A Comparison of Code-Compliant Roof Insulation and Roof Albedo Impacts and Benefits

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Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
BCR	Benefit to Cost Ratio
BEM	Building Energy Models
BL	Baesline Model
BOMA	Building Owners and Managers Association International
CASE	Codes and Standards Enhancement
CBECS	EIA's Commercial Building Energy Consumption Survey
CFA	Conditioned Floor Area
CRRC	Cool Roof Rating Council
CZ	Climate Zone
DOE	U.S. Department of Energy
eGRID	Emissions and Generation Resource Integrated Database
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
EPD	Environmental Product Declaration
ERA	EPDM Roofing Assocaiton
EUI	Energy Use Index (kBtu/sf/yr)
EUL	Effective Useful Life
FEMP	U.S. DOE's Federal Energy Management Program
GHG	Greenhouse Gas Emissions
HVAC	Heating, Ventilation, and Air Conditioning
IEAD	Insulation Entirely Above Deck
IES	Illuminating Engineering Society
IN	Inch
LB	Pound
NIST	National Institute of Standards
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
OS	OpenStudio
SF	Square Foot
SPP	Simple Payback Period
YR	Year

Introduction

Cool roofs have become one of several widely accepted strategies for mitigating the impacts of urban heat islands and have long been a prescriptive requirement of ASHRAE 90.1-2019 in Climate Zones 1, 2, and 3. They consist of a cool or high-albedo roofing surface material that reflects a portion of the incoming solar radiation away from a building's roof before it is transmitted to and absorbed by the building. This reduction in solar heat gain typically decreases space cooling, increases space heating requirements, and increases overall building energy use in heating dominated climates.

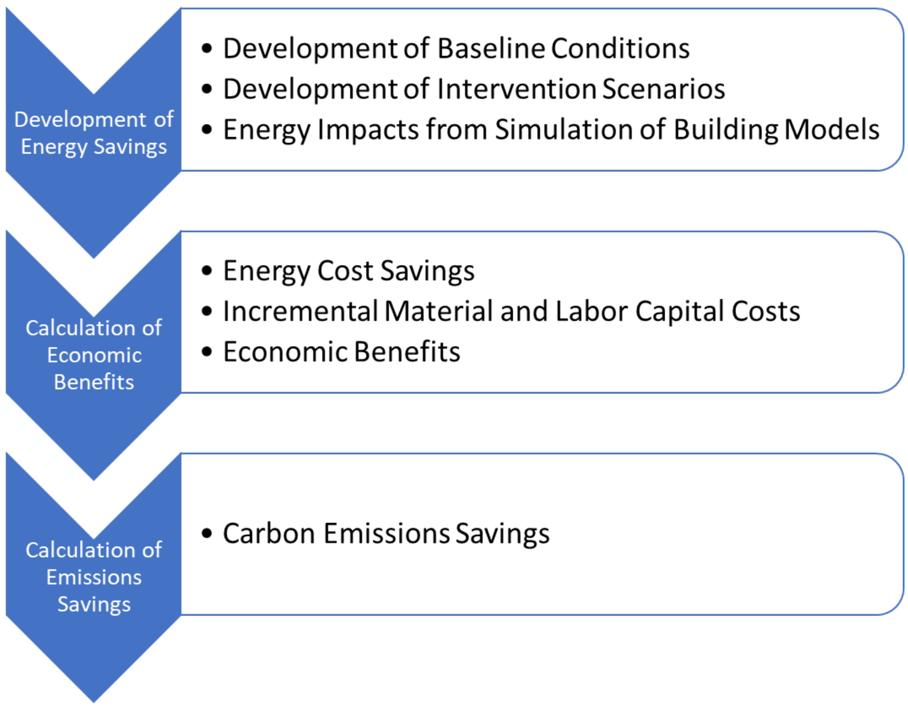
Researched conducted by ERA found cool roofs tend to provide a marginal and positive reduction in energy use across all modeled climate zones when installed with traditional levels of insulation, for most commercial building types with low sloped roofs and insulation installed entirely above deck. However, those impacts tend to marginally decrease when coupled with increased levels of insulation and for colder compared to warmer climate zones, reducing the incremental benefit of cool roofs as a mitigation strategy for roof replacements required to meet the prescriptive insulation requirements of ASHRAE Standard 90.1-2019.

To better understand and communicate where insulation and cool roofs provide the greatest benefits, ERA commissioned this study to assess and quantify the life-cycle energy, economics, and emission benefits of code-compliant roof replacements and cool roof projects ("interventions") for a select number of commercial building types constructed with low-sloped roofs and representative city/climate zone combinations. In support of communication with building owners, code officials, policy makers, and other industry and marketplace stakeholders, a compendium of supporting fact sheets will be developed to summarize the energy, economic, and emissions benefits of installing code-compliant insulation compared to cool roof projects, at the time of roof replacement. In contrast to the fact sheets, this report documents details of the analytical approach, including its methods, data sources, and assumptions. Detailed intermediate and final calculations can be found in the accompanying M.S. Excel datafiles referenced in *Appendix E – Attachments*.

Energy Code-Compliant Roof Replacements

This analysis was conducted to assess the energy, economic, and emissions benefits for installation of code-compliant roof insulation at time of a roof replacement compared a cool roof intervention scenario. A primary assumption is that roofs being replaced today were originally constructed on buildings that precede widespread adoption of building energy codes and are therefore under insulated; and when installing a cool roof on top of a code-compliant roofing system, the incremental impacts and benefits of cool roofs are lessoned.

Figure 1 – Methodology for Development of Energy and Emissions Impacts and Economics Benefits



The approach illustrated in Figure 1 was used to estimate the energy, economic, and emissions benefits of code-compliant roof replacements and cool roof projects for four commercial building types with low-sloped roofs in three primary- and seven sub-U.S. climate zones, and nine U.S. city locations.

- First, building energy models were developed to represent the baseline and intervention scenarios. Both sets of models were simulated to produce annual estimates of whole-building energy use and their energy use was subtracted to produce incremental energy savings.
- Second, energy cost savings were calculated as the product of energy savings by fuel type and the corresponding price of fuel and then combined with secondary research on incremental material and labor capital costs to produce life-cycle economic metrics.
- Finally, emissions benefits were developed directly from energy savings as the product of energy savings by fuel type and the corresponding emissions factors.

A summary of analytical resources and assumptions can be found in *Appendix D – Modeling Data Sources.*

Development of Whole-Building Energy Savings

Incremental energy savings were calculated as the difference between the baseline and intervention building energy models simulated whole-building energy performance. Baseline building models were derived from DOE's commercial prototypical building models and their roof insulation R-values and 3-year aged solar reflectance and thermal emittance values modified to represent average values in the existing commercial building stock. Similarly, intervention models were developed from the same DOE commercial prototypical building models but with their roof insulation R-values and 3-year aged solar reflectance and thermal emittance values modified to represent the prescriptive values required by the most current version of the commercial building energy code, ASHRAE 90.1-2019.

Development of Baseline Conditions

Baseline building energy models were developed from DOE's commercial prototypical building models[1]. A custom measure workflow was developed to create and modify DOE's prototypical building models within the OpenStudio (OS) building energy modeling environment. Building models were created for the Medium Office, Hospital, Primary School, and Warehouse building types, in three primary- and seven sub-U.S. climate zones, to represent nine U.S. city locations, using the 2004 (New Construction) building energy model vintage, as depicted in Table 1.

Table 1 – Building Energy Modeling Characteristics

DOE Commercial Building Types			DOE Model Vintage	Climate Zone / City Locations	
Building Type	# Floors	Floor Area (SF)			
Medium Office	3-story	53,628	New Construction (2004)	3A Warm Humid	Oklahoma City, OK
Hospital	5-story	241,351			Atlanta, GA
Primary School	1-story	73,960		3B Warm Dry	Las Vegas, NV
Warehouse	1 story	52,045		4A Mixed Humid	Philadelphia, PA
					Baltimore, MD
				4B Mixed Dry	Albuquerque, NM
				4C Mixed Marine	Seattle, WA
				5A Cool Humid	Chicago, IL
				5B Cool Dry	Denver, CO

The 2004 DOE vintage building model was selected as the baseline condition because most commercial buildings with low-sloped roofs were constructed prior to 1980 and using the 2004-vintage models would be conservative and defensible because they include comparatively more energy efficient space heating and cooling system and lighting systems. Secondary research conducted on building characteristics such as lighting from EIA's 2015 Commercial Building Energy Consumption Survey (CBECS) did not yield defensible data that could be used to update building model inputs, nor did sample modeling of alternative vintage models such as pre-1980 show significant variations in energy performance that would lead to the recommended use of an

[1] Prototype Building Models | Building Energy Codes Program

alternate baseline model.

The prototypical building models were then modified using the measure workflow to represent baseline conditions depicted in Table 2, representing average values in the existing commercial building stock, with low-sloped roofs.

Roof insulation R-values were modified from the DOE prototypical baseline insulation values to be average roof insulation values of R-12.5 (installed as a single non-continuous insulation layer) for all building model types in all climate zones. The baseline R-value of R-12.5 was selected in consultation with ERA to represent typical roof insulation values found in commercial buildings 20-years and older with low-sloped roofs. It is based on secondary research conducted by PIMA (Polyisocyanurate Insulation Manufacturer’s Association) that found baseline levels of insulation to be between R-10 and R-15 for existing low-slope roofs. A primary assumption is that roofs being replaced today were originally constructed on buildings that date back prior to the widespread adoption of building energy codes and remain under insulated, where common practice was to install a single layer of 2” to 2.5” insulation.

Table 2 – Baseline Scenario Roofing Characteristic Values by Climate Zone

Baseline Scenario		Climate Zone	Above-deck Roof Insulation (IEAD) R-value	3-year aged solar reflectance (CRRC S100-tested)	3-year aged thermal emittance (CRRC S100-tested)
Baseline	BL	3	R-12.5	0.3	0.9
		4	R-12.5	0.3	0.9
		5	R-12.5	0.3	0.9

Similarly, for all building types and climate zones, roof 3-year solar reflectance and thermal emittance values were modified from their DOE prototypical baseline values to reflect the 3-year aged solar reflectance and thermal emittance values of the ASHRAE 90.1-2004 standard.

Development of Intervention Scenarios

Intervention models were developed from the baseline building energy models scenarios depicted in Table 3 and described below. They represent 3-year aged solar reflectance and thermal emittance values commonly used in modeling for building-level code compliance.

Table 3 –Roofing Characteristic Values by Intervention Scenario by Climate Zone

Model Scenarios		Climate Zone	Above-deck Roof Insulation (IEAD) R-value	3-year aged solar reflectance (CRRC S100-tested)	3-year aged thermal emittance (CRRC S100-tested)
Black Roof Intervention with code compliant levels of insulation	I1	3	R-25	0.3	0.9
		4	R-30	0.3	0.9
		5	R-30	0.3	0.9
White Roof Intervention with baseline levels of insulation	I2	3	R-12.5	0.55	0.75
		4	R-12.5	0.55	0.75
		5	R-12.5	0.55	0.75

Model Scenarios		Climate Zone	Above-deck Roof Insulation (IEAD) R-value	3-year aged solar reflectance (CRRC S100-tested)	3-year aged thermal emittance (CRRC S100-tested)
White Roof Intervention with code compliant levels of insulation	I3	3	R-25	0.55	0.75
		4	R-30	0.55	0.75
		5	R-30	0.55	0.75

Intervention (I1): The black roof with code-compliant levels of insulation intervention is identical to the baseline condition but with roof insulation levels based on the ASHRAE Standard 90.1-2019 prescriptive building envelope compliance path for conditioned non-residential opaque roof (exterior) elements for insulation entirely above deck minimum rated R-value building envelop criteria. The R-values assume continuous insulation and varies according to U.S. climate zones specified by ASHRAE Standard 169. The insulation is assumed to be of rigid form type, like Polyiso, installed between a concrete, wood, or metal roof deck and an EPDM water-proof roofing membrane.

Intervention (I2): The cool roof with baseline levels of insulation intervention is identical to the baseline condition but with 3-year aged solar reflectance and thermal emittance values of the ASHRAE 90.1-2019 standard for cool (or white) roofs.

Intervention (I3): The cool Roof with code-compliant levels of insulation intervention is identical to the black roof with code-compliant levels of insulation but with the 3-year aged solar reflectance and thermal emittance of the cool roof intervention (I2). In contrast to (I2), this intervention assumes a cool roof would be installed at the time of a roofing replacement: when the roof membrane and insulation installed entirely above deck are both removed to expose the structural roof deck and replaced with (1) insulation that complies ASHRAE Standard 90.1-2019 and (2) a water-proof membrane that exhibits both high solar reflectance and thermal emittance consistent with conventional characteristics of a cool roof.

Energy Impacts from Simulation of Building Energy Models

A custom measure workflow was used to simulate the baseline and intervention building energy models in EnergyPlus. Raw annual energy end use performance data from the EnergyPlus simulations, by scenario, building type, climate zone, and representative city location were post-processed to produce incremental energy impacts. They were calculated as the difference between the simulated whole-building energy performance of the baseline and each of the three intervention scenarios.

Intervention (I1): Black roof with code-compliant levels of insulation energy impacts result from increased roof insulation, which increases thermal resistance, reduces heat transfer through the roof assembly, reduces space heating and space cooling requirements (a function of load and efficiency), and decreases energy use. Roof insulation measures reduce both space heating and cooling energy in all building types and climate zones modeled in this study.

Intervention (I2): Cool roof with baseline levels of insulation energy impacts result from increased roof albedo (reflectance) and emittance that reduces the solar energy (radiation) absorbed by and transmitted as heat gain through the buildings roofing assembly. Cool roof measures tend to reduce overall building energy use and space cooling energy use but can lead to increased space heating loads in select building types [Warehouse CZ 4A, 4C, 5A, 5B] and heating dominated climate zones due to loss of heat input or radiation heat transfer.

Intervention (I3): Cool Roof with code-compliant levels of insulation energy impacts result from the interactive effects of the increased roof insulation and high reflectance and emittance of the cool roofing system. The combined effect tends to be a moderate increase in overall energy savings compared to the black roof intervention due to a decrease in benefits from cool roofs when combined with greater levels of roof insulation.

Absolute energy savings per conditioned floor area varied significantly according to building type and climate zone, as depicted in Figure 2, with the greatest energy savings generally occurring for buildings with larger roof areas and space heating and space cooling requirements.

Figure 2 – Average Absolute Energy Savings per SF by Building Type, Climate Zone, and Scenario

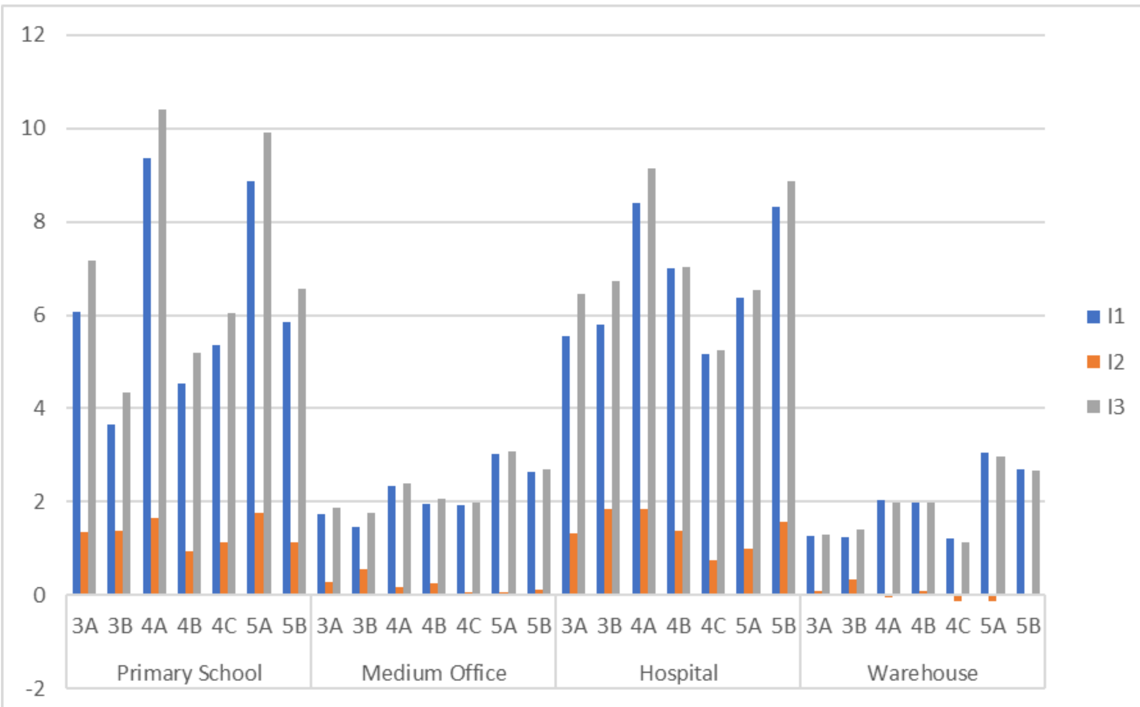
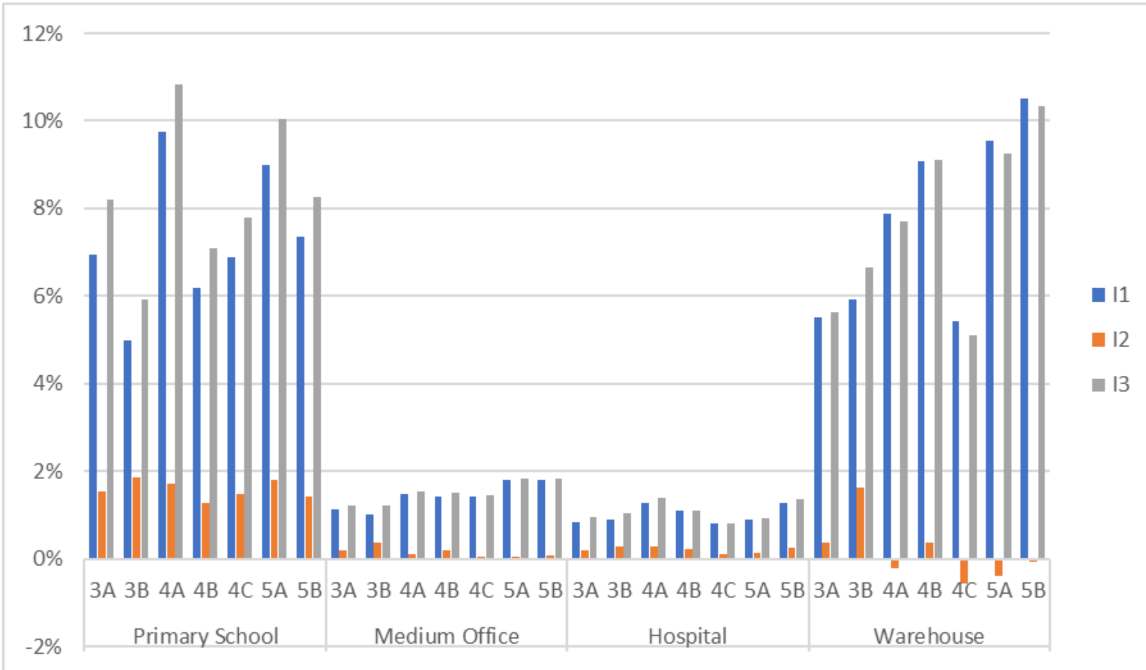


Figure 3 – Average Relative Energy Savings by Building Type, Climate Zone, and Scenario



Relative energy savings also varied according to building type and climate zone but was highly correlated with the building's roof-to-floor area ratio - calculated as the quotient of the building's roof and floor areas. As seen in Figure 3, both the Primary School (1-story) and Warehouse (1-story, with small 2-story section) building types, which have roof-to-floor area ratios of about 1.0, have generally similar relative energy savings profiles compared to the Medium Office (3-stories) and Hospital (5-stories) building types that have fractional roof-to-floor area ratios.

Key take-aways are as follows:

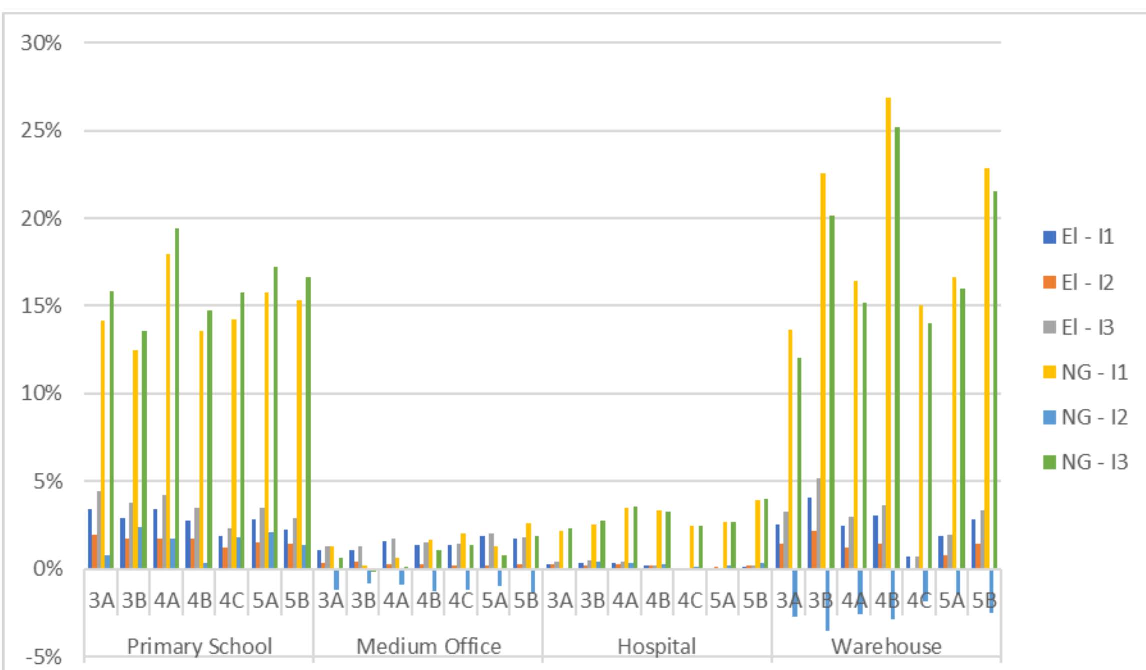
- Implementation of cool roof with baseline levels of insulation results in less than 2% of savings across all the building types modeled. The cool roof implementation affects the building in ways including a reduction of external radiation heat gain. The effects are particularly noticed for buildings with large area footprints and flat roofs.
- The impacts of cool roofs alone are small (and in some cases negligible [Medium Office and Hospital] and even negative [Warehouse climate zones 4 and 5]) compared to the benefits of adding code-compliant levels of insulation, which is required during a full roof replacement and results in positive energy savings for all modeled cases.
- The impacts of cool roofs tend to be moderated when combined with code-compliant levels of roof insulation, as shown in Table 4. For example, a cool roof installed on a Primary School building in climate zone 3 with baseline-levels of insulation could be expected to save, on average, 1.7%, but only 1.2% when installed on the same building with code-compliant levels of insulation.

Table 4 – Average Relative Energy Savings by Building Type, Climate Zone, and Scenario

Building Type	Aggregated Climate Zone	Intervention			Cool Roof Impact	
		I1	I2	I3	(I3 - I1)	I2 - (I3 - I1)
Primary School	3	6.3%	1.7%	7.4%	1.2%	0.5%
	4	8.1%	1.6%	9.1%	1.0%	0.6%
	5	8.2%	1.6%	9.1%	1.0%	0.6%
Medium Office	3	1.1%	0.3%	1.2%	0.1%	0.1%
	4	1.5%	0.1%	1.5%	0.1%	0.1%
	5	1.8%	0.1%	1.8%	0.0%	0.0%
Hospital	3	0.9%	0.2%	1.0%	0.1%	0.1%
	4	1.1%	0.2%	1.2%	0.1%	0.2%
	5	1.1%	0.2%	1.1%	0.1%	0.1%
Warehouse	3	5.7%	0.8%	6.0%	0.3%	0.5%
	4	7.6%	-0.2%	7.4%	-0.2%	0.0%
	5	10.0%	-0.2%	9.8%	-0.2%	0.0%

Aside from the Medium Office, the greatest energy savings is from the reduction natural gas used for space heating, for the code-compliant insulation intervention, compared to a smaller reduction in electric use for space cooling, as shown in Figure 4. Whereas increased insulation results in both natural gas and electric energy use savings irrespective of building type and climate zone, energy impacts from the cool roof intervention tends to be both building type and climate zone specific, with cases of increased natural gas use only in the Medium Office and Warehouse building types.

Figure 4 – Average Relative Electric and Natural Gas Savings by Building Type, Climate Zone



Increased natural gas use for space heating load for the Medium Office and Warehouses building types is likely driven by operating characteristics and schedules of the DOE prototypical building models. Generally, offices are not conditioned to the optimum point for significant amount of the day – medium offices operate in an unoccupied mode for more than 12-hours a day; and warehouses are a combination of small office space and a large bulk storage space, the latter which is likely to be conditioned to sub-optimal setpoints or left unconditioned entirely.

Table 5, Table 6, and Table 7, summarize the aggregate average energy savings by building type, and climate zone for each of the three interventions, compared to the baseline scenario. As stated above, absolute energy savings varies significantly according to building type and climate zone, with the greatest energy savings occurring for buildings with larger roof areas and space heating and space cooling requirements, while relative energy savings were highly correlated with the building's roof-to-floor area ratio. Individual intervention-level energy savings can be found in *Appendix A – Energy Impacts*.

Table 5 – Average Energy Savings by Building Type and Climate Zone, Intervention I1

Energy Savings		Building Type				Climate Zone						
		PS	MO	HO	WH	3A	3B	4A	4B	4C	5A	5B
First Year (Physical Units)	Electric (kWh)	34104	10110	13366	6370	19572	20206	20036	14684	5703	11484	12595
	Natural Gas (Therms)	3695	36	2794	754	1367	917	2433	1528	1660	2549	2124
	Total (MMBtu)	486	38	325	97	204	161	312	203	185	294	255
First Year (MMBtu)	Electric (MMBtu)	116	34	46	22	67	69	68	50	19	39	43
	Natural Gas (MMBtu)	370	4	279	75	137	92	243	153	166	255	212
	Total (MMBtu)	486	38	325	97	204	161	312	203	185	294	255
Annual	EUI (kBtu/SF/year)	6.57	0.71	1.35	1.87	2.26	1.64	3.47	2.14	2.06	3.55	2.77
	Energy Savings	7.5%	1.4%	1.0%	7.5%	3.6%	3.2%	5.1%	4.4%	3.6%	5.3%	5.2%

Table 6 – Average Energy Savings by Building Type and Climate Zone, Intervention I2

Energy Savings		Building Type				Climate Zone						
		PS	MO	HO	WH	3A	3B	4A	4B	4C	5A	5B
First Year (Physical Units)	Electric (kWh)	19395	2027	13287	3200	11873	11853	10367	9280	4785	6757	8140
	Natural Gas (Therms)	352	-30	237	-97	26	142	175	44	124	204	124
	Total (MMBtu)	101	4	69	1	43	55	53	36	29	43	40
First Year (MMBtu)	Electric (MMBtu)	66	7	45	11	41	40	35	32	16	23	28
	Natural Gas (MMBtu)	35	-3	24	-10	3	14	17	4	12	20	12
	Total (MMBtu)	101	4	69	1	43	55	53	36	29	43	40
Annual	EUI (kBtu/SF/year)	1.37	0.07	0.29	0.02	0.45	0.57	0.51	0.34	0.30	0.47	0.37
	Energy Savings	1.6%	0.1%	0.2%	0.1%	0.6%	1.0%	0.5%	0.5%	0.3%	0.4%	0.4%

Table 7 – Average Energy Savings by Building Type and Climate Zone, Intervention I3

Energy Savings		Building Type				Climate Zone						
		PS	MO	HO	WH	3A	3B	4A	4B	4C	5A	5B
First Year (Physical Units)	Electric (kWh)	43330	11136	19233	7745	25888	26308	24546	18132	7552	14303	16088
	Natural Gas (Therms)	4042	20	2861	702	1475	976	2553	1538	1730	2655	2202
	Total (MMBtu)	552	40	352	97	236	187	339	216	199	314	275
First Year (MMBtu)	Electric (MMBtu)	148	38	66	26	88	90	84	62	26	49	55
	Natural Gas (MMBtu)	404	2	286	70	147	98	255	154	173	265	220
	Total (MMBtu)	552	40	352	97	236	187	339	216	199	314	275
Annual	EUI (kBtu/SF/year)	7.46	0.75	1.46	1.86	2.60	1.92	3.75	2.32	2.22	3.80	2.97
	Energy Savings	8.6%	1.5%	1.1%	7.5%	4.0%	3.7%	5.4%	4.7%	3.8%	5.5%	5.4%

Calculation of Economic Benefits

Installation of code-compliant levels of roof insulation (at the time of roof replacement) and cool roof intervention projects directly result in energy savings and downstream operational savings (e.g., energy cost savings), the latter which can be monetized over the life project to quantify the economic benefits of the proposed intervention, compared to the baseline scenario.

Energy Cost Savings

Energy cost savings accrue from the incremental reduction in space heating and space cooling requirements and corresponding reduction in natural gas and electric usage. Energy cost savings were calculated as the product of energy savings and energy price, by fuel type, inclusive of 1.8% and 2.9% annual energy price escalation (for electricity and natural gas, respectively) over a 25-year effective useful life, for each scenario.

Table 8, Table 9, and Table 10 depict the average first year and cumulative energy cost savings, and cumulative energy cost savings per square foot of conditioned building floor area, for each of three interventions, by building type and climate zone compared to the baseline scenario. Similar to energy savings, energy cost savings varies according to building type and climate zone, with the greatest cost savings occurring for buildings with larger roof areas and space heating and space cooling requirements.

Table 8 – Average Energy Cost Savings by Building Type and Climate Zone, Intervention I1

Energy Cost Savings	Building Type				Climate Zone						
	PS	MO	HO	WH	3A	3B	4A	4B	4C	5A	5B
First Year ($)	6739	1143	3727	1310	3260	2967	4171	2851	1967	3322	3102
Cumulative ($)	287327	45176	163429	56078	136462	122187	178692	121345	87378	146005	134797
Cumulative ($/sf)	$3.88	$0.84	$0.68	$1.08	$1.57	$1.35	$2.05	$1.40	$1.10	$1.92	$1.59

Table 9 – Average Energy Cost Savings by Building Type and Climate Zone, Intervention I2

Energy Cost Savings	Building Type				Climate Zone						
	PS	MO	HO	WH	3A	3B	4A	4B	4C	5A	5B
First Year ($)	2422	199	1656	274	1330	1421	1284	1058	627	909	997
Cumulative ($)	97365	7650	66557	10195	52452	56755	51540	41868	25414	36991	39965
Cumulative ($/sf)	$1.32	$0.14	$0.28	$0.20	$0.56	$0.62	$0.52	$0.44	$0.28	$0.42	$0.41

Table 10 – Average Energy Cost Savings by Building Type and Climate Zone, Intervention I3

Energy Cost Savings	Building Type				Climate Zone						
	PS	MO	HO	WH	3A	3B	4A	4B	4C	5A	5B
First Year ($)	8036	1244	4428	1420	4043	3688	4765	3239	2228	3718	3550
Cumulative ($)	340411	49034	191384	60076	167885	150897	202786	136654	98052	162218	152876
Cumulative ($/sf)	$4.60	$0.91	$0.79	$1.15	$1.91	$1.67	$2.30	$1.59	$1.22	$2.11	$1.78

Incremental Material and Labor Capital Costs

Incremental capital costs were developed using a combination of industry accepted resources and web research.

Insulation capital costs were developed using 2019 RS Means national average material and labor costs per square foot for Polyiso insulation. Incremental costs were used to isolate the incremental benefit of code-compliant insulation compared to the baseline scenario. 2019 RS Means was selected as the most recent year for which to base the representative analysis. It provides cost details for insulation thicknesses ranging from 0.75 to 4.4 inches but is exclusive of cost data for the baseline (R-12.5: 2.2 inches at R-5.7/inch) and code-compliant (R-25: 4.4 inches at R-5.7/inch; and R-30: 3.1 inches at R-5.7/inch) scenarios evaluated in this analysis. For the baseline and intervention scenarios, capital costs were developed as the sum of the material and labor costs, inclusive of overhead and profit. Material costs are generally linear with respect to installed insulation thickness and were therefore estimated as the product of the average material unit cost, with overhead and profit, and the installed insulation thickness. In contrast, labor costs, are generally not linear with installed insulation thickness and were therefore developed from a logarithmic expression of insulation R-value and costs per square foot.

Cool roof costs, on the other hand, were developed by averaging multiple sources of cost data obtained from literature research and product internet research. Generalized unit costs for warmer and cooler roof options obtained from EPA's Heat Island Compendium, Chapter 4: Cool Roofs[2], were converted to current dollars using the U.S. Bureau of Labor Statistics Consumer Price Index[3]. Product specific unit costs were obtained through internet research of products listed on the CRRC Roof Products Directory. Incremental costs of each were averaged to define a single unit cost for cool roof exclusive of labor costs (assumed to be same for black and cool roofs) and maintenance costs for cleaning, which were omitted to be consistent with the modeling 3-year aged solar reflectance and thermal emittance.

Table 11, Table 12, and Table 13 depict the average incremental cost for each of three interventions, by building type and climate zone. Incremental costs vary according to both building type and climate zone; the former because of roof area and the later because variations in insulation thickness required to meet the ASHRAE Standard 90.1-2019 requirements compared to the baseline condition.

Table 11 – Average Incremental Capital Cost by Building Type and Climate Zone, Intervention I1

Incremental Costs	Building Type				Climate Zone						
	PS	MO	HO	WH	3A	3B	4A	4B	4C	5A	5B
Incremental Costs	82589	19962	53902	58117	38911	38911	61008	61008	61008	61008	61008

[2] Heat Island Compendium | US EPA
[3] https://www.bls.gov/data/inflation_calculator.htm

Table 12 – Average Incremental Capital Cost by Building Type and Climate Zone, Intervention I2

Energy Cost Savings	Building Type				Climate Zone						
	PS	MO	HO	WH	3A	3B	4A	4B	4C	5A	5B
Incremental Costs	20275	4900	13233	14267	#REF!	13169	13169	13169	13169	13169	13169

Table 13 – Average Incremental Capital Cost by Building Type and Climate Zone, Intervention I3

Energy Cost Savings	Building Type				Climate Zone						
	PS	MO	HO	WH	3A	3B	4A	4B	4C	5A	5B
Incremental Costs	102864	24862	67134	72384	52079	52079	74177	74177	74177	74177	74177

Economic Benefits

Economic benefits associated with each intervention scenario were quantified using two life-cycle cost analysis methods: the net present value (NPV) and the benefit-to-cost ratio (BCR), and the simple payback period (SPP).

NPV and BCR use a life-cycle cost approach to account for the time value of money. This enables a comparison of the project's benefits and costs over its effective useful life and is the economic method referenced by DOE in their *Methodology for Evaluating Cost-Effectiveness of Commercial Energy Code Changes* document and is also a method used by utility program administrators and implementers in development of cost-effective demand-side management incentive programs.

- **Benefit-to-Cost Ratio** is calculated as the ratio of the present value of benefits to the present value of costs. The intervention is cost-effective when the BCR is greater than 1.0, indicating its life-cycle benefits exceed its cost.
- **Net Present Value** is calculated by subtracting the present value of the benefits from the present value of the costs. A positive NPV indicates the intervention is cost-effective, when evaluated over its effective useful life.

The NPV and BCR of each intervention scenario was calculated using inputs of energy cost savings, incremental capital costs, and the modeling assumptions listed in Table 14. Details and data sources for the assumptions in Table 14 can be found in *Appendix C – Modeling Data Sources*.

Table 14 – Lifecycle Cost Economic Modeling Assumptions

Input Variable		Value	Source
Discount Rate		3.00%	DOE, FEMP
Modeling Timeline (years)		30	DOE, FEMP
Effective Useful Life (EUL)	Black Roof	25	Various
	Cool Roof	20	Various
Electricity Commodity Cost ($/kWh)		$0.11	DOE/EIA
Electricity Annual Escalation Rate		1.80%	DOE/EIA
Natural Gas Commodity Cost ($/therm)		$0.77	DOE/EIA

Input Variable	Value	Source
Natural Gas Annual Escalation Rate	2.90%	DOE/EIA

Simple payback period, on the other hand, is the ratio of the investment capital cost to annual energy cost savings. The intervention in considered cost effective when the SPP is less than the intervention's EUL.

Table 15, Table 16, and Table 17 summarize the average economic benefits for each of the three interventions, by building type and climate zone, compared to the baseline scenario. Economic benefits vary according to building type and climate zone but are not as strongly tied to either model characteristic as energy savings and energy cost savings due to greater uniformity in incremental capital costs across building types and climate zones. *Appendix B – Energy and Economic Benefits*.

Intervention (I1): Black roof with code-compliant levels of insulation is cost effective for all building types except Warehouse and all climate zones except 4B and 4C, all having shorter SPP than intervention EUL, a BCR greater than one, and a positive NPV.

Intervention (I2): Cool roof with baseline levels of insulation is cost effective for all building types except Warehouse [CZ 4A, 4B, 4C, 5A, and 5B] and Medium Office [CZ 4C, 5A, and 5B].

Intervention (I3): Cool Roof with code-compliant levels of insulation has similar economics to Intervention (I1), which is cost effective for all building types except Warehouse and all climate zones except 4B and 4C.

Table 15 – Average Economics by Building Type and Climate Zone, Intervention I1

Economic Metric	Building Type				Climate Zone						
	PS	MO	HO	WH	3A	3B	4A	4B	4C	5A	5B
SPP (years)	13	18	17	48	19	16	22	25	47	24	22
BCR	1.95	1.26	1.72	0.54	1.74	1.64	1.47	1.05	0.75	1.25	1.20
NPV ($)	72998	5046	33902	-27784	35370	27908	35619	4732	-14229	17382	11593

Table 16 – Average Economics by Building Type and Climate Zone, Intervention I2

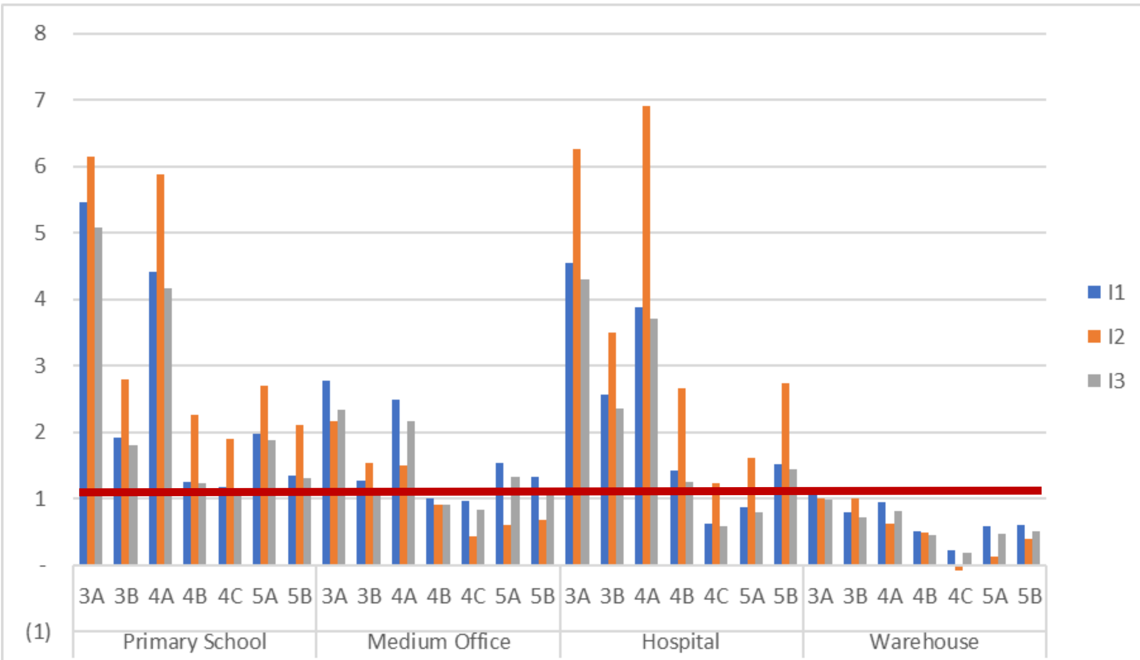
Economic Metric	Building Type				Climate Zone						
	PS	MO	HO	WH	3A	3B	4A	4B	4C	5A	5B
SPP (years)	9	28	9	11	19	12	27	21	-75	51	25
BCR	2.64	0.87	2.77	0.40	1.95	2.22	1.87	1.58	0.87	1.27	1.48
NPV ($)	42522	67	29697	-7615	15882	18151	15228	9997	796	7133	8862

Table 17 – Average Economics by Building Type and Climate Zone, Scenario I3

Economic Metric	Building Type				Climate Zone						
	PS	MO	HO	WH	3A	3B	4A	4B	4C	5A	5B
SPP (years)	14	20	18	57	21	18	25	28	55	27	25
BCR	1.84	1.10	1.61	0.46	1.59	1.51	1.36	0.96	0.68	1.12	1.10
NPV ($)	81804	2300	36100	-39782	39514	30595	35686	41	-21551	13095	8369

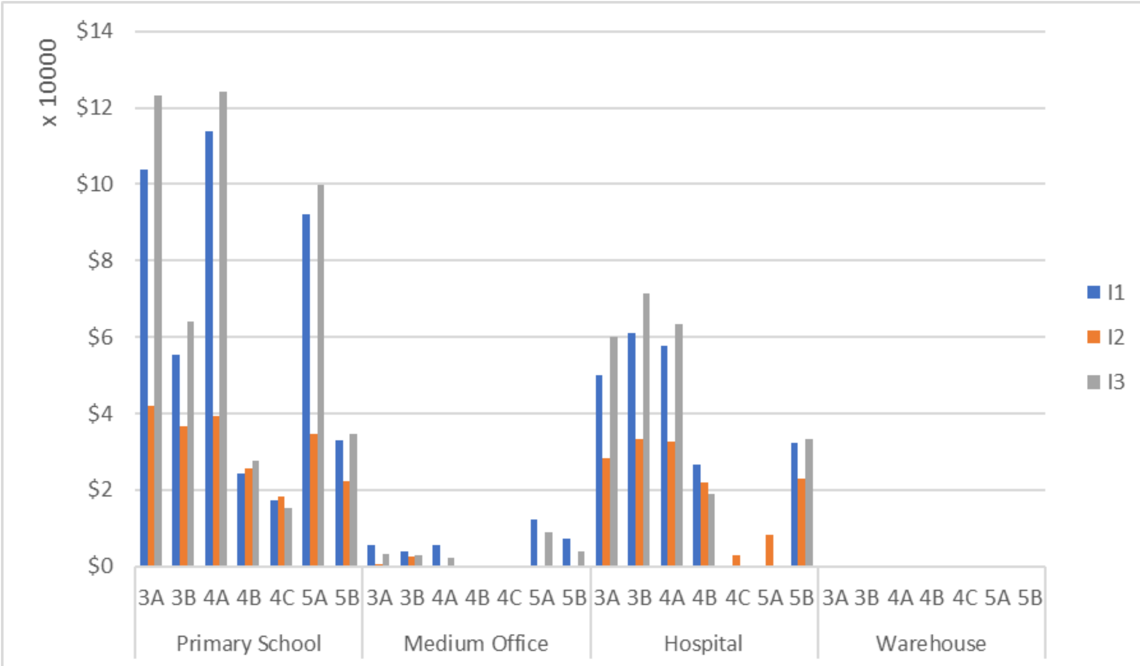
When economics are viewed individually by building type and climate zone, as in Figure 5, the generalized variation of economics summarized above is confirmed while the individual benefits of each intervention are revealed – more clearly showing that economics for code-compliant insulation tends to generally be more favorable in cooling dominated climate zones and for Primary School and Hospital building types; while for the same buildings, cool roofs are always more economically attractive.

Figure 5 – Benefit-to-Cost Ratio (BCR) by Building Type and Climate Zone



However, when economics are viewed as the net benefits (net present value of benefits) that accrue from the implementation of an intervention over its lifetime, as in Figure 6, it becomes clear that code-compliant insulation in most cases provides significantly greater net benefits than the cool roof intervention in all but a few rare cases where the insulation intervention is not cost effective. And despite a modest reduction in cool roof impacts when combined with code-compliant insulation, the combination of code-compliant insulation and a cool roof provide greater benefits than either alone, although similar to energy impacts the benefits are not additive. This finding suggests that when there is an equal opportunity to either increase the roof insulation to be code-compliant or pursue a cool roof project, one would be remiss to not elect the insulation intervention, after which the incremental economics of installing a cool roof tend to be lessened.

Figure 6 – Net Present Value (NPV) by Building Type and Climate Zone



Calculation of Carbon Emissions Savings

Reductions in building emissions are the direct result of energy savings that occur from a reduction in space heating and cooling requirements and the corresponding reduction in onsite combustion of natural gas and purchased electricity. Scope 1 direct and Scope 2 indirect emissions were calculated as the product of the site energy savings (derived as the difference in energy use between the baseline and code-compliant scenarios), by fuel type, and the corresponding EPA national-level emissions factor for that fuel type and constituent emission source. Average emissions savings data are presented in Table 18, Table 19, and Table 20, by building type and climate zone.

Table 18 – Average Avoided Emissions by Building Type and Climate Zone, Intervention I1

Avoided Emissions, Cumulative (lbs)	Building Type				Climate Zone						
	PS	MO	HO	WH	3A	3B	4A	4B	4C	5A	5B
CO2e/SF	41	5	8	12	15	11	22	14	13	22	17
CO2	1929514	262137	1149870	379068	887081	771006	1210183	812436	627322	1031253	934780
CH4	20442	220	15430	4170	7580	5097	13453	8456	9160	14074	11737
N2O	2047	23	1544	418	760	512	1347	847	917	1408	1175
CO2e	3050643	274468	1995818	607757	1303005	1050854	1947955	1276201	1129465	1802812	1578292

Table 19 – Average Avoided Emissions by Building Type and Climate Zone, Intervention I2

Avoided Emissions, Cumulative (lbs)	Building Type				Climate Zone						
	PS	MO	HO	WH	3A	3B	4A	4B	4C	5A	5B
CO2e/SF	9	1	2	3	4	4	4	3	3	4	4
CO2	585769	59255	400173	108124	320428	343895	333085	259330	169226	252781	262715
CH4	1984	170	1338	544	495	947	1437	555	955	1609	1151
N2O	200	17	135	55	51	96	145	56	96	162	116
CO2e	695030	68647	473859	138008	347897	396108	412130	289977	221701	341149	325986

Table 20 – Average Avoided Emissions by Building Type and Climate Zone, Intervention I3

Avoided Emissions, Cumulative (lbs)	Building Type				Climate Zone						
	PS	MO	HO	WH	3A	3B	4A	4B	4C	5A	5B
CO2e/SF	47	5	9	12	17	13	24	15	14	24	19
CO2	2260593	283277	1315473	398100	1075645	940763	1357655	901080	693945	1132361	1044499
CH4	22374	139	15812	3887	8185	5447	14127	8516	9552	14663	12174
N2O	2241	15	1583	389	821	547	1415	853	956	1468	1219
CO2e	3487857	291218	2182516	611296	1524904	1239970	2132474	1368271	1217628	1936297	1712073

Conclusion

The energy, economic, and emissions analysis produced first year and cumulative estimates of whole-building energy savings, energy savings by electric and natural gas fuel types, and the downstream benefits of energy savings including energy costs savings and reduction in carbon emissions. Incremental energy savings from both code-compliant roof replacements and cool roof projects accrue when they produce a reduction in space heating and/or space cooling loads that reduces respective natural gas and electricity energy use, costs, and emissions.

Resulting impacts and benefits of the analysis include the following:

Black roof w/ code-compliant insulation impacts and benefits

- **Energy savings impacts** are the greatest for buildings with larger conditioned floor areas and space heating and cooling requirements and are largely, but not entirely, driven by a reduction in natural gas use for space heating. Relative energy savings are highly correlated with the building's roof-to-floor area ratio.
- **Economic benefits** of roof replacements tend to be cost-effective for all but the Warehouse building type and climate zones 4B and 4C.

Cool roof w/ baseline levels of insulation impacts and benefits

- **Energy savings impacts** results in less than 2% savings across the building types modeled. The cool roof implementation affects the building in ways including a reduction of external radiation heat gain, with effects particularly noticed for buildings with large area footprints and flat roofs. The impacts of cool roofs alone, when positive, are small.
- **Economic benefits** of cool roof projects tend to be cost effective for all building types except Warehouse and all climate zones except 4C although their lifetime net benefits are small compared to increased insulation.

Cool Roof w/code-compliant insulation impacts and benefits

- **Energy savings impacts** are the greatest for buildings with larger conditioned floor areas and space heating and cooling requirements and are largely, but not entirely, driven by a reduction in natural gas use for space heating. Relative energy savings are highly correlated with the building's roof-to-floor area ratio. The impacts of cool roofs when combined with insulation tend to be moderated.
- **Economic benefits** of roof replacements tend to be cost-effective for all but the Warehouse [CZ 4, 5] building type and Medium Office [CZ 4B, 4C].

Code-compliant insulation in most cases provides significantly greater net benefits than the cool roof intervention in all but a few rare cases where the insulation intervention is not cost effective. And despite a modest reduction in cool roof impacts when combined with code-compliant insulation, the combination of code-compliant insulation and a cool roof provide greater benefits than either alone, although similar to energy impacts the benefits are not additive. This finding suggests that when there is an equal opportunity to either increase the roof insulation to be code-compliant or pursue a cool roof project, one would be remiss to not elect the insulation intervention, after which the incremental economics of installing a cool roof tend to be lessened.

Appendix A – Energy Impacts

Building Type	Climate Zone (CZ)	City Location	Scenario	Absolute Energy Savings			Relative Energy Savings		
				Annual Energy Savings (EUI)	Annual Electric Savings (kWh)	Annual Natural Gas Savings (Therms)	Annual Electric Energy Savings (%)	Annual Natural Gas Energy Savings (%)	Annual Total Energy Savings (%)
Primary School	3A	Atlanta	I1	5.68	43364	2721	3.44%	14.71%	6.83%
Primary School	3A	Atlanta	I2	1.53	25495	262	2.02%	1.42%	1.84%
Primary School	3A	Atlanta	I3	6.72	57144	3019	4.54%	16.32%	8.08%
Primary School	3A	Oklahoma City	I1	6.45	42869	3309	3.37%	13.66%	7.05%
Primary School	3A	Oklahoma City	I2	1.15	23827	35	1.87%	0.14%	1.25%
Primary School	3A	Oklahoma City	I3	7.63	56279	3723	4.42%	15.37%	8.34%
Primary School	4A	Philadelphia	I1	9.63	39911	5759	3.41%	18.01%	9.90%
Primary School	4A	Philadelphia	I2	1.71	20155	576	1.72%	1.80%	1.76%
Primary School	4A	Philadelphia	I3	10.67	48820	6226	4.17%	19.47%	10.98%
Primary School	4A	Baltimore	I1	9.11	40767	5349	3.44%	17.96%	9.60%
Primary School	4A	Baltimore	I2	1.61	20715	482	1.75%	1.62%	1.69%
Primary School	4A	Baltimore	I3	10.12	49989	5783	4.22%	19.42%	10.67%
Primary School	4C	Seattle	I1	5.35	18678	3322	1.87%	14.25%	6.89%
Primary School	4C	Seattle	I2	1.14	12547	416	1.25%	1.79%	1.47%
Primary School	4C	Seattle	I3	6.05	23346	3675	2.33%	15.76%	7.79%
Primary School	5A	Chicago	I1	8.86	32130	5455	2.86%	15.74%	8.98%
Primary School	5A	Chicago	I2	1.77	16719	740	1.49%	2.14%	1.80%
Primary School	5A	Chicago	I3	9.90	39450	5979	3.52%	17.25%	10.04%
Primary School	3B	Las Vegas	I1	3.66	35626	1493	2.87%	12.50%	4.99%
Primary School	3B	Las Vegas	I2	1.37	21262	290	1.72%	2.42%	1.87%
Primary School	3B	Las Vegas	I3	4.34	46599	1619	3.76%	13.55%	5.92%
Primary School	4B	Albuquerque	I1	4.53	29922	2331	2.76%	13.56%	6.19%
Primary School	4B	Albuquerque	I2	0.94	18656	55	1.72%	0.32%	1.28%
Primary School	4B	Albuquerque	I3	5.18	38015	2534	3.51%	14.75%	7.08%
Primary School	5B	Denver	I1	5.85	23672	3517	2.25%	15.31%	7.35%
Primary School	5B	Denver	I2	1.12	15181	312	1.45%	1.36%	1.41%
Primary School	5B	Denver	I3	6.56	30329	3820	2.89%	16.63%	8.26%
Medium Office	3A	Atlanta	I1	0.52	7184	34	1.01%	1.44%	1.05%
Medium Office	3A	Atlanta	I2	0.10	2496	-29	0.35%	-1.22%	0.21%
Medium Office	3A	Atlanta	I3	0.57	8476	19	1.19%	0.78%	1.16%
Medium Office	3A	Oklahoma City	I1	0.64	8993	37	1.21%	1.13%	1.20%
Medium Office	3A	Oklahoma City	I2	0.09	2473	-37	0.33%	-1.10%	0.17%

Building Type	Climate Zone (CZ)	City Location	Scenario	Absolute Energy Savings			Relative Energy Savings		
				Annual Energy Savings (EUI)	Annual Electric Savings (kWh)	Annual Natural Gas Savings (Therms)	Annual Electric Energy Savings (%)	Annual Natural Gas Energy Savings (%)	Annual Total Energy Savings (%)
Medium Office	3A	Oklahoma City	I3	0.68	10155	19	1.37%	0.57%	1.28%
Medium Office	4A	Philadelphia	I1	0.80	11886	23	1.67%	0.61%	1.53%
Medium Office	4A	Philadelphia	I2	0.05	1769	-33	0.25%	-0.89%	0.10%
Medium Office	4A	Philadelphia	I3	0.82	12764	5	1.79%	0.14%	1.57%
Medium Office	4A	Baltimore	I1	0.75	11248	21	1.59%	0.62%	1.47%
Medium Office	4A	Baltimore	I2	0.06	1799	-29	0.25%	-0.87%	0.12%
Medium Office	4A	Baltimore	I3	0.78	12115	5	1.71%	0.16%	1.52%
Medium Office	4C	Seattle	I1	0.64	8832	44	1.36%	2.01%	1.42%
Medium Office	4C	Seattle	I2	0.02	1113	-26	0.17%	-1.19%	0.05%
Medium Office	4C	Seattle	I3	0.66	9457	31	1.46%	1.39%	1.45%
Medium Office	5A	Chicago	I1	1.01	13976	63	1.89%	1.34%	1.80%
Medium Office	5A	Chicago	I2	0.02	1629	-45	0.22%	-0.95%	0.04%
Medium Office	5A	Chicago	I3	1.02	14931	39	2.02%	0.83%	1.83%
Medium Office	3B	Las Vegas	I1	0.49	7631	3	1.07%	0.21%	1.02%
Medium Office	3B	Las Vegas	I2	0.18	3222	-11	0.45%	-0.82%	0.38%
Medium Office	3B	Las Vegas	I3	0.59	9312	-2	1.31%	-0.18%	1.23%
Medium Office	4B	Albuquerque	I1	0.65	9262	32	1.39%	1.69%	1.41%
Medium Office	4B	Albuquerque	I2	0.08	2047	-25	0.31%	-1.28%	0.18%
Medium Office	4B	Albuquerque	I3	0.69	10264	20	1.54%	1.05%	1.50%
Medium Office	5B	Denver	I1	0.88	11980	64	1.73%	2.60%	1.81%
Medium Office	5B	Denver	I2	0.04	1694	-35	0.24%	-1.43%	0.09%
Medium Office	5B	Denver	I3	0.90	12751	46	1.84%	1.87%	1.85%
Warehouse	3A	Atlanta	I1	1.05	6192	334	2.47%	13.62%	4.96%
Warehouse	3A	Atlanta	I2	0.09	3553	-72	1.42%	-2.95%	0.45%
Warehouse	3A	Atlanta	I3	1.08	7972	292	3.18%	11.90%	5.13%
Warehouse	3A	Oklahoma City	I1	1.48	6741	542	2.65%	13.62%	6.10%
Warehouse	3A	Oklahoma City	I2	0.07	3863	-98	1.52%	-2.46%	0.27%
Warehouse	3A	Oklahoma City	I3	1.50	8644	485	3.40%	12.19%	6.16%
Warehouse	4A	Philadelphia	I1	2.09	6006	882	2.48%	16.08%	7.91%
Warehouse	4A	Philadelphia	I2	-0.06	2986	-131	1.23%	-2.40%	-0.21%
Warehouse	4A	Philadelphia	I3	2.03	7170	813	2.97%	14.82%	7.70%
Warehouse	4A	Baltimore	I1	1.98	6072	824	2.51%	16.75%	7.83%
Warehouse	4A	Baltimore	I2	-0.06	2980	-133	1.23%	-2.70%	-0.24%
Warehouse	4A	Baltimore	I3	1.95	7258	767	3.00%	15.59%	7.70%
Warehouse	4C	Seattle	I1	1.20	1605	571	0.71%	15.03%	5.43%
Warehouse	4C	Seattle	I2	-0.12	163	-69	0.07%	-1.81%	-0.55%

Building Type	Climate Zone (CZ)	City Location	Scenario	Absolute Energy Savings			Relative Energy Savings		
				Annual Energy Savings (EUI)	Annual Electric Savings (kWh)	Annual Natural Gas Savings (Therms)	Annual Electric Energy Savings (%)	Annual Natural Gas Energy Savings (%)	Annual Total Energy Savings (%)
Warehouse	4C	Seattle	I3	1.13	1669	531	0.74%	13.98%	5.10%
Warehouse	5A	Chicago	I1	3.06	4375	1443	1.87%	16.64%	9.56%
Warehouse	5A	Chicago	I2	-0.12	1794	-126	0.77%	-1.45%	-0.39%
Warehouse	5A	Chicago	I3	2.96	4638	1385	1.98%	15.97%	9.26%
Warehouse	3B	Las Vegas	I1	1.25	11905	244	4.11%	22.58%	5.92%
Warehouse	3B	Las Vegas	I2	0.34	6350	-38	2.19%	-3.50%	1.63%
Warehouse	3B	Las Vegas	I3	1.41	15075	217	5.20%	20.13%	6.67%
Warehouse	4B	Albuquerque	I1	1.98	7648	772	3.07%	26.86%	9.08%
Warehouse	4B	Albuquerque	I2	0.08	3662	-82	1.47%	-2.85%	0.38%
Warehouse	4B	Albuquerque	I3	1.99	9121	723	3.66%	25.16%	9.09%
Warehouse	5B	Denver	I1	2.70	6786	1175	2.80%	22.88%	10.50%
Warehouse	5B	Denver	I2	-0.02	3448	-128	1.42%	-2.49%	-0.08%
Warehouse	5B	Denver	I3	2.66	8159	1105	3.37%	21.53%	10.33%
Hospital	3A	Atlanta	I1	1.07	20842	1877	0.31%	2.14%	0.82%
Hospital	3A	Atlanta	I2	0.30	16814	140	0.25%	0.16%	0.22%
Hospital	3A	Atlanta	I3	1.25	29567	2010	0.44%	2.29%	0.95%
Hospital	3A	Oklahoma City	I1	1.15	20395	2084	0.30%	2.19%	0.86%
Hospital	3A	Oklahoma City	I2	0.24	16465	7	0.24%	0.01%	0.18%
Hospital	3A	Oklahoma City	I3	1.33	28865	2231	0.43%	2.34%	0.99%
Hospital	4A	Philadelphia	I1	1.70	21959	3359	0.34%	3.49%	1.30%
Hospital	4A	Philadelphia	I2	0.37	16185	334	0.25%	0.35%	0.28%
Hospital	4A	Philadelphia	I3	1.85	28850	3470	0.45%	3.60%	1.41%
Hospital	4A	Baltimore	I1	1.66	22440	3246	0.35%	3.45%	1.28%
Hospital	4A	Baltimore	I2	0.37	16346	333	0.25%	0.35%	0.28%
Hospital	4A	Baltimore	I3	1.81	29400	3357	0.46%	3.57%	1.39%
Hospital	4C	Seattle	I1	1.03	-6304	2702	-0.11%	2.49%	0.80%
Hospital	4C	Seattle	I2	0.15	5317	174	0.09%	0.16%	0.11%
Hospital	4C	Seattle	I3	1.05	-4264	2684	-0.07%	2.47%	0.81%
Hospital	5A	Chicago	I1	1.28	-4545	3234	-0.07%	2.69%	0.91%
Hospital	5A	Chicago	I2	0.20	6886	246	0.11%	0.20%	0.14%
Hospital	5A	Chicago	I3	1.31	-1809	3216	-0.03%	2.67%	0.93%
Hospital	3B	Las Vegas	I1	1.16	25663	1927	0.37%	2.56%	0.90%
Hospital	3B	Las Vegas	I2	0.37	16579	329	0.24%	0.44%	0.29%
Hospital	3B	Las Vegas	I3	1.34	34247	2072	0.50%	2.75%	1.04%
Hospital	4B	Albuquerque	I1	1.40	11906	2978	0.18%	3.38%	1.09%
Hospital	4B	Albuquerque	I2	0.27	12756	226	0.20%	0.26%	0.21%

Building Type	Climate Zone (CZ)	City Location	Scenario	Absolute Energy Savings			Relative Energy Savings		
				Annual Energy Savings (EUI)	Annual Electric Savings (kWh)	Annual Natural Gas Savings (Therms)	Annual Electric Energy Savings (%)	Annual Natural Gas Energy Savings (%)	Annual Total Energy Savings (%)
Hospital	4B	Albuquerque	I3	1.40	15129	2874	0.23%	3.26%	1.09%
Hospital	5B	Denver	I1	1.66	7943	3741	0.12%	3.90%	1.27%
Hospital	5B	Denver	I2	0.32	12239	347	0.19%	0.36%	0.24%
Hospital	5B	Denver	I3	1.78	13112	3838	0.20%	4.00%	1.35%

Appendix B – Energy and Economic Benefits

Building Type	Climate Zone (CZ)	City Location	Scenario	Energy Cost Savings		Economic Benefits		
				Annual Energy Cost Savings ($/SF)	Cumulative Energy Cost Savings ($/SF)	Simple Payback (SPP)	Benefit to Cost Ratio (BCR)	Net Present Value (NPV) [$/SF]
Primary School	3A	Atlanta	I1	$0.09	$3.09	9	2.64	$1.33
Primary School	3A	Atlanta	I2	$0.04	$1.29	7	3.28	$0.62
Primary School	3A	Atlanta	I3	$0.12	$3.84	9	2.46	$1.59
Primary School	3A	Oklahoma City	I1	$0.10	$3.29	8	2.82	$1.47
Primary School	3A	Oklahoma City	I2	$0.04	$1.12	8	2.86	$0.51
Primary School	3A	Oklahoma City	I3	$0.12	$4.08	9	2.61	$1.75
Primary School	4A	Philadelphia	I1	$0.12	$4.12	10	2.24	$1.58
Primary School	4A	Philadelphia	I2	$0.04	$1.16	8	2.96	$0.54
Primary School	4A	Philadelphia	I3	$0.14	$4.71	11	2.11	$1.72
Primary School	4A	Baltimore	I1	$0.12	$4.00	11	2.18	$1.50
Primary School	4A	Baltimore	I2	$0.04	$1.15	8	2.93	$0.53
Primary School	4A	Baltimore	I3	$0.14	$4.60	11	2.06	$1.64
Primary School	4C	Seattle	I1	$0.06	$2.17	20	1.18	$0.23
Primary School	4C	Seattle	I2	$0.02	$0.75	12	1.90	$0.25
Primary School	4C	Seattle	I3	$0.07	$2.53	21	1.13	$0.20
Primary School	5A	Chicago	I1	$0.11	$3.64	12	1.98	$1.24
Primary School	5A	Chicago	I2	$0.03	$1.07	8	2.71	$0.47
Primary School	5A	Chicago	I3	$0.12	$4.18	12	1.87	$1.35
Primary School	3B	Las Vegas	I1	$0.07	$2.24	12	1.93	$0.75
Primary School	3B	Las Vegas	I2	$0.03	$1.10	8	2.80	$0.49
Primary School	3B	Las Vegas	I3	$0.09	$2.80	12	1.80	$0.87
Primary School	4B	Albuquerque	I1	$0.07	$2.31	18	1.26	$0.33
Primary School	4B	Albuquerque	I2	$0.03	$0.89	10	2.27	$0.35
Primary School	4B	Albuquerque	I3	$0.08	$2.76	18	1.24	$0.37
Primary School	5B	Denver	I1	$0.07	$2.48	17	1.35	$0.45
Primary School	5B	Denver	I2	$0.03	$0.83	11	2.11	$0.30
Primary School	5B	Denver	I3	$0.09	$2.91	18	1.30	$0.47
Medium Office	3A	Atlanta	I1	$0.02	$0.48	18	1.24	$0.19
Medium Office	3A	Atlanta	I2	$0.00	$0.14	19	1.11	$0.03
Medium Office	3A	Atlanta	I3	$0.02	$0.55	20	1.07	$0.08
Medium Office	3A	Oklahoma City	I1	$0.02	$0.60	14	1.54	$0.44
Medium Office	3A	Oklahoma City	I2	$0.00	$0.14	20	1.06	$0.02
Medium Office	3A	Oklahoma City	I3	$0.02	$0.66	17	1.28	$0.30

Building Type	Climate Zone (CZ)	City Location	Scenario	Energy Cost Savings		Economic Benefits		
				Annual Energy Cost Savings ($/SF)	Cumulative Energy Cost Savings ($/SF)	Simple Payback (SPP)	Benefit to Cost Ratio (BCR)	Net Present Value (NPV) [$/SF]
Medium Office	4A	Philadelphia	I1	$0.02	$0.78	17	1.28	$0.35
Medium Office	4A	Philadelphia	I2	$0.00	$0.10	29	0.73	-$0.07
Medium Office	4A	Philadelphia	I3	$0.03	$0.82	20	1.11	$0.18
Medium Office	4A	Baltimore	I1	$0.02	$0.73	18	1.21	$0.27
Medium Office	4A	Baltimore	I2	$0.00	$0.10	28	0.76	-$0.07
Medium Office	4A	Baltimore	I3	$0.02	$0.78	21	1.06	$0.09
Medium Office	4C	Seattle	I1	$0.02	$0.59	22	0.97	-$0.03
Medium Office	4C	Seattle	I2	$0.00	$0.06	48	0.44	-$0.15
Medium Office	4C	Seattle	I3	$0.02	$0.62	26	0.85	-$0.24
Medium Office	5A	Chicago	I1	$0.03	$0.93	14	1.53	$0.68
Medium Office	5A	Chicago	I2	$0.00	$0.08	34	0.62	-$0.11
Medium Office	5A	Chicago	I3	$0.03	$0.98	16	1.33	$0.51
Medium Office	3B	Las Vegas	I1	$0.02	$0.49	17	1.27	$0.22
Medium Office	3B	Las Vegas	I2	$0.01	$0.20	14	1.53	$0.15
Medium Office	3B	Las Vegas	I3	$0.02	$0.60	19	1.15	$0.16
Medium Office	4B	Albuquerque	I1	$0.02	$0.61	22	1.01	$0.01
Medium Office	4B	Albuquerque	I2	$0.00	$0.12	24	0.90	-$0.03
Medium Office	4B	Albuquerque	I3	$0.02	$0.67	24	0.91	-$0.14
Medium Office	5B	Denver	I1	$0.03	$0.80	17	1.32	$0.41
Medium Office	5B	Denver	I2	$0.00	$0.09	31	0.69	-$0.09
Medium Office	5B	Denver	I3	$0.03	$0.84	19	1.14	$0.22
Warehouse	3A	Atlanta	I1	$0.02	$0.60	44	0.51	-$0.40
Warehouse	3A	Atlanta	I2	$0.01	$0.19	43	0.50	-$0.14
Warehouse	3A	Atlanta	I3	$0.02	$0.69	51	0.44	-$0.60
Warehouse	3A	Oklahoma City	I1	$0.02	$0.75	36	0.64	-$0.29
Warehouse	3A	Oklahoma City	I2	$0.01	$0.20	41	0.51	-$0.13
Warehouse	3A	Oklahoma City	I3	$0.03	$0.84	42	0.54	-$0.50
Warehouse	4A	Philadelphia	I1	$0.03	$0.89	48	0.48	-$0.66
Warehouse	4A	Philadelphia	I2	$0.00	$0.12	64	0.32	-$0.19
Warehouse	4A	Philadelphia	I3	$0.03	$0.93	56	0.42	-$0.90
Warehouse	4A	Baltimore	I1	$0.03	$0.86	50	0.47	-$0.67
Warehouse	4A	Baltimore	I2	$0.00	$0.12	64	0.32	-$0.19
Warehouse	4A	Baltimore	I3	$0.03	$0.91	57	0.41	-$0.92
Warehouse	4C	Seattle	I1	$0.01	$0.42	104	0.23	-$0.98
Warehouse	4C	Seattle	I2	$0.00	-$0.03	-379	-0.07	-$0.29
Warehouse	4C	Seattle	I3	$0.01	$0.41	131	0.18	-$1.26

Building Type	Climate Zone (CZ)	City Location	Scenario	Energy Cost Savings		Economic Benefits		
				Annual Energy Cost Savings ($/SF)	Cumulative Energy Cost Savings ($/SF)	Simple Payback (SPP)	Benefit to Cost Ratio (BCR)	Net Present Value (NPV) [$/SF]
Warehouse	5A	Chicago	I1	$0.03	$1.09	40	0.59	-$0.52
Warehouse	5A	Chicago	I2	$0.00	$0.05	148	0.13	-$0.24
Warehouse	5A	Chicago	I3	$0.03	$1.08	49	0.48	-$0.80
Warehouse	3B	Las Vegas	I1	$0.03	$0.92	28	0.79	-$0.17
Warehouse	3B	Las Vegas	I2	$0.01	$0.40	21	1.02	$0.00
Warehouse	3B	Las Vegas	I3	$0.04	$1.12	31	0.72	-$0.30
Warehouse	4B	Albuquerque	I1	$0.03	$0.94	45	0.51	-$0.62
Warehouse	4B	Albuquerque	I2	$0.01	$0.20	42	0.50	-$0.14
Warehouse	4B	Albuquerque	I3	$0.03	$1.01	51	0.45	-$0.85
Warehouse	5B	Denver	I1	$0.03	$1.10	39	0.60	-$0.51
Warehouse	5B	Denver	I2	$0.01	$0.16	51	0.40	-$0.16
Warehouse	5B	Denver	I3	$0.03	$1.16	45	0.52	-$0.74
Hospital	3A	Atlanta	I1	$0.02	$0.52	10	2.24	$1.00
Hospital	3A	Atlanta	I2	$0.01	$0.26	7	3.26	$0.62
Hospital	3A	Atlanta	I3	$0.02	$0.66	11	2.12	$1.22
Hospital	3A	Oklahoma City	I1	$0.02	$0.54	10	2.32	$1.07
Hospital	3A	Oklahoma City	I2	$0.01	$0.24	7	3.00	$0.55
Hospital	3A	Oklahoma City	I3	$0.02	$0.68	11	2.17	$1.27
Hospital	4A	Philadelphia	I1	$0.02	$0.72	12	1.95	$1.21
Hospital	4A	Philadelphia	I2	$0.01	$0.27	6	3.44	$0.67
Hospital	4A	Philadelphia	I3	$0.02	$0.83	12	1.86	$1.32
Hospital	4A	Baltimore	I1	$0.02	$0.71	12	1.93	$1.19
Hospital	4A	Baltimore	I2	$0.01	$0.27	6	3.47	$0.68
Hospital	4A	Baltimore	I3	$0.02	$0.82	13	1.85	$1.31
Hospital	4C	Seattle	I1	$0.01	$0.23	41	0.63	-$0.47
Hospital	4C	Seattle	I2	$0.00	$0.10	18	1.23	$0.06
Hospital	4C	Seattle	I3	$0.01	$0.26	44	0.58	-$0.65
Hospital	5A	Chicago	I1	$0.01	$0.32	29	0.87	-$0.16
Hospital	5A	Chicago	I2	$0.00	$0.13	14	1.62	$0.17
Hospital	5A	Chicago	I3	$0.01	$0.36	31	0.80	-$0.31
Hospital	3B	Las Vegas	I1	$0.02	$0.60	9	2.56	$1.26
Hospital	3B	Las Vegas	I2	$0.01	$0.28	6	3.51	$0.69
Hospital	3B	Las Vegas	I3	$0.02	$0.74	10	2.36	$1.48
Hospital	4B	Albuquerque	I1	$0.02	$0.53	17	1.43	$0.55
Hospital	4B	Albuquerque	I2	$0.01	$0.21	8	2.66	$0.45
Hospital	4B	Albuquerque	I3	$0.02	$0.56	19	1.26	$0.40

Building Type	Climate Zone (CZ)	City Location	Scenario	Energy Cost Savings		Economic Benefits		
				Annual Energy Cost Savings ($/SF)	Cumulative Energy Cost Savings ($/SF)	Simple Payback (SPP)	Benefit to Cost Ratio (BCR)	Net Present Value (NPV) [$/SF]
Hospital	5B	Denver	I1	$0.02	$0.56	16	1.53	$0.67
Hospital	5B	Denver	I2	$0.01	$0.22	8	2.74	$0.48
Hospital	5B	Denver	I3	$0.02	$0.65	16	1.45	$0.69

Appendix C – Impacts and Benefits, by Building Type

Table 21 – Building Energy, Economics, and Emissions Summary – Hospital

		Energy Savings					Energy Cost Savings			Economics			Emissions	
Climate Zone	Scenario	Annual Electric Savings (kWh)	Annual Natural Gas Savings (Therms)	Annual Energy Savings (MMBtu)	Annual Energy Savings (%)	Annual Savings (EUI)	Annual Energy Cost Savings ($)	Cumulative Energy Cost Savings ($)	Cumulative Energy Cost Savings per SF ($/SF)	Simple Payback Period (Years)	BCR (Savings to Investment Ratio)	Net Benefits ($/SF)	Cumulative CO2e (lb)	Cumulative CO2e per SF (lb/SF)
3A	I1	20618	1981	268	0.8%	1.11	3870	128449	0.53	10.10	2.28	2.07	3387499	14
3A	I2	16639	74	64	0.2%	0.27	1894	59416	0.25	7.00	3.13	1.17	921118	4
3A	I3	29216	2120	312	1.0%	1.29	4931	162097	0.67	10.61	2.15	2.49	3984210	17
3B	I1	25663	1927	280	0.9%	1.16	4383	144254	0.60	8.92	2.56	1.26	1788151	7
3B	I2	16579	329	89	0.3%	0.37	2093	66620	0.28	6.32	3.51	0.69	610854	3
3B	I3	34247	2072	324	1.0%	1.34	5446	178016	0.74	9.61	2.36	1.48	2089443	9
4A	I1	22199	3302	406	1.3%	1.68	5111	172251	0.71	12.00	1.94	2.40	5038256	21
4A	I2	16265	334	89	0.3%	0.37	2062	65673	0.27	6.42	3.46	1.35	1211461	5
4A	I3	29125	3413	441	1.4%	1.83	5963	199311	0.83	12.50	1.85	2.63	5517102	23
4B	I1	11906	2978	338	1.1%	1.40	3714	127401	0.53	16.51	1.43	0.55	2068404	9
4B	I2	12756	226	66	0.2%	0.27	1588	50454	0.21	8.33	2.66	0.45	453524	2
4B	I3	15129	2874	339	1.1%	1.40	3985	135466	0.56	18.70	1.26	0.40	2087096	9
4C	I1	-6304	2702	249	0.8%	1.03	1484	56715	0.23	41.30	0.63	-0.47	1448428	6
4C	I2	5317	174	36	0.1%	0.15	726	23345	0.10	18.22	1.23	0.06	236461	1
4C	I3	-4264	2684	254	0.8%	1.05	1694	63205	0.26	43.99	0.58	-0.65	1488625	6
5A	I1	-4545	3234	308	0.9%	1.28	2107	78212	0.32	29.09	0.87	-0.16	1808810	7
5A	I2	6886	246	48	0.1%	0.20	958	30848	0.13	13.82	1.62	0.17	318828	1
5A	I3	-1809	3216	315	0.9%	1.31	2394	87096	0.36	31.13	0.80	-0.31	1866370	8
5B	I1	7943	3741	401	1.3%	1.66	3893	135905	0.56	15.75	1.53	0.67	2422810	10
5B	I2	12239	347	76	0.2%	0.32	1629	52183	0.22	8.13	2.74	0.48	512489	2
5B	I3	13112	3838	429	1.4%	1.78	4540	156505	0.65	16.42	1.45	0.69	2609798	11

Table 22 – Building Energy, Economics, and Emissions Summary – Medium Office

		Energy Savings					Energy Cost Savings			Economics			Emissions	
Climate Zone	Scenario	Annual Electric Savings (kWh)	Annual Natural Gas Savings (Therms)	Annual Energy Savings (MMBtu)	Annual Energy Savings (%)	Annual Savings (EUI)	Annual Energy Cost Savings ($)	Cumulative Energy Cost Savings ($)	Cumulative Energy Cost Savings per SF ($/SF)	Simple Payback Period (Years)	BCR (Savings to Investment Ratio)	Net Benefits ($/SF)	Cumulative CO2e (lb)	Cumulative CO2e per SF (lb/SF)
3A	I1	8088	36	31	1.1%	0.58	921	28884	0.54	15.92	1.39	0.63	447827	8
3A	I2	2485	-33	5	0.2%	0.10	247	7597	0.14	19.82	1.08	0.05	163619	3
3A	I3	9316	19	34	1.2%	0.63	1042	32614	0.61	18.74	1.17	0.38	489024	9
3B	I1	7631	3	26	1.0%	0.49	844	26349	0.49	17.17	1.27	0.22	192803	4
3B	I2	3222	-11	10	0.4%	0.18	346	10759	0.20	14.16	1.53	0.15	87482	2
3B	I3	9312	-2	32	1.2%	0.59	1024	31979	0.60	18.92	1.15	0.16	234659	4
4A	I1	11567	22	42	1.5%	0.78	1293	40448	0.75	17.58	1.24	0.62	605245	11
4A	I2	1784	-31	3	0.1%	0.06	172	5236	0.10	28.58	0.75	-0.14	126481	2
4A	I3	12439	5	43	1.5%	0.80	1375	42969	0.80	20.08	1.09	0.27	629230	12
4B	I1	9262	32	35	1.4%	0.65	1047	32823	0.61	21.68	1.01	0.01	251252	5
4B	I2	2047	-25	5	0.2%	0.08	206	6328	0.12	23.82	0.90	-0.03	65931	1
4B	I3	10264	20	37	1.5%	0.69	1148	35918	0.67	24.05	0.91	-0.14	269057	5
4C	I1	8832	44	35	1.4%	0.64	1009	31681	0.59	22.50	0.97	-0.03	247406	5
4C	I2	1113	-26	1	0.0%	0.02	102	3069	0.06	48.28	0.44	-0.15	43479	1
4C	I3	9457	31	35	1.5%	0.66	1067	33442	0.62	25.86	0.85	-0.24	255056	5
5A	I1	13976	63	54	1.8%	1.01	1591	49934	0.93	14.27	1.53	0.68	387412	7
5A	I2	1629	-45	1	0.0%	0.02	143	4306	0.08	34.17	0.62	-0.11	67452	1
5A	I3	14931	39	55	1.8%	1.02	1677	52525	0.98	16.46	1.33	0.51	397067	7
5B	I1	11980	64	47	1.8%	0.88	1373	43104	0.80	16.54	1.32	0.41	338271	6
5B	I2	1694	-35	2	0.1%	0.04	158	4807	0.09	30.96	0.69	-0.09	63378	1
5B	I3	12751	46	48	1.8%	0.90	1443	45235	0.84	19.13	1.14	0.22	346866	6

Table 23 – Building Energy, Economics, and Emissions Summary – Primary School

		Energy Savings					Energy Cost Savings			Economics			Emissions	
Climate Zone	Scenario	Annual Electric Savings (kWh)	Annual Natural Gas Savings (Therms)	Annual Energy Savings (MMBtu)	Annual Energy Savings (%)	Annual Savings (EUI)	Annual Energy Cost Savings ($)	Cumulative Energy Cost Savings ($)	Cumulative Energy Cost Savings per SF ($/SF)	Simple Payback Period (Years)	BCR (Savings to Investment Ratio)	Net Benefits ($/SF)	Cumulative CO2e (lb)	Cumulative CO2e per SF (lb/SF)
3A	I1	43116	3015	449	6.9%	6.07	7184	235908	3.19	8.35	2.73	2.81	5744142	78
3A	I2	24661	149	99	1.5%	1.34	2838	89196	1.21	7.17	3.07	1.13	1411716	19
3A	I3	56711	3371	531	8.2%	7.17	8970	293031	3.96	8.95	2.54	3.33	6848161	93
3B	I1	35626	1493	271	5.0%	3.66	5131	165943	2.24	11.68	1.93	0.75	1779455	24
3B	I2	21262	290	102	1.9%	1.37	2577	81590	1.10	7.87	2.80	0.49	704595	10
3B	I3	46599	1619	321	5.9%	4.34	6442	207369	2.80	12.45	1.80	0.87	2129113	29
4A	I1	40339	5554	693	9.8%	9.37	8926	300026	4.06	10.53	2.21	3.07	8623565	117
4A	I2	20435	529	123	1.7%	1.66	2679	85697	1.16	7.57	2.94	1.06	1652684	22
4A	I3	49405	6004	769	10.8%	10.40	10288	344294	4.66	11.10	2.09	3.36	9612807	130
4B	I1	29922	2331	335	6.2%	4.53	5178	170629	2.31	18.14	1.26	0.33	2134802	29
4B	I2	18656	55	69	1.3%	0.94	2101	65817	0.89	9.65	2.27	0.35	499998	7
4B	I3	38015	2534	383	7.1%	5.18	6235	204400	2.76	18.32	1.24	0.37	2458594	33
4C	I1	18678	3322	396	6.9%	5.35	4738	160688	2.17	19.83	1.18	0.23	2442398	33
4C	I2	12547	416	84	1.5%	1.14	1719	55275	0.75	11.79	1.90	0.25	561790	8
4C	I3	23346	3675	447	7.8%	6.05	5537	187009	2.53	20.62	1.13	0.20	2769320	37
5A	I1	32130	5455	655	9.0%	8.86	7941	268910	3.64	11.83	1.98	1.24	4047660	55
5A	I2	16719	740	131	1.8%	1.77	2440	79029	1.07	8.31	2.71	0.47	858700	12
5A	I3	39450	5979	733	10.0%	9.90	9171	309315	4.18	12.45	1.87	1.35	4542502	61
5B	I1	23672	3517	433	7.4%	5.85	5446	183557	2.48	17.25	1.35	0.45	2683764	36
5B	I2	15181	312	83	1.4%	1.12	1925	61315	0.83	10.53	2.11	0.30	565786	8
5B	I3	30329	3820	485	8.3%	6.56	6424	215244	2.91	17.78	1.30	0.47	3030217	41

Table 24 – Building Energy, Economics, and Emissions Summary – Warehouse

		Energy Savings					Energy Cost Savings			Economics			Emissions	
Climate Zone	Scenario	Annual Electric Savings (kWh)	Annual Natural Gas Savings (Therms)	Annual Energy Savings (MMBtu)	Annual Energy Savings (%)	Annual Savings (EUI)	Annual Energy Cost Savings ($)	Cumulative Energy Cost Savings ($)	Cumulative Energy Cost Savings per SF ($/SF)	Simple Payback Period (Years)	BCR (Savings to Investment Ratio)	Net Benefits ($/SF)	Cumulative CO2e (lb)	Cumulative CO2e per SF (lb/SF)
3A	I1	6467	438	66	5.5%	1.27	1066	34969	0.67	40.00	0.58	-0.69	844570	16
3A	I2	3708	-85	4	0.4%	0.08	340	10298	0.20	41.95	0.51	-0.27	286720	6
3A	I3	8308	388	67	5.6%	1.29	1229	39868	0.77	46.31	0.49	-1.10	877842	17
3B	I1	11905	244	65	5.9%	1.25	1509	48051	0.92	27.94	0.79	-0.17	443005	9
3B	I2	6350	-38	18	1.6%	0.34	669	20760	0.40	21.31	1.02	0.00	181500	3
3B	I3	15075	217	73	6.7%	1.41	1837	58195	1.12	30.71	0.72	-0.30	506666	10
4A	I1	6039	853	106	7.9%	2.03	1354	45540	0.88	48.84	0.48	-1.33	1316575	25
4A	I2	2983	-132	-3	-0.2%	-0.06	222	6433	0.12	64.19	0.32	-0.37	306414	6
4A	I3	7214	790	104	7.7%	1.99	1432	47759	0.92	56.11	0.41	-1.82	1300650	25
4B	I1	7648	772	103	9.1%	1.98	1466	48723	0.94	45.10	0.51	-0.62	650347	12
4B	I2	3662	-82	4	0.4%	0.08	338	10224	0.20	42.27	0.50	-0.14	140454	3
4B	I3	9121	723	103	9.1%	1.99	1589	52383	1.01	50.58	0.45	-0.85	658336	13
4C	I1	1605	571	63	5.4%	1.20	637	22095	0.42	103.70	0.23	-0.98	379628	7
4C	I2	163	-69	-6	-0.5%	-0.12	-38	-1439	-0.03	-379.31	-0.07	-0.29	45072	1
4C	I3	1669	531	59	5.1%	1.13	612	21157	0.41	131.25	0.18	-1.26	357510	7
5A	I1	4375	1443	159	9.6%	3.06	1646	56934	1.09	40.16	0.59	-0.52	967366	19
5A	I2	1794	-126	-6	-0.4%	-0.12	96	2530	0.05	147.90	0.13	-0.24	119617	2
5A	I3	4638	1385	154	9.3%	2.96	1628	56147	1.08	49.37	0.48	-0.80	939249	18
5B	I1	6786	1175	141	10.5%	2.70	1696	57452	1.10	38.98	0.60	-0.51	868324	17
5B	I2	3448	-128	-1	-0.1%	-0.02	277	8163	0.16	51.48	0.40	-0.16	162293	3
5B	I3	8159	1105	138	10.3%	2.66	1791	60162	1.16	44.88	0.52	-0.74	861409	17

Appendix D – Modeling Data Sources

Model Input	Data Source	Description of Data Source and Use	Data Location
Baseline: Building Energy Model	DOE New Construction (2004 vintage) Commercial Reference Buildings	2004 DOE Commercial Reference Building Models created using OpenStudio workflow measures, modified, and simulated in OpenStudio/EnergyPlus. Baseline roof insulation R-value modified to be R12.5 for all modeled building types, in all climate zones; baseline roof 3-year aged solar reflectance and thermal emittance modified to be 0.3 and 0.9, respectively, for all modeled building types, in all climate zones.	https://www.energy.gov/eere/buildings/commercial-reference-buildings
Intervention: Roof Insulation R-Value	DOE Building Codes Program, ANSI/ASHRAE/IES Standard 90.1-2019: Section 5, Building Envelope and Normative Appendix G.	Baseline building energy models modified to meet ANSI/ASHRAE/IES Standard 90.1-2019: Building Envelope minimum prescriptive R-value requirements, by climate zone and construction type for insulation and ASHRAE Standard 90.1-2019, Normative Appendix G for 3-year aged solar reflectance and thermal emittance.	https://www.energycodes.gov/technical-assistance/training/courses/ansiashraeies-standard-901-2019
Intervention: Roof 3-year Solar Reflectance and Thermal Emittance Values	ANSI/ASHRAE/IES Standard 90.1-2019: Envelope and Appendix	Baseline building energy models modified to meet ANSI/ASHRAE/IES Standard 90.1-2019 prescriptive cool roof requirements irrespective of climate zone.	Product Directories - Cool Roof Rating Council (coolroofs.org)
Economics: Energy Rates	EIA's Annual Energy Outlook 2021	Obtained from DOE's EIA Annual Energy Outlook 2021 – national average.	https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2021&region=1-0&cases=ref2021&start=2019&end=2050&f=A&linechart=~ref2021-d113020a.79-3-AEO2021.1-0~ref2021-d113020a.80-3-AEO2021.1-0&map=ref2021-d113020a.4-3-AEO2021.1-0&ctype=linechart&chartindexed=0&maptype=0&sid=~~~~&sourcekey=0

Model Input	Data Source	Description of Data Source and Use	Data Location
Economics: Energy Escalation Rates	EIA's Annual Energy Outlook 2021	Obtained from DOE's EIA Annual Energy Outlook 2021 – national average, escalated annually.	https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2021&region=1-0&cases=ref2021&start=2019&end=2050&f=A&linechart=~ref2021-d113020a.79-3-AEO2021.1-0~ref2021-d113020a.80-3-AEO2021.1-0&map=ref2021-d113020a.4-3-AEO2021.1-0&ctype=linechart&chartindexed=0&maptype=0&sid=~~~~&sourcekey=0
Economics: Capital Costs	RS Means, 2019	Insulation costs derived from 2019 RS Means ($/ft2) for materials and labor – national average, varies by baseline-to-code compliant difference. Black and cool roof membrane costs derived from cost research using standard products listed in the CRRC Roof Product Directory.	RS Means not publicly available
Economics: Discount Rate	DOE, Energy Efficiency & Renewable Energy, Federal Energy Management Program	3% FEMP prescribed floor discount rate used in lieu of 2021 nominal discount rate.	https://www.energy.gov/eere/femp/articles/2021-discount-rates
Economics: Effective Useful Life	Effective Useful Life (EUL)	Derived from publicly available warranty information.	Various data sources.
Emission Factors: Electric	EPA eGRID	National-level emission factors obtained from Table 1: Subregion Output Emission Rates (eGRID2018).	https://www.epa.gov/sites/default/files/2020-01/documents/egrid2018_summary_tables.pdf
Emission Factors: Natural Gas	EPA Emission Factors for Greenhouse Gas Inventories	National-level emission factors obtained from Table 1: Stationary Combustion for natural gas.	https://www.epa.gov/sites/default/files/2021-04/documents/emission-factors_mar2020.pdf

Appendix E - Attachments

File Name	File Description
Modeling Parameters_ 06_03_2022	Contains baseline and intervention building energy model input parameters, by climate zone, for roof insulation entirely above deck and three-year roof reflectance and thermal emittance Includes links to underlying data sources.
Modeling Results _06_03_2022	Contains raw energy performance data extracted from baseline and intervention building energy models output reports, for each of the scenarios. Data are summarized for relative energy impacts and presented in a two-way table for inclusion in the final report, and pivot tables for assessing general building-level and aggregate data trends by building type, climate zone, and scenario, for quality control. Data serves as input to the Energy, Economic, and Emissions Analysis file.
Energy Economic Emissions Analysis _06_03_2022	Quantifies the energy, emissions, and life-cycle economic benefits that accrue for each scenario relative to the baseline condition. Uses inputs of building simulated energy model performance data to calculate city location and climate zone representative building first-year and lifetime (cumulative) benefits. Benefits are presented in a series of two-way tables and charts for inclusion in the final report. Underlying economic and emissions assumptions are included in the datafile along with links to corresponding data sources.

Appendix F – Resources

Polyisocyanurate Insulation Manufacturers Association (PIMA); Environmental Product Declaration; Polyiso Roof Insulation Boards; November 4, 2020; Found at: https://www.polyiso.org/page/EPDs

U.S. Department of Energy, Energy Efficiency & Renewable Energy, Prepared by Pacific Northwest National Laboratory; Methodology for Evaluating Cost-Effectiveness of Commercial Energy Code Changes; August 2005. Found at: Methodology for Evaluating Cost-effectiveness of Commercial Energy Code Changes (energycodes.gov)

National Renewable Energy Laboratory; U.S. Department of Energy Commercial Reference Building Models of the National Building Stock; Technical Report, NREL/TP-5500-46861; February 2011. Found at: U.S. Department of Energy Commercial Reference Building Models of the National Building Stock (nrel.gov)

National Institute of Standards and Technology, U.S. Department of Commerce; NIST Handbook 135, Life Cycle Costing Manual for the Federal Energy Management Program; NIST.HB.135-2020. Found at: Life Cycle Cost Manual for the Federal Energy Management Program (nist.gov)

Codes and Standards Enhancement (CASE) Initiative 2022 California Energy Code; Nonresidential High-Performance Envelope, Final CASE Report; Prepared by Energy Solutions and Determinant; 2022-NR-ENV1-F, Envelope, October 2020. Found at: 2020-T24-NR-HP-Envelope-Final-CASE-Report.pdf (title24stakeholders.com)

U.S. Department of Energy, Energy Efficiency & Renewable Energy, Building Energy Codes Program; ANSI/ASHRAE/IES Standard 90.1-2019: Envelope; Prepared by Pacific Northwest National Laboratory for the U.S. Department of Energy; PNNL-SA-153209; May 2020. Found at: ANSI/ASHRAE/IES Standard 90.1-2019 | Building Energy Codes Program

Lawrence Berkeley National Laboratory, Building Technologies Department, Environmental Energy Technologies Division, University of California; Commercial Heating and Cooling Loads Component Analysis; LBNL-37208; November 1999. Found at: Commercial Heating and Cooling Loads Component Analysis (lbl.gov)

GAF, EnergyGuard™ ISO Sell Sheet (COMGT318); Updated May 2015; Found at: 898708.pdf (construction.com)

Cool Roof Rating Council Directory; Found at: Product Directories - Cool Roof Rating Council (coolroofs.org)

NRCA; July 2014; It's a Wash, There is much to consider when cleaning a low-sloped cool roof membrane; Found at: It's a wash | Professional Roofing magazine

BOMA; Preventive Maintenance Guidebook Best Practices to Maintain Efficient and Sustainable Buildings; Found at: Project Lifespan Estimates.pdf (illinois.edu)

END OF REPORT