanged.

When cleaning maintenance was factored into the equation, the payback period in ROI #5 was changed from 13 to barely over 13 years, which was an insignificant change.

When calculating for cleaning into ROI #6, the payback period was reduced from 19 to 20 years.

Table 5.

ROI #1: 30% Energy Reduction		
kWh Annual Consumption	2,473,922	
Projected Savings	30%	
kWh $	$0.088	
kWh Inflation (annually)	1%	
Roof Square Footage	65,313	
$ per SF	$13.09	$854,947.17
Estimated Project Value		**$854,947.17**

kWh Inflation	Year	Before				After				Year	Payback
		kWh	$ kWh	Yearly $	Cumulative $	kWh	$ kWh	Yearly $	Cumulative $		
1%	1	2,473,922	$ 0.09	$ 217,705.14	$ 217,705.14	1,731,745	$ 0.09	$ 152,393.60	$ 152,393.60	**1**	**$ 65,311.54**
	2	2,473,922	$ 0.09	$ 219,882.19	$ 437,587.32	1,731,745	$ 0.09	$ 153,917.53	$ 306,311.13	**2**	**$ 131,276.20**
	3	2,473,922	$ 0.09	$ 222,081.01	$ 659,668.33	1,731,745	$ 0.09	$ 155,456.71	$ 461,767.83	**3**	**$ 197,900.50**
	4	2,473,922	$ 0.09	$ 224,301.82	$ 883,970.15	1,731,745	$ 0.09	$ 157,011.27	$ 618,779.11	**4**	**$ 265,191.05**
	5	2,473,922	$ 0.09	$ 226,544.84	$ 1,110,514.99	1,731,745	$ 0.09	$ 158,581.39	$ 777,360.49	**5**	**$ 333,154.50**
	6	2,473,922	$ 0.09	$ 228,810.29	$ 1,339,325.28	1,731,745	$ 0.09	$ 160,167.20	$ 937,527.69	**6**	**$ 401,797.58**
	7	2,473,922	$ 0.09	$ 231,098.39	$ 1,570,423.66	1,731,745	$ 0.09	$ 161,768.87	$ 1,099,296.56	**7**	**$ 471,127.10**
	8	2,473,922	$ 0.09	$ 233,409.37	$ 1,803,833.04	1,731,745	$ 0.09	$ 163,386.56	$ 1,262,683.13	**8**	**$ 541,149.91**
	9	2,473,922	$ 0.10	$ 235,743.47	$ 2,039,576.50	1,731,745	$ 0.10	$ 165,020.43	$ 1,427,703.55	**9**	**$ 611,872.95**
	10	2,473,922	$ 0.10	$ 238,100.90	$ 2,277,677.40	1,731,745	$ 0.10	$ 166,670.63	$ 1,594,374.18	**10**	**$ 683,303.22**
	11	2,473,922	$ 0.10	$ 240,481.91	$ 2,518,159.31	1,731,745	$ 0.10	$ 168,337.34	$ 1,762,711.52	**11**	**$ 755,447.79**
	12	2,473,922	$ 0.10	$ 242,886.73	$ 2,761,046.04	1,731,745	$ 0.10	$ 170,020.71	$ 1,932,732.23	**12**	**$ 828,313.81**
	13	2,473,922	$ 0.10	$ 245,315.60	$ 3,006,361.64	1,731,745	$ 0.10	$ 171,720.92	$ 2,104,453.15	**13**	**$ 901,908.49**
	14	2,473,922	$ 0.10	$ 247,768.75	$ 3,254,130.39	1,731,745	$ 0.10	$ 173,438.13	$ 2,277,891.27	**14**	**$ 976,239.12**
	15	2,473,922	$ 0.10	$ 250,246.44	$ 3,504,376.83	1,731,745	$ 0.10	$ 175,172.51	$ 2,453,063.78	**15**	**$ 1,051,313.05**
	16	2,473,922	$ 0.10	$ 252,748.90	$ 3,757,125.74	1,731,745	$ 0.10	$ 176,924.23	$ 2,629,988.02	**16**	**$ 1,127,137.72**
	17	2,473,922	$ 0.10	$ 255,276.39	$ 4,012,402.13	1,731,745	$ 0.10	$ 178,693.48	$ 2,808,681.49	**17**	**$ 1,203,720.64**
	18	2,473,922	$ 0.10	$ 257,829.16	$ 4,270,231.29	1,731,745	$ 0.10	$ 180,480.41	$ 2,989,161.90	**18**	**$ 1,281,069.39**
	19	2,473,922	$ 0.11	$ 260,407.45	$ 4,530,638.74	1,731,745	$ 0.11	$ 182,285.21	$ 3,171,447.12	**19**	**$ 1,359,191.62**
	20	2,473,922	$ 0.11	$ 263,011.52	$ 4,793,650.26	1,731,745	$ 0.11	$ 184,108.07	$ 3,355,555.18	**20**	**$ 1,438,095.08**

Table 6.

ROI #2: 20% Energy Reduction

kWh Annual Consumption	2,473,922	
Projected Savings	20%	
kWh $	$0.088	
kWh Inflation (annually)	1%	
Roof Square Footage	65,313	
$ per SF	$13.09	$854,947.17

Estimated Project Value **$854,947.17**

kWh Inflation	Year	Before				After				Year	Payback
		kWh	$ kWh	Yearly $	Cumulative $	kWh	$ kWh	Yearly $	Cumulative $		
1%	1	2,473,922	$ 0.09	$ 217,705.14	$ 217,705.14	1,979,138	$ 0.09	$ 174,164.11	$ 174,164.11	1	$ 43,541.03
	2	2,473,922	$ 0.09	$ 219,882.19	$ 437,587.32	1,979,138	$ 0.09	$ 175,905.75	$ 350,069.86	2	$ 87,517.46
	3	2,473,922	$ 0.09	$ 222,081.01	$ 659,668.33	1,979,138	$ 0.09	$ 177,664.81	$ 527,734.67	3	$ 131,933.67
	4	2,473,922	$ 0.09	$ 224,301.82	$ 883,970.15	1,979,138	$ 0.09	$ 179,441.46	$ 707,176.12	4	$ 176,794.03
	5	2,473,922	$ 0.09	$ 226,544.84	$ 1,110,514.99	1,979,138	$ 0.09	$ 181,235.87	$ 888,411.99	5	$ 222,103.00
	6	2,473,922	$ 0.09	$ 228,810.29	$ 1,339,325.28	1,979,138	$ 0.09	$ 183,048.23	$ 1,071,460.22	6	$ 267,865.06
	7	2,473,922	$ 0.09	$ 231,098.39	$ 1,570,423.66	1,979,138	$ 0.09	$ 184,878.71	$ 1,256,338.93	7	$ 314,084.73
	8	2,473,922	$ 0.09	$ 233,409.37	$ 1,803,833.04	1,979,138	$ 0.09	$ 186,727.50	$ 1,443,066.43	8	$ 360,766.61
	9	2,473,922	$ 0.10	$ 235,743.47	$ 2,039,576.50	1,979,138	$ 0.10	$ 188,594.77	$ 1,631,661.20	9	$ 407,915.30
	10	2,473,922	$ 0.10	$ 238,100.90	$ 2,277,677.40	1,979,138	$ 0.10	$ 190,480.72	$ 1,822,141.92	10	$ 455,535.48
	11	2,473,922	$ 0.10	$ 240,481.91	$ 2,518,159.31	1,979,138	$ 0.10	$ 192,385.53	$ 2,014,527.45	11	$ 503,631.86
	12	2,473,922	$ 0.10	$ 242,886.73	$ 2,761,046.04	1,979,138	$ 0.10	$ 194,309.38	$ 2,208,836.83	12	$ 552,209.21
	13	2,473,922	$ 0.10	$ 245,315.60	$ 3,006,361.64	1,979,138	$ 0.10	$ 196,252.48	$ 2,405,089.31	13	$ 601,272.33
	14	2,473,922	$ 0.10	$ 247,768.75	$ 3,254,130.39	1,979,138	$ 0.10	$ 198,215.00	$ 2,603,304.31	14	$ 650,826.08
	15	2,473,922	$ 0.10	$ 250,246.44	$ 3,504,376.83	1,979,138	$ 0.10	$ 200,197.15	$ 2,803,501.47	15	$ 700,875.37
	16	2,473,922	$ 0.10	$ 252,748.90	$ 3,757,125.74	1,979,138	$ 0.10	$ 202,199.12	$ 3,005,700.59	16	$ 751,425.15
	17	2,473,922	$ 0.10	$ 255,276.39	$ 4,012,402.13	1,979,138	$ 0.10	$ 204,221.11	$ 3,209,921.70	17	$ 802,480.43
	18	2,473,922	$ 0.10	$ 257,829.16	$ 4,270,231.29	1,979,138	$ 0.10	$ 206,263.33	$ 3,416,185.03	18	$ 854,046.26
	19	2,473,922	$ 0.11	$ 260,407.45	$ 4,530,638.74	1,979,138	$ 0.11	$ 208,325.96	$ 3,624,510.99	19	$ 906,127.75
	20	2,473,922	$ 0.11	$ 263,011.52	$ 4,793,650.26	1,979,138	$ 0.11	$ 210,409.22	$ 3,834,920.21	20	$ 958,730.05

Table 7.

ROI #3: Impact of Solar Reflectance Attenuation - No Cleaning

kWh Annual Consumption	2,473,922	
Projected Savings	30%	
kWh $	$0.088	
kWh Inflation (annually)	1%	
Roof Square Footage	65,313	
$ per SF	$13.09	$854,947.17

Estimated Project Value **$854,947.17**

kWh Inflation	Year	Before				After				Year	Payback	Cost Reduction due to Solar Reflectance Attenuation	Actual Payback
		kWh	$ kWh	Yearly $	Cumulative $	kWh	$ kWh	Yearly $	Cumulative $				
1%	1	2,473,922	$ 0.088	$ 217,705.14	$ 217,705.14	1,731,745	$ 0.088	$ 152,393.60	$ 152,393.60	1	$ 65,311.54	$ 833.39	$ 64,478.15
	2	2,473,922	$ 0.089	$ 219,882.19	$ 437,587.32	1,731,745	$ 0.089	$ 153,917.53	$ 306,311.13	2	$ 131,276.20	$ 2,264.33	$ 129,011.87
	3	2,473,922	$ 0.090	$ 222,081.01	$ 659,668.33	1,731,745	$ 0.090	$ 155,456.71	$ 461,767.83	3	$ 197,900.50	$ 4,304.68	$ 193,595.82
	4	2,473,922	$ 0.091	$ 224,301.82	$ 883,970.15	1,731,745	$ 0.091	$ 157,011.27	$ 618,779.11	4	$ 265,191.05	$ 6,365.43	$ 258,825.61
	5	2,473,922	$ 0.092	$ 226,544.84	$ 1,110,514.99	1,731,745	$ 0.092	$ 158,581.39	$ 777,360.49	5	$ 333,154.50	$ 8,446.79	$ 324,707.71
	6	2,473,922	$ 0.092	$ 228,810.29	$ 1,339,325.28	1,731,745	$ 0.092	$ 160,167.20	$ 937,527.69	6	$ 401,797.58	$ 10,548.96	$ 391,248.62
	7	2,473,922	$ 0.093	$ 231,098.39	$ 1,570,423.66	1,731,745	$ 0.093	$ 161,768.87	$ 1,099,296.56	7	$ 471,127.10	$ 12,672.16	$ 458,454.94
	8	2,473,922	$ 0.094	$ 233,409.37	$ 1,803,833.04	1,731,745	$ 0.094	$ 163,386.56	$ 1,262,683.13	8	$ 541,149.91	$ 14,816.58	$ 526,333.33
	9	2,473,922	$ 0.095	$ 235,743.47	$ 2,039,576.50	1,731,745	$ 0.095	$ 165,020.43	$ 1,427,703.55	9	$ 611,872.95	$ 16,982.45	$ 594,890.50
	10	2,473,922	$ 0.096	$ 238,100.90	$ 2,277,677.40	1,731,745	$ 0.096	$ 166,670.63	$ 1,594,374.18	10	$ 683,303.22	$ 19,169.98	$ 664,133.24
	11	2,473,922	$ 0.097	$ 240,481.91	$ 2,518,159.31	1,731,745	$ 0.097	$ 168,337.34	$ 1,762,711.52	11	$ 755,447.79	$ 21,379.39	$ 734,068.41
	12	2,473,922	$ 0.098	$ 242,886.73	$ 2,761,046.04	1,731,745	$ 0.098	$ 170,020.71	$ 1,932,732.23	12	$ 828,313.81	$ 23,610.89	$ 804,702.92
	13	2,473,922	$ 0.099	$ 245,315.60	$ 3,006,361.64	1,731,745	$ 0.099	$ 171,720.92	$ 2,104,453.15	13	$ 901,908.49	$ 25,864.70	$ 876,043.79
	14	2,473,922	$ 0.100	$ 247,768.75	$ 3,254,130.39	1,731,745	$ 0.100	$ 173,438.13	$ 2,277,891.27	14	$ 976,239.12	$ 28,141.05	$ 948,098.06
	15	2,473,922	$ 0.101	$ 250,246.44	$ 3,504,376.83	1,731,745	$ 0.101	$ 175,172.51	$ 2,453,063.78	15	$ 1,051,313.05	$ 30,440.17	$ 1,020,872.88
	16	2,473,922	$ 0.102	$ 252,748.90	$ 3,757,125.74	1,731,745	$ 0.102	$ 176,924.23	$ 2,629,988.02	16	$ 1,127,137.72	$ 32,762.28	$ 1,094,375.45
	17	2,473,922	$ 0.103	$ 255,276.39	$ 4,012,402.13	1,731,745	$ 0.103	$ 178,693.48	$ 2,808,681.49	17	$ 1,203,720.64	$ 35,107.60	$ 1,168,613.04
	18	2,473,922	$ 0.104	$ 257,829.16	$ 4,270,231.29	1,731,745	$ 0.104	$ 180,480.41	$ 2,989,161.90	18	$ 1,281,069.39	$ 37,476.38	$ 1,243,593.00
	19	2,473,922	$ 0.105	$ 260,407.45	$ 4,530,638.74	1,731,745	$ 0.105	$ 182,285.21	$ 3,171,447.12	19	$ 1,359,191.62	$ 39,868.85	$ 1,319,322.77
	20	2,473,922	$ 0.106	$ 263,011.52	$ 4,793,650.26	1,731,745	$ 0.106	$ 184,108.07	$ 3,355,555.18	20	$ 1,438,095.08	$ 42,285.25	$ 1,395,809.83

Table 8.

ROI #4: Impact of Solar Reflectance Attenuation - No Cleaning

kWh Annual Consumption	2,473,922	
Projected Savings	20%	
kWh $	$0.088	
kWh Inflation (annually)	1%	
Roof Square Footage	65,313	
$ per SF	$13.09	$854,947.17
Estimated Project Value		**$854,947.17**

kWh Inflation	Year	Before				After				Year	Payback	Cost Reduction due to Solar Reflectance Attenuation	Actual Payback
		kWh	$ kWh	Yearly $	Cumulative $	kWh	$ kWh	Yearly $	Cumulative $				
1%	1	2,473,922	$ 0.088	$ 217,705.14	$ 217,705.14	1,979,138	$ 0.088	$ 174,164.11	$ 174,164.11	**1**	**$ 43,541.03**	**$ 833.39**	**$ 42,707.63**
	2	2,473,922	$ 0.089	$ 219,882.19	$ 437,587.32	1,979,138	$ 0.089	$ 175,905.75	$ 350,069.86	**2**	**$ 87,517.46**	**$ 2,264.33**	**$ 85,253.13**
	3	2,473,922	$ 0.090	$ 222,081.01	$ 659,668.33	1,979,138	$ 0.090	$ 177,664.81	$ 527,734.67	**3**	**$ 131,933.67**	**$ 4,304.68**	**$ 127,628.99**
	4	2,473,922	$ 0.091	$ 224,301.82	$ 883,970.15	1,979,138	$ 0.091	$ 179,441.46	$ 707,176.12	**4**	**$ 176,794.03**	**$ 6,365.43**	**$ 170,428.60**
	5	2,473,922	$ 0.092	$ 226,544.84	$ 1,110,514.99	1,979,138	$ 0.092	$ 181,235.87	$ 888,411.99	**5**	**$ 222,103.00**	**$ 8,446.79**	**$ 213,656.21**
	6	2,473,922	$ 0.092	$ 228,810.29	$ 1,339,325.28	1,979,138	$ 0.092	$ 183,048.23	$ 1,071,460.22	**6**	**$ 267,865.06**	**$ 10,548.96**	**$ 257,316.09**
	7	2,473,922	$ 0.093	$ 231,098.39	$ 1,570,423.66	1,979,138	$ 0.093	$ 184,878.71	$ 1,256,338.93	**7**	**$ 314,084.73**	**$ 12,672.16**	**$ 301,412.58**
	8	2,473,922	$ 0.094	$ 233,409.37	$ 1,803,833.04	1,979,138	$ 0.094	$ 186,727.50	$ 1,443,066.43	**8**	**$ 360,766.61**	**$ 14,816.58**	**$ 345,950.02**
	9	2,473,922	$ 0.095	$ 235,743.47	$ 2,039,576.50	1,979,138	$ 0.095	$ 188,594.77	$ 1,631,661.20	**9**	**$ 407,915.30**	**$ 16,982.45**	**$ 390,932.85**
	10	2,473,922	$ 0.096	$ 238,100.90	$ 2,277,677.40	1,979,138	$ 0.096	$ 190,480.72	$ 1,822,141.92	**10**	**$ 455,535.48**	**$ 19,169.98**	**$ 436,365.50**
	11	2,473,922	$ 0.097	$ 240,481.91	$ 2,518,159.31	1,979,138	$ 0.097	$ 192,385.53	$ 2,014,527.45	**11**	**$ 503,631.86**	**$ 21,379.39**	**$ 482,252.47**
	12	2,473,922	$ 0.098	$ 242,886.73	$ 2,761,046.04	1,979,138	$ 0.098	$ 194,309.38	$ 2,208,836.83	**12**	**$ 552,209.21**	**$ 23,610.89**	**$ 528,598.32**
	13	2,473,922	$ 0.099	$ 245,315.60	$ 3,006,361.64	1,979,138	$ 0.099	$ 196,252.48	$ 2,405,089.31	**13**	**$ 601,272.33**	**$ 25,864.70**	**$ 575,407.63**
	14	2,473,922	$ 0.100	$ 247,768.75	$ 3,254,130.39	1,979,138	$ 0.100	$ 198,215.00	$ 2,603,304.31	**14**	**$ 650,826.08**	**$ 28,141.05**	**$ 622,685.02**
	15	2,473,922	$ 0.101	$ 250,246.44	$ 3,504,376.83	1,979,138	$ 0.101	$ 200,197.15	$ 2,803,501.47	**15**	**$ 700,875.37**	**$ 30,440.17**	**$ 670,435.20**
	16	2,473,922	$ 0.102	$ 252,748.90	$ 3,757,125.74	1,979,138	$ 0.102	$ 202,199.12	$ 3,005,700.59	**16**	**$ 751,425.15**	**$ 32,762.28**	**$ 718,662.87**
	17	2,473,922	$ 0.103	$ 255,276.39	$ 4,012,402.13	1,979,138	$ 0.103	$ 204,221.11	$ 3,209,921.70	**17**	**$ 802,480.43**	**$ 35,107.60**	**$ 767,372.82**
	18	2,473,922	$ 0.104	$ 257,829.16	$ 4,270,231.29	1,979,138	$ 0.104	$ 206,263.33	$ 3,416,185.03	**18**	**$ 854,046.26**	**$ 37,476.38**	**$ 816,569.87**
	19	2,473,922	$ 0.105	$ 260,407.45	$ 4,530,638.74	1,979,138	$ 0.105	$ 208,325.96	$ 3,624,510.99	**19**	**$ 906,127.75**	**$ 39,868.85**	**$ 866,258.89**
	20	2,473,922	$ 0.106	$ 263,011.52	$ 4,793,650.26	1,979,138	$ 0.106	$ 210,409.22	$ 3,834,920.21	**20**	**$ 958,730.05**	**$ 42,285.25**	**$ 916,444.81**

Table 9.

ROI #5: Impact of Solar Reflectance Attenuation and Cleaning Cost

kWh Annual Consumption	2,473,922	
Projected Savings	30%	
kWh $	$0.088	
kWh Inflation (annually)	1%	
Annual Cleaning Costs	$3,208.73	
Roof Square Footage	65,313	
$ per SF	$13.09	$854,947.17
SIES	0%	$0.00
Contingency	0%	$0.00
Estimated Project Value		**$854,947.17**

kWh Inflation	Year	Before				After				Year	Payback	Cost Reduction due to Solar Reflectance Attenuation	Payback w/ Cleaning
		kWh	$ kWh	Yearly $	Cumulative $	kWh	$ kWh	Yearly $	Cumulative $				
1%	1	2,473,922	$ 0.09	$ 217,705.14	$ 217,705.14	1,731,745	$ 0.09	$ 152,393.60	$ 152,393.60	**1**	**$ 65,311.54**	**$ 833.39**	**$ 61,269.42**
	2	2,473,922	$ 0.09	$ 219,882.19	$ 437,587.32	1,731,745	$ 0.09	$ 153,917.53	$ 306,311.13	**2**	**$ 131,276.20**	**$ 2,264.33**	**$ 122,594.41**
	3	2,473,922	$ 0.09	$ 222,081.01	$ 659,668.33	1,731,745	$ 0.09	$ 155,456.71	$ 461,767.83	**3**	**$ 197,900.50**	**$ 4,304.68**	**$ 183,969.63**
	4	2,473,922	$ 0.09	$ 224,301.82	$ 883,970.15	1,731,745	$ 0.09	$ 157,011.27	$ 618,779.11	**4**	**$ 265,191.05**	**$ 6,365.43**	**$ 245,990.69**
	5	2,473,922	$ 0.09	$ 226,544.84	$ 1,110,514.99	1,731,745	$ 0.09	$ 158,581.39	$ 777,360.49	**5**	**$ 333,154.50**	**$ 7,232.66**	**$ 309,878.18**
	6	2,473,922	$ 0.09	$ 228,810.29	$ 1,339,325.28	1,731,745	$ 0.09	$ 160,167.20	$ 937,527.69	**6**	**$ 401,797.58**	**$ 8,721.70**	**$ 373,823.50**
	7	2,473,922	$ 0.09	$ 231,098.39	$ 1,570,423.66	1,731,745	$ 0.09	$ 161,768.87	$ 1,099,296.56	**7**	**$ 471,127.10**	**$ 10,844.90**	**$ 437,821.09**
	8	2,473,922	$ 0.09	$ 233,409.37	$ 1,803,833.04	1,731,745	$ 0.09	$ 163,386.56	$ 1,262,683.13	**8**	**$ 541,149.91**	**$ 12,989.32**	**$ 502,490.75**
	9	2,473,922	$ 0.10	$ 235,743.47	$ 2,039,576.50	1,731,745	$ 0.10	$ 165,020.43	$ 1,427,703.55	**9**	**$ 611,872.95**	**$ 13,891.77**	**$ 569,102.61**
	10	2,473,922	$ 0.10	$ 238,100.90	$ 2,277,677.40	1,731,745	$ 0.10	$ 166,670.63	$ 1,594,374.18	**10**	**$ 683,303.22**	**$ 15,441.27**	**$ 635,774.65**
	11	2,473,922	$ 0.10	$ 240,481.91	$ 2,518,159.31	1,731,745	$ 0.10	$ 168,337.34	$ 1,762,711.52	**11**	**$ 755,447.79**	**$ 17,650.68**	**$ 702,501.09**
	12	2,473,922	$ 0.10	$ 242,886.73	$ 2,761,046.04	1,731,745	$ 0.10	$ 170,020.71	$ 1,932,732.23	**12**	**$ 828,313.81**	**$ 19,882.17**	**$ 769,926.88**
	13	2,473,922	$ 0.10	$ 245,315.60	$ 3,006,361.64	1,731,745	$ 0.10	$ 171,720.92	$ 2,104,453.15	**13**	**$ 901,908.49**	**$ 20,821.26**	**$ 839,373.74**
	14	2,473,922	$ 0.10	$ 247,768.75	$ 3,254,130.39	1,731,745	$ 0.10	$ 173,438.13	$ 2,277,891.27	**14**	**$ 976,239.12**	**$ 22,433.68**	**$ 908,883.22**
	15	2,473,922	$ 0.10	$ 250,246.44	$ 3,504,376.83	1,731,745	$ 0.10	$ 175,172.51	$ 2,453,063.78	**15**	**$ 1,051,313.05**	**$ 24,732.79**	**$ 978,449.31**
	16	2,473,922	$ 0.10	$ 252,748.90	$ 3,757,125.74	1,731,745	$ 0.10	$ 176,924.23	$ 2,629,988.02	**16**	**$ 1,127,137.72**	**$ 27,054.90**	**$ 1,048,743.14**
	17	2,473,922	$ 0.10	$ 255,276.39	$ 4,012,402.13	1,731,745	$ 0.10	$ 178,693.48	$ 2,808,681.49	**17**	**$ 1,203,720.64**	**$ 28,032.12**	**$ 1,121,140.11**
	18	2,473,922	$ 0.10	$ 257,829.16	$ 4,270,231.29	1,731,745	$ 0.10	$ 180,480.41	$ 2,989,161.90	**18**	**$ 1,281,069.39**	**$ 29,710.01**	**$ 1,193,602.24**
	19	2,473,922	$ 0.11	$ 260,407.45	$ 4,530,638.74	1,731,745	$ 0.11	$ 182,285.21	$ 3,171,447.12	**19**	**$ 1,359,191.62**	**$ 32,102.48**	**$ 1,266,123.27**
	20	2,473,922	$ 0.11	$ 263,011.52	$ 4,793,650.26	1,731,745	$ 0.11	$ 184,108.07	$ 3,355,555.18	**20**	**$ 1,438,095.08**	**$ 34,518.87**	**$ 1,339,401.61**

Table 10.

ROI #6: Impact of Solar Reflectance Attenuation and Cleaning Cost

kWh Annual Consumption	2,473,922	
Projected Savings	20%	
kWh $	$0.088	
kWh Inflation (annually)	1%	
Annual Cleaning Costs	$3,208.73	
Roof Square Footage	65,313	
$ per SF	$13.09	$854,947.17
SIES	0%	$0.00
Contingency	0%	$0.00
Estimated Project Value		**$854,947.17**

kWh Inflation	Year	Before				After				Year	Payback	Cost Reduction due to Solar Reflectance Attenuation	Payback w/ Cleaning
		kWh	$ kWh	Yearly $	Cumulative $	kWh	$ kWh	Yearly $	Cumulative $				
	1	2,473,922	$ 0.09	$ 217,705.14	$ 217,705.14	1,979,138	$ 0.09	$ 174,164.11	$ 174,164.11	**1**	**$ 43,541.03**	**$ 833.39**	**$ 39,498.90**
	2	2,473,922	$ 0.09	$ 219,882.19	$ 437,587.32	1,979,138	$ 0.09	$ 175,905.75	$ 350,069.86	**2**	**$ 87,517.46**	**$ 2,264.33**	**$ 81,100.00**
	3	2,473,922	$ 0.09	$ 222,081.01	$ 659,668.33	1,979,138	$ 0.09	$ 177,664.81	$ 527,734.67	**3**	**$ 131,933.67**	**$ 4,304.68**	**$ 122,307.48**
	4	2,473,922	$ 0.09	$ 224,301.82	$ 883,970.15	1,979,138	$ 0.09	$ 179,441.46	$ 707,176.12	**4**	**$ 176,794.03**	**$ 6,365.43**	**$ 163,959.11**
	5	2,473,922	$ 0.09	$ 226,544.84	$ 1,110,514.99	1,979,138	$ 0.09	$ 181,235.87	$ 888,411.99	**5**	**$ 222,103.00**	**$ 7,232.66**	**$ 206,059.35**
	6	2,473,922	$ 0.09	$ 228,810.29	$ 1,339,325.28	1,979,138	$ 0.09	$ 183,048.23	$ 1,071,460.22	**6**	**$ 267,865.06**	**$ 8,721.70**	**$ 248,612.68**
	7	2,473,922	$ 0.09	$ 231,098.39	$ 1,570,423.66	1,979,138	$ 0.09	$ 184,878.71	$ 1,256,338.93	**7**	**$ 314,084.73**	**$ 10,844.90**	**$ 291,623.62**
	8	2,473,922	$ 0.09	$ 233,409.37	$ 1,803,833.04	1,979,138	$ 0.09	$ 186,727.50	$ 1,443,066.43	**8**	**$ 360,766.61**	**$ 12,989.32**	**$ 335,096.77**
	9	2,473,922	$ 0.10	$ 235,743.47	$ 2,039,576.50	1,979,138	$ 0.10	$ 188,594.77	$ 1,631,661.20	**9**	**$ 407,915.30**	**$ 13,891.77**	**$ 379,036.73**
1%	10	2,473,922	$ 0.10	$ 238,100.90	$ 2,277,677.40	1,979,138	$ 0.10	$ 190,480.72	$ 1,822,141.92	**10**	**$ 455,535.48**	**$ 15,441.27**	**$ 423,448.18**
	11	2,473,922	$ 0.10	$ 240,481.91	$ 2,518,159.31	1,979,138	$ 0.10	$ 192,385.53	$ 2,014,527.45	**11**	**$ 503,631.86**	**$ 17,650.68**	**$ 468,335.83**
	12	2,473,922	$ 0.10	$ 242,886.73	$ 2,761,046.04	1,979,138	$ 0.10	$ 194,309.38	$ 2,208,836.83	**12**	**$ 552,209.21**	**$ 19,882.17**	**$ 513,704.45**
	13	2,473,922	$ 0.10	$ 245,315.60	$ 3,006,361.64	1,979,138	$ 0.10	$ 196,252.48	$ 2,405,089.31	**13**	**$ 601,272.33**	**$ 20,821.26**	**$ 559,558.84**
	14	2,473,922	$ 0.10	$ 247,768.75	$ 3,254,130.39	1,979,138	$ 0.10	$ 198,215.00	$ 2,603,304.31	**14**	**$ 650,826.08**	**$ 22,433.68**	**$ 605,903.86**
	15	2,473,922	$ 0.10	$ 250,246.44	$ 3,504,376.83	1,979,138	$ 0.10	$ 200,197.15	$ 2,803,501.47	**15**	**$ 700,875.37**	**$ 24,732.79**	**$ 652,744.42**
	16	2,473,922	$ 0.10	$ 252,748.90	$ 3,757,125.74	1,979,138	$ 0.10	$ 202,199.12	$ 3,005,700.59	**16**	**$ 751,425.15**	**$ 27,054.90**	**$ 700,085.47**
	17	2,473,922	$ 0.10	$ 255,276.39	$ 4,012,402.13	1,979,138	$ 0.10	$ 204,221.11	$ 3,209,921.70	**17**	**$ 802,480.43**	**$ 28,032.12**	**$ 747,932.02**
	18	2,473,922	$ 0.10	$ 257,829.16	$ 4,270,231.29	1,979,138	$ 0.10	$ 206,263.33	$ 3,416,185.03	**18**	**$ 854,046.26**	**$ 29,710.01**	**$ 796,289.12**
	19	2,473,922	$ 0.11	$ 260,407.45	$ 4,530,638.74	1,979,138	$ 0.11	$ 208,325.96	$ 3,624,510.99	**19**	**$ 906,127.75**	**$ 32,102.48**	**$ 845,161.88**
	20	2,473,922	$ 0.11	$ 263,011.52	$ 4,793,650.26	1,979,138	$ 0.11	$ 210,409.22	$ 3,834,920.21	**20**	**$ 958,730.05**	**$ 34,518.87**	**$ 894,555.45**

CHAPTER 6

DISCUSSION

Results of the study show that factoring in specific building information provided only minor changes and no overall change to the project payback period year. While some may conclude that including the specific building information into the equation is inconsequential, it only shows that to be the case for this particular scenario. The other aspect of this argument worth consideration is that cleaning maintenance offsets solar attenuation to such a degree while offering so little impact to project payback that it pays for itself. The other benefit that comes from this investment is that a cleaning maintenance schedule will actually mitigate potential degradation and other roof maintenance issues while ensuring the cool roof is kept in good condition. While some research suggests cleaning is cost prohibitive, this study showed the extra costs were offset to a large degree by the increased return on energy savings and therefore the impact to project payback was minor. In the same time, the study showed that cleaning actually saved 262,244.8 kWh in energy savings and should not be dismissed. Therefore cleaning maintenance should not be taken for granted or categorically omitted altogether from the project planning process.

IMPLICATIONS AND LIMITATIONS

When considering cleaning maintenance, several factors should be considered to maximize your ROI for this labor. These include timing of cleaning to maximize restoration of solar reflectance before peak-cooling season begins as well as other weather considerations. For example, the southern Gulf Coast typically experiences its driest months from October through January. This means that any accumulated dirt and biomass has a decreased chance of being cleaned by rain during this period. Letting any accumulated dirt and biomass remain on the roof during this dry period will actually improve energy loss heating penalties. In the spring before the peak-cooling season begins would best take advantage of both the past heating season and the upcoming cooling season.

The heating penalty was discussed in the literature review and analysis and was originally factored into the estimating process and part of the original calculations. While a decrease in solar reflectance would actually reduce the heating penalty in theory, there were no studies found that could properly correlate and quantify the heating penalty reduction relation to solar reflectance, and therefore heating penalty was treated as a constant. Since the focus of the thesis was regarding impact of solar reflection attenuation and cleaning on project payback, and considering heating penalty would be a constant, it was therefore excluded from the calculations.

There is a wealth of research on primarily TPO, acrylic, latex, silicone, PVC, and EPDM roofing. Some research accounts for PVDF, but this is typically involves metal roofing where the PVDF was baked on in the factory. There is a need for more studies on the ever-growing list of new fluid applied cool roof coatings. The product that was specified for the case study was a fluoropolymer based resin and while the coating was available on the CRRC website, there was no specific research found concerning this specific coating.

RECOMMENDATIONS FOR COOL ROOF PLANNING

Recommendations for any facility manager when considering a cool roof should start with talking to roofing contractors and manufacturing representative experts to see if a cool roof would be a good option. Gather specific recommended product information and specifications and cross-reference with the CRRC for solar reflectance, thermal emittance, and SRI information. Ask the experts if a similar roof was installed on a building in the area. If so, request contact information for that project to gather information from the owner or owner representative and perhaps even arrange for a site visit. Either could provide invaluable data as to expected energy savings as well as expected cleaning maintenance that may be required. This will aid significantly in developing the most accurate cool roof installation ROI.

CHAPTER 7

CONCLUSION

A cool roof's high solar reflectance, thermal emissivity, and ability to stay clean allow for reductions to cooling energy costs. Industry standards show averages of 20-30% energy savings compared to conventional roofing systems. Project payback planning should factor in building specifics and consider whether or not a cleaning schedule will be warranted to provide the most accurate project payback.

Cool roof coating's chemical composition and mixtures are as various as the climates and geographical biological challenges in which they are installed. Each roof and building is truly unique, thus it is impossible to accurately predict the true effects of ageing and dirt and biological growth for every building, and likewise the true energy savings for the entire life cycle. However, manufacturer's specifications for the specific cool roof product as well as information from the CRRC can help aid in predicting anticipated savings, but most importantly provide anticipated solar reflectance impacts that come with age. While factoring in building material specifics and cleaning costs into the cool roof ROI may not prove significant to results, it is important not to overlook the energy savings over the life of the roof. Considering the anticipated solar reflectance attenuation from exposure as well as cleaning maintenance will help the owner calculate the most accurate ROI and project payback.

Whether or not a cool roof will provide sufficient energy reductions to provide 100% payback within its life cycle is not the only measure of a cool roof. Data proves that cool roof technology saves energy. With the increasing focus on energy reduction by both industry and government, the reduction in energy consumption may be the foremost priority, with project payback being only a fringe benefit if the case allows.

REFERENCES

Alchapar, N. L., & Correa, E. N. (2016). Aging of roof coatings. Solar reflectance stability according to their morphological characteristics. Construction and Building Materials, 102, 297–305. http://doi.org/10.1016/j.conbuildmat.2015.11.005

Berdahl, P., Akbari, H., Levinson, R., & Miller, W. A. (2008). Weathering of roofing materials – An overview. Construction and Building Materials, 22(4), 423–433. http://doi.org/10.1016/j.conbuildmat.2006.10.015

Berdahl, H. G., Quelen, S., Marlot, L., Preble, C., Chen, S., Montalbano, A., … Destaillats, H. (2013). Soiling of building envelope surfaces and its effect on solar reflectance–Part II: Development of an accelerated aging method for roofing materials. Retrieved from https://ses.lbl.gov/sites/all/files/lbnl-6714e.pdf

Bretz, S.E., Akbar, H. (1994). Durability of High-Albedo Roof Coatings. California Institute for Energy Efficiency, University of California.

Cool Roof Rating Council. (2016). Retrieved from http://coolroofs.org/resources/faq

Dornelles, K., Caram, R., & Sichieri, E. (2015). Natural Weathering of Cool Coatings and its Effect on Solar Reflectance of Roof Surfaces. Energy Procedia, 78, 1587–1592. http://doi.org/10.1016/j.egypro.2015.11.216

Gernetzke, T.M. (2016). Cut Costs with Cool Roofs. Retrieved from http://www.buildings.com/article-details/articleid/19859/title/cut-costs-with-cool-roofs/viewall/true.aspx

Levinson, R., Akbari, H., Konopacki, S., & Bretz, S. (2005). Inclusion of cool roofs in nonresidential Title 24 prescriptive requirements. Energy Policy, 33(2), 151–170. http://doi.org/10.1016/S0301-4215(03)00206-4

Levinson, R., Berdahl, P., Asefawberhe, A., & Akbari, H. (2005). Effects of soiling and cleaning on the reflectance and solar heat gain of a light-colored roofing membrane. Atmospheric Environment, 39(40), 7807–7824. http://doi.org/10.1016/j.atmosenv.2005.08.037

Mastrapostoli, E., Santamouris, M., Kolokotsa, D., Vassilis, P., Venieri, D., & Gompakis, K. (2016). On the ageing of cool roofs: Measure of the optical degradation, chemical and biological analysis and assessment of the energy impact. Energy and Buildings, 114, 191–199. http://doi.org/10.1016/j.enbuild.2015.05.030

Muraya, N. K. (2007). Reflective roof coatings calculations, results, and exponential growth. Energy Engineering, 104(2), 6–14.

Parker, D.S., Barkaszi, S.F. (1997). Roof solar reflectance and cooling energy use: field research results from Florida. Energy and Buildings, 25, 105–115

Paolini, R., Zinzi, M., Poli, T., Carnielo, E., & Mainini, A. G. (2014). Effect of ageing on solar spectral reflectance of roofing membranes: Natural exposure in Roma and Milano and the impact on the energy needs of commercial buildings. Energy and Buildings, 84, 333–343. http://doi.org/10.1016/j.enbuild.2014.08.008

Pisello, A. L., Santamouris, M., & Cotana, F. (2013). Active cool roof effect: impact of cool roofs on cooling system efficiency. Advances in Building Energy Research, 7(2), 209–221. http://doi.org/10.1080/17512549.2013.865560

Revel, G. M., Martarelli, M., Bengochea, M. Á., Gozalbo, A., Orts, M. J., Gaki, A., … Emiliani, M. (2013). Nanobased coatings with improved NIR reflecting properties for building envelope materials: Development and natural aging effect measurement. Cement and Concrete Composites, 36, 128–135. http://doi.org/10.1016/j.cemconcomp.2012.10.002

Shi, Z., & Zhang, X. (2011). Analyzing the effect of the longwave emissivity and solar reflectance of building envelopes on energy-saving in buildings in various climates. Solar Energy, 85(1), 28–37. http://doi.org/10.1016/j.solener.2010.11.009

Synnefa, A., Saliari, M., & Santamouris, M. (2012). Experimental and numerical assessment of the impact of increased roof reflectance on a school building in Athens. Energy and Buildings, 55, 7–15. http://doi.org/10.1016/j.enbuild.2012.01.044

Synnefa, A., Santamouris, M., & Akbari, H. (2007). Estimating the effect of using cool coatings on energy loads and thermal comfort in residential buildings in various climatic conditions. Energy and Buildings, 39(11), 1167–1174. http://doi.org/10.1016/j.enbuild.2007.01.004

U.S. Department of Energy (2010). Guidelines for Selecting Cool Roofs. Retrieved from http://www.ws012.cedengineering.com/userfiles/Selecting%20Cool%20Roofs.pdf

U.S. Energy Information Administration, (2016). 2012 Commercial Buildings Energy Consumption Survey: Energy Usage Summary. Retrieved from http://www.eia.gov/consumption/commercial/reports/2012/energyusage/

U.S. Environmental Protection Agency, ENERGY STAR (2016). Cool Roofs and Emissivity. Retrieved from https://www.energystar.gov/products/building_products/roof_products/cool_roofs_emissivity

U.S. Green Building Council, (2016). Solar Reflectance Index (SRI). Retrieved from http://www.usgbc.org/glossary/term/5590

Xue, X., Yang, J., Zhang, W., Jiang, L., Qu, J., Xu, L., … Zhang, Z. (2015). The study of an energy efficient cool white roof coating based on styrene acrylate copolymer and cement for waterproofing purpose—Part I: Optical properties, estimated cooling effect and relevant properties after dirt and accelerated exposures. Construction and Building Materials, 98, 176–184. http://doi.org/10.1016/j.conbuildmat.2015.08.045

Zhang, W., Song, Z., Shi, Y., Song, J., Qu, J., Qin, J., … Xue, X. (2013). The effects of manufacturing processes and artificial accelerated weathering on the solar reflectance and cooling effect of cool roof coatings. Solar Energy Materials and Solar Cells, 118, 61–71. http://doi.org/10.1016/j.solmat.2013.07.039 40