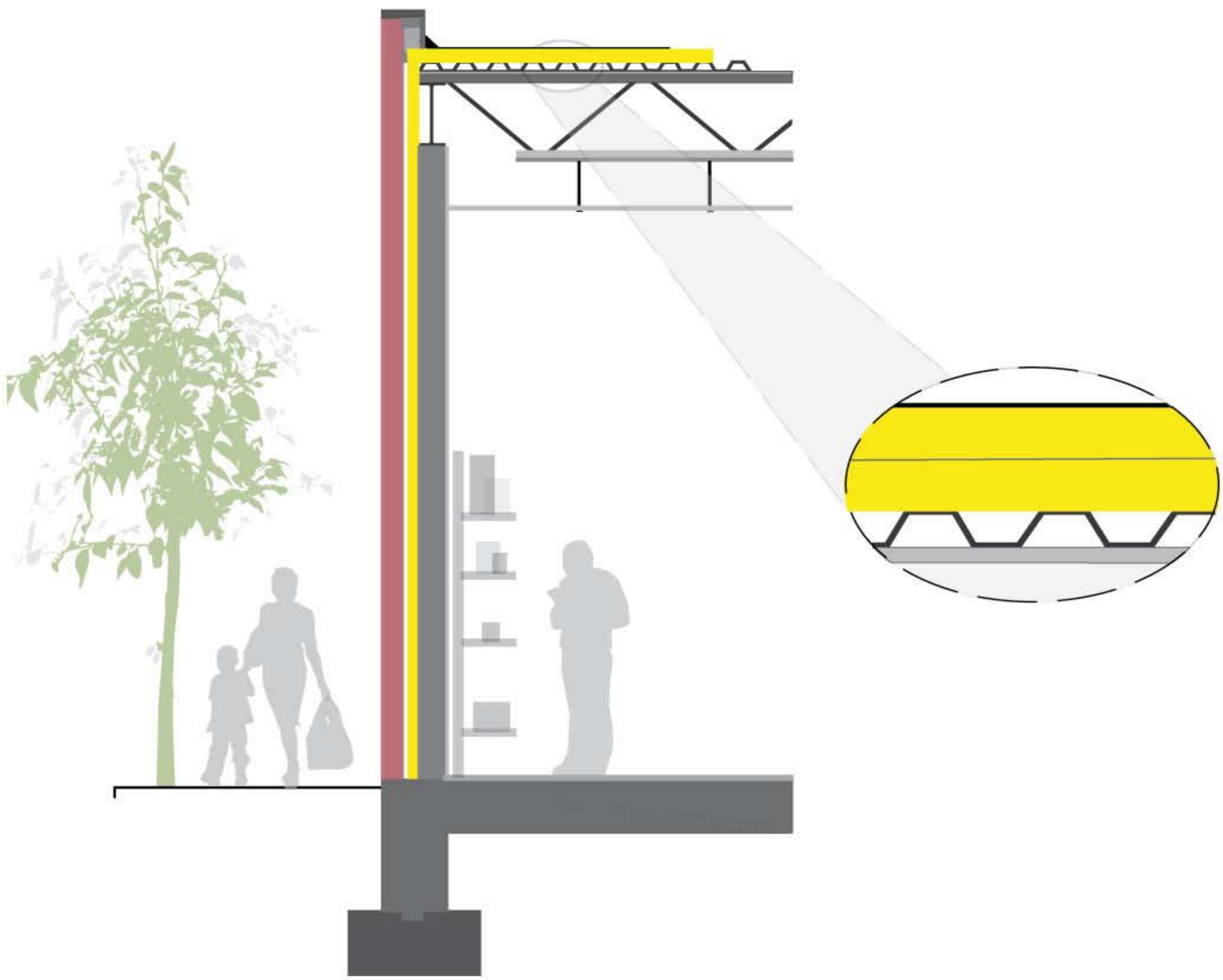
Bayer MaterialScience

Energy and Environmental Impact Reduction Opportunities for Existing Buildings with Low-Slope Roofs



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DISCLAIMER

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We also acknowledge the Department of Energy's Office of Energy Efficiency and Renewable Energy, contributing contractors and the National Laboratories involved in the development and continuing optimization of the EnergyPlus simulation program as well as the Commercial Building Benchmark Models through the "Net Zero Commercial Building Initiative". These tools provided vital resources on which this study was conducted and will certainly contribute highly to other energy efficiency and environmental based research in the future.

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EXECUTIVE SUMMARY

Substantial reductions in operating costs, energy, and Global Warming Potential (GWP) emissions can be achieved in existing buildings. Much of the three billion square feet of low-slope roofs that require replacement every year in this country can be retrofitted with an energy efficient system in a practical and economically feasible fashion. The extensive research conducted in this study provides the basis for concluding that at least one and one half billion square feet of high thermal performance roofing can be installed each year for many years, ultimately saving billions of dollars in utility costs, preserving trillions of Btu of energy and preventing hundreds of millions of metric tons of GWP and other environmentally damaging emissions. The results presented in this report range from individual building type in specific climate zones to aggregate national results. The table below provides research findings following ten consecutive years of replacing failing existing low-slope roofs with energy efficient systems:

Impact Basis	***Floor Area*** **(billion ft^2)**	***Cost Savings*** **(billion $)**	***Source Energy Savings*** ***trillion Btu***	***Emissions Prevention*** ***million tons CO_2-eq.***
Annual	**15.4**	**2.4**	**266**	**19**
Ten Year Cumulative		**12.2**	**1,464**	**105**

The research involved in this analysis is based on several credible resources, tools and standardized procedures including the following:

- Performing **Whole Building Energy Analysis** (WBEA) with more frequently than hourly energy balance calculations and climatic data in order to estimate a building design's annual energy performance using the state of the art DOE simulation tool, **EnergyPlus**.
- Utilization of ten of the sixteen DOE Office of Energy Efficiency and Renewable Energy (EERE) **Commercial Building Benchmark Prototypes**. These models are fully described in EnergyPlus input files for each of the locations. The WBEA simulations for this study are performed on these files.
- In order to perform the impact assessment, a connection is made between each of the models and their respective estimated market weightings. For this exercise, the latest Energy Information Administration (EIA) **Commercial Building Energy Consumption Survey** (CBEC-2003) data are utilized.
- The consumed utilities of electricity and natural gas as well as the additional installed insulation required for an energy efficient roof system are evaluated from a **"Cradle to Grave"** (Life Cycle Assessment, LCA) perspective. As a result, the complete life cycle energy, known as **Source Energy** and the resulting GWP emissions are quantified and compared.
- Economic analyses performed utilize established resources for the basis of all calculations. **Utility cost** calculations are left to the EnergyPlus program, flat **annual inflation rates** on electricity and natural gas are based on EIA projections, and current installed insulation costs are taken from **RS Means CostWorks Online Construction Estimator**.

1.0 BACKGROUND, PURPOSES AND SCOPE

A rapidly accelerating awareness of the energy and environmental challenges facing us today has spurred enhanced energy efficiency standards, stricter codes and emerging technologies in new construction. As a result, there is confidence that buildings constructed over the coming years will consume less and less energy. Unfortunately, these activities rarely impact the energy consumption levels of the more than 70 billion square feet of existing commercial building floor space in this country.

This study explores one of the most practical and economically feasible opportunities for improving the energy efficiency in existing buildings: Roof replacement of low-slope roofed buildings, i.e. replacement of waterproofing membrane. It is commonly known that a typical building requires three roof replacements during its lifetime or roughly one replacement every twenty years. Thus, routine roof replacement facilitates implementation of the long-proven energy efficiency measure of added levels of insulation.

The current economic crisis has all but stalled the re-roofing market and thus so has also deeply impacted the opportunity to decrease energy consumption in buildings. Initial costs and tight capital cause building owners to resort to patch work in order to extend the life of roofs. This report serves to aid in evaluating the impact of this dilemma and provides support to measures taken to help resolve it.

The Polyisocyanurate Insulation Manufacturers Association (PIMA) and Center for Environmental Innovation in Roofing (CEIR) are proposing that the U.S. Congress implement a tax incentive for the purpose of encouraging the installation of energy efficient roofs on existing buildings. This incentive would be applicable specifically to any existing commercial and high rise (i.e. greater than three stories) residential building with a low-slope roof. The majority of commercial floor space in the United States is in buildings that have low-slope roofs. In order to qualify, the replacement roof would be required to have a minimum insulation R-value of 25, 30 or 35 depending on the climate zone in which the building is located, and would required to be placed in service during 2009 through 2013.

The adoption of a tax incentive requires full vetting of tax revenue impacts weighed against incurred benefits to the public. Here, the benefits would include immediate and long lasting energy cost and resource savings, prevention of substantial global warming emissions, and jobs creation. One of the purposes of this study is to assess the potential impact of a surge of energy efficient roof replacements in terms of cumulative national energy savings, global warming emissions prevention. Therefore, by conducting this analysis, the authors are providing detailed and credible information for legislators so that a sound decision can be made regarding the merits of this proposal.

The scope established for this research is all existing buildings in the United States with low-slope roofs that are in need of roof replacement, or whose owners upgrade their facility in such ways as installing solar equipment or improving energy efficiency. This serves as the boundary for relating the energy modeling performed in this analysis to available commercial building market information. The energy modeling, along with weighting factors developed from market data (Section 7) form the basis for performing the impact assessment (Section 8).

2.0 ENERGY MODELING

Climatic conditions, location and building orientation, envelope characteristics, HVAC and other operating systems, and building use and occupant activities along with the interactions between these components create great complexity in determining the energy consumption of any specific building. Computer-based simulation programs which make thousands of complete energy balance calculations that incorporate all of these variables and their interactions are utilized to perform Whole Building Energy Analysis (WBEA). WBEA is frequently conducted on individual building designs in order to predict energy performance. This analysis is required during the design phase in cases such as qualifying for LEED certification and tax deductions under the Energy Conservation Act of 2005. Appendix G of ASHRAE 90.1, "Performance Rating Method", includes WBEA as a key component and lists in Section G2 a number of requirements which any simulation tool must satisfy in order to be utilized in this widely accepted energy rating method.

Clearly, the use of a rigorous energy simulation tool is essential in order to closely predict the performance of any specific building design. However, the resources required in order to conduct this type of analysis make it impractical for every project, particularly retrofit jobs such as roof replacement. The authors believe that one can reference specific detailed results from this study to provide an estimate of the benefits realized by completing an energy efficient roof replacement project.

2.1 EnergyPlus

EnergyPlus is a fully integrated building and HVAC simulation software program. It is a product of the Department of Energy (DOE) and was originally developed and is updated twice annually by DOE contractors. The basis for EnergyPlus is BLAST and DOE-2.1E, two earlier DOE programs. The strongest features of these programs were incorporated into EnergyPlus along with additional capabilities.[1]

The latest version of EnergyPlus, 3.0.0, can be downloaded from the DOE Energy Efficiency and Renewable Energy website free of charge. Along with the program setup and launch, the download provides extensive reference documentation on the engineering basis behind the simulation calculations. The website also provides access to hundreds of hourly weather data files from around the world which can be linked to the specific EnergyPlus simulation file that one is utilizing.

[1] U.S. Department of Energy, Energy Efficiency and Renewable Energy, www.eere.energy.gov Programs: Building Technologies.

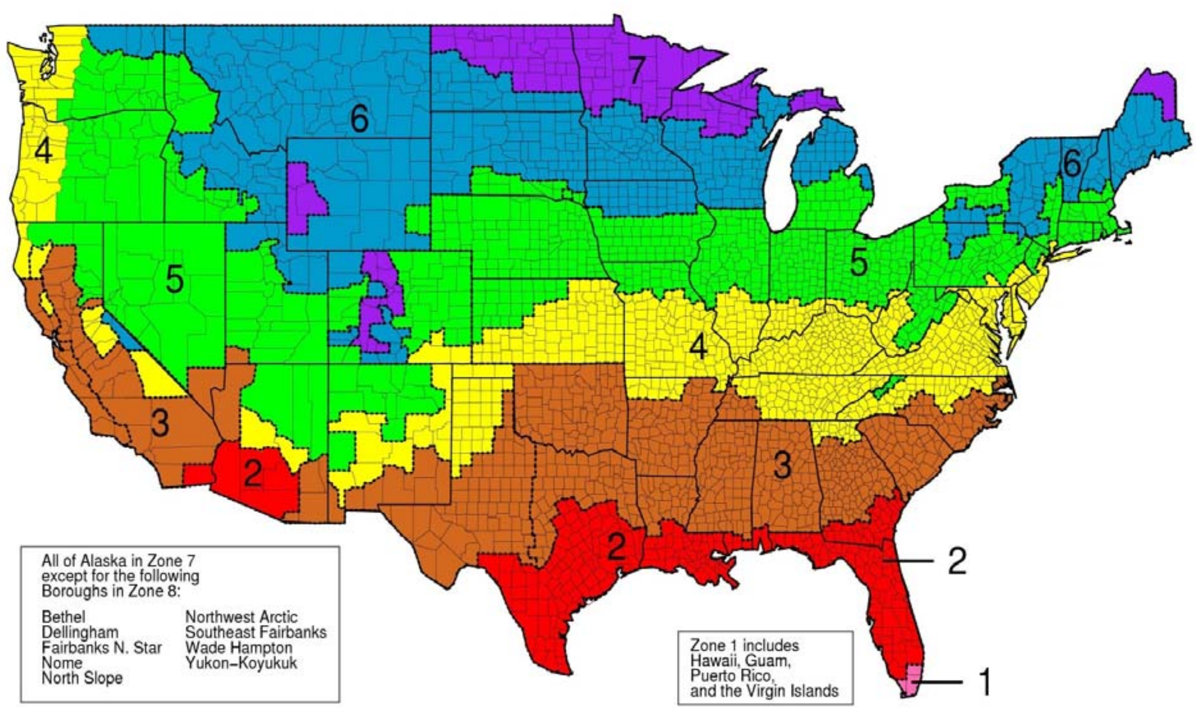
2.2 Commercial Building Benchmark Models

The DOE has sanctioned three of its national laboratories to develop commercial building benchmark models which will provide complete descriptions for WBEA using EnergyPlus. This project includes the establishment of 16 separate building prototypes which, according to DOE analysis, represents approximately 70 percent of the commercial buildings in the U.S. For each building prototype, EnergyPlus files are generated with specific input data for 16 U.S. locations representing each of the ASHRAE sub-climate zones (Figure 2.2). Lastly, the project includes establishing three prototype categories according to building vintage:

- New Construction
- Buildings constructed in or after 1980
- Buildings constructed prior to 1980

In November, 2008, the DOE released the complete set of EnergyPlus input files for the first vintage category, New Construction.[2]

Figure 2.2: ASHRAE Climate Zones



[2] U.S. Department of Energy, Energy Efficiency and Renewable Energy, www.eere.energy.gov Programs: High Performance Commercial Building/Commercial Building Benchmark.

3.0 STUDY SIMULATION DESCRIPTIONS

The release of the DOE Benchmark Models was important for conducting this study. Even though these input files were designed for new construction, the building envelope and operating parameters are appropriate for the modeling completed here. In addition to providing the credibility of the national laboratories, this greatly reduced the workload of researching parameters and populating the many input files involved. Nevertheless, the modeling was very onerous and by far and away the greatest time-consuming portion of this project. Throughout the development of the energy modeling protocol, care was taken to limit the number of required simulations without sacrificing the credibility of the assessment and realized benefits of energy efficient roof replacements. Nearly 400 individual simulations were conducted in this project. The authors are confident that this objective was achieved and credits this largely to possessing a strong understanding of the low-slope commercial roofing market prior to establishing the modeling protocol.

3.1 Model Building Types

Of the sixteen building types established in the DOE Commercial Building Benchmark Project, ten were used in this study and are listed in Table 3.1 below. Analyses of existing commercial building data indicate that the modeling of these types would provide a sufficient representation of the energy performance of buildings with low-slope roofs. Section 7, “Commercial Building Market Analysis”, offers further explanation to substantiate this conclusion.

Table 3.1: Building Types Used in Simulation And Impact Assessment Weighting

Retail
Strip Mall
Warehouse
Small Office
Medium Office
Restaurant
Supermarket
Primary School
Secondary School
Small Hotel

3.2 Building Locations and Climate Zones

Of the sixteen building locations in which EnergyPlus input files were developed in the DOE Commercial Building Benchmark Project, thirteen were used in this study and are listed in Table 3.2 below. These thirteen locations represent Climate Zones 2 through 6 and all three of the Moist, Dry and Marine locations. Market data indicate that greater than 97 percent of total floor area in existing buildings is located in these five climate zones.

Table 3.2: Simulation Locations, Climate Zones and Energy Efficient R-value Requirement

Location	Climate Zone	Minimum R-Value
Houston, TX	2A	25
Phoenix, AZ	2B	25
Atlanta, GA	3A	25
Los Angeles, CA	3B	25
Las Vegas, NV	3B	25
San Francisco, CA	3C	25
Baltimore, MD	4A	30
Albuquerque, NM	4B	30
Seattle, WA	4C	30
Chicago, IL	5A	30
Boulder, CO	5B	30
Minneapolis, MN	6A	30
Helena, MT	6B	30

3.3 Characteristics of Existing and Retrofit Building Models

As mentioned above, the DOE benchmark models released thus far are designed as prototypical of newly constructed buildings. Therefore, the input parameters included building envelope and operating systems criteria as established in ASHRAE 90.1-2004 and include equipment specifications representative of current day technologies. Two specific examples of substantial advancements in technologies include lighting and HVAC efficiencies. The authors chose not to make modifications in the benchmark files in order to account for these differences in technologies. There are several reasons why this decision was made, the least of which was certainly not the amount of time involved in researching the specifications of 15 – 45 year old equipment and entering it into the input files. Rather, it is likely that the original equipment in any given existing building has been or will soon be replaced with modern technology, as it has reached its functional life or the building owner decides that replacement would be beneficial.

As noted, the benchmark models were designed to ASHRAE 90.1-2004 including the thermal envelope. For post-1980 commercial buildings, across all building types and climate areas, the average roof insulation level is R-12.4 and for pre-1980 buildings the average is R-10.4.[3] For this study, the input models representing all of the existing buildings were modified to reflect an "Insulation Entirely Above the Deck" (IEAD) of R-12.4. In the input files for the energy efficient roofs following replacement, the overall R-value for IEAD of 25.4 for Climate Zones 2 and 3 and 30.5 for Climate Zones 4, 5 and 6 were represented. This assumes that the existing R-12.4 insulation is reused and 2.2 inches or 3 inches of Polyiso, respectively, is installed on top of it (See Table 3.2). These insulation thicknesses were used because they were the nearest advertised LTTR valued Polyiso product that met or exceeded the total insulation requirements for an energy efficient roof.

No modifications were made to the thermal characteristics of the walls and foundations of the benchmark models. The input files of the Small Office and Restaurant were modified to reflect the redesign of a building with an attic to a building with a flat roof. Also, a minor change in the Warehouse model was made to convert the building from a generic metal building roof to one with IEAD plus a membrane.

The original benchmark models included a built-up-roof (BUR) waterproofing system which is typical for existing buildings. This was maintained in this analysis in the model for the simulation. For the simulation of the energy efficient roof, a Thermoplastic Polyolefin (TPO) membrane was modeled for all buildings simulated in Climate Zones 2, 3 and 4. For all simulations for Climate Zones 5 and 6, models with a TPO membrane and with a BUR system were both modeled. The model selected for the study comparison was the system that exhibited the better energy performance in the simulation.

[3] Huang, J. and E. Franconi (1999), Commercial Heating and Cooling Loads Component Analysis," LBL-37208, Berkeley, CA: Lawrence Berkley Ntaional Laboratory, table 2-7.

3.4 U-value Calculation Methodology

It is known that small, yet unavoidable gaps occur between adjoining boards of single layer roof insulation.[4] Parallel flow heat transfer calculations show that the percentage of heat loss is much greater in proportion to the percent area of the gaps. For re-roofing projects in which the original insulation is re-used and the new insulation is installed so that board edges of both layers are overlapped, much of this heat loss can be eliminated.

The benefits of double layering of insulation are illustrated in the U-value calculations conducted to determine the input data utilized in this study. The R-values of the individual roofing materials are listed in Table 3.4:[5]

Table 3.4: R-value of roofing materials

	$^{o}F \cdot ft^{2} \cdot h/Btu$
$R_{OutsideAir}$	0.170
$R_{membrane}$	0.068
R_{deck}	0.015
$R_{InsideAir}$	0.610
R_{M+D}	0.863
Insulation	
$R_{layer\ 1}$	12.4
$R_{layer\ 2}$	13.0, 18.1
$R_{air\ space}$	1.0

With gaps accounting for 0.5 percent of total area of each layer, the U-value calculations are as follows:

One layer:

$U = 0.995/(R_{PIR}+R_{M+D}) + 0.005/(R_{air\ space}+R_{M+D})$

Existing insulation at R-12.4 U = 0.078 Btu/ $^{o}F \cdot ft^{2} \cdot h$/Btu

Average Insulation layer R-value = 12.0 $^{o}F \cdot ft^{2} \cdot h$/Btu

Two layers:

$U = 0.99/(R_{PIR\ layers\ 1+2}+R_{M+D}) + 0.005/(R_{PIR\ layer\ 1} + R_{air\ space}+R_{M+D}) + 0.005/(R_{PIR\ layer\ 2} + R_{air\ space}+R_{M+D})$

For adding R-13.0 to total R-25.4 U = 0.038 Btu/ $^{o}F \cdot ft^{2} \cdot h$

Average Insulation layer R-value = 25.2 $^{o}F \cdot ft^{2} \cdot h$/Btu

For adding R-18.1 to total R-30.5 U = 0.032 Btu/ $^{o}F \cdot ft^{2} \cdot h$

Average Insulation layer R-value = 30.2 $^{o}F \cdot ft^{2} \cdot h$/Btu

[4] Lewis, J.E. (Date NA), "Thermal Evaluation of the Effects of Gaps Between Adjacent Roof Insulation Panels," Granville, Ohio Research and Development Division, Owens Corning Fiberglass Corporation.

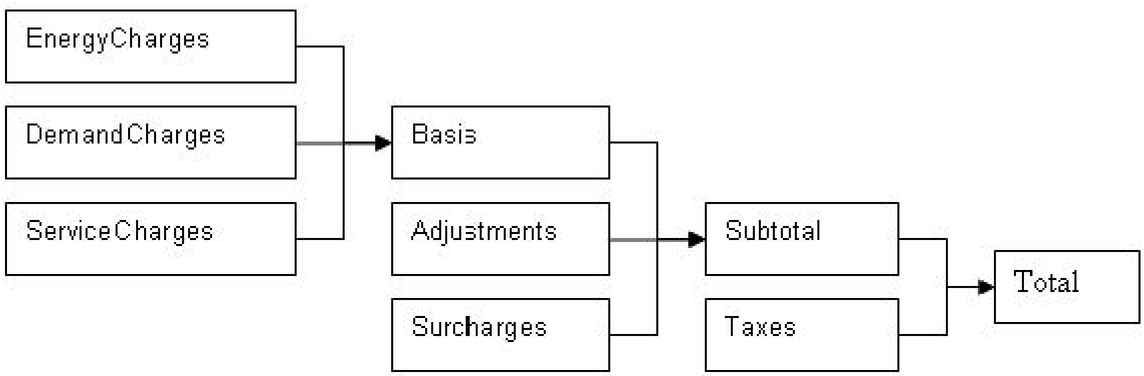
[5] ASHRAE (2005, Handbook of Fundamentals: ASHRAE Research.

4.0 Economic Analysis

4.1 Utility Costs

The utility costs for the models in this study were calculated entirely by the EnergyPlus program and serve as the first year operating savings basis for the review of simulation results (Section 5) and the impact assessment (Section 8). The average energy costs varied widely by location as well as by building type within the same location. EnergyPlus has a number of program modules to model the economics of a building including utility rate charges that calculates monthly costs based on all charges listed on the bills. Figure 4.1 below is taken from the EP Input-Output Reference Manual available in the Documentation file of the download.

Figure 4.1: EnergyPlus Monthly Utility Charges Calculation Hierarchy



Lifetime (thirty year) energy savings were calculated using the first year utility costs calculated by EnergyPlus as described above with a fuel inflation rate starting in the second year. The annual inflation rates used for these calculations are 2.2 percent for electricity and 2.8 percent for natural gas. These rates of inflation are forecasted by the Energy Information Administration (EIA).

4.2 First Costs

As was indicated earlier, Polyiso was chosen for the roof insulation in this study. It is the most widely used insulation for low-slope IEAD applications. In addition, the authors published a report in 2008 on the energy and environmental benefits of Polyiso, referenced in Section 6, Energy and Environmental Impacts. In order to establish credible information on the material and labor costs of installing Polyiso, the RS Means CostWorks Online Construction Estimator was subscribed to and utilized. This tool provides cost estimation information on all building materials and the labor involved in their installation specific to dozens of locations.

For Polyiso, CostWorks has costing data on products of several thicknesses. In reviewing the data available, the relative pricing on the various thicknesses appeared to be inconsistent. Contact was made to RS Means Customer Support in order to understand the data collection process. It was from this conversation that the author chose to use the most commonly used product, two inch Polyiso, as the basis for the first costs of the insulation. For each location modeled in this study, the most recent CostWorks material and installed labor data for this product were collected. Using this as the basis, the costs were prorated on a board foot basis to determine the estimated installed price. The square foot installed costs for each location are listed below in Table 4.2.

Table 4.2: Polyiso Installed Costs

Location	R-Value	Thickness, inches	Cost per ft^2
Houston	25.4	2.1	$1.02
Phoenix	25.4	2.1	$1.04
Atlanta	25.4	2.1	$1.01
Los Angeles	25.4	2.1	$1.20
Las Vegas	25.4	2.1	$1.26
San Francisco	25.4	2.1	$1.33
Baltimore	30.5	2.9	$1.36
Albuquerque	30.5	2.9	$1.37
Seattle	30.5	2.9	$1.45
Chicago	30.5	2.9	$1.58
Boulder	30.5	2.9	$1.44
Minneapolis	30.5	2.9	$1.60
Helena	30.5	2.9	$1.40

5.0 SIMULATION RESULTS

The purpose of this section of the report is to organize this information into general conclusions regarding the characteristics of this large cross section of building types, uses and locations as well as the benefits of an energy efficient roof. Sub-sections 5.1 through 5.3 describe the conclusions from the simulations for the existing buildings (R-12.4 roof insulation) and Sub-sections 5.4 through 5.6 summarize the benefits.

5.1 Energy Consumption Characteristics by Building Type

5.1.1 Building Size

In terms of the quantity of energy required to operate a building, the size of the building or floor area comes to mind as a very important characteristic. This, of course, provides an idea of the volume of space~~d~~ required to be conditioned, a general idea of the number of occupants, etc. When studying the impact of greater insulation levels on the roof, the square footage of roof area and the proportion of roof area to the overall building envelope (i.e. “Roof to Skin Ratio”) are also important criteria. In order to provide reference for analysis, Table 5.1.1 lists the building types in descending order of floor area, the roof areas, and the roof to skin ratios.

Table 5.1.1 Building Size Criteria

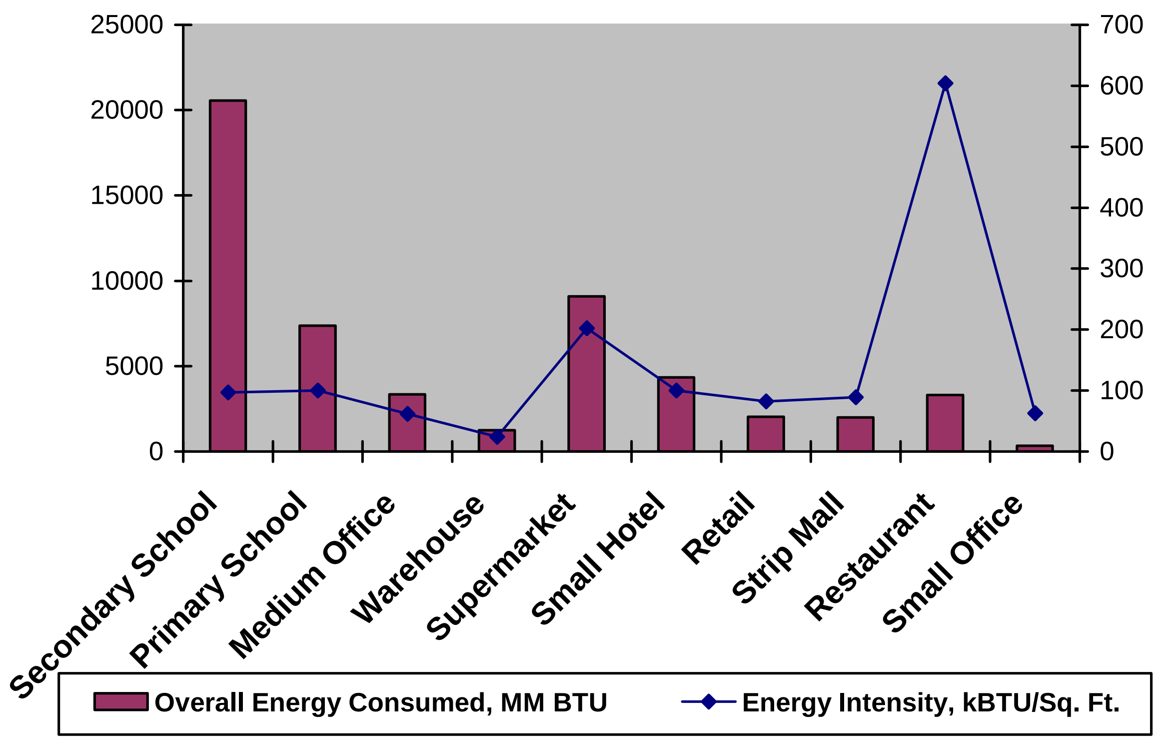
	Floor Area	Roof Area		Roof To Skin	
	ft^2	ft^2	Ranking	Ratio	Ranking
Secondary School	**210,886**	**126,677**	**1**	**0.65**	**4**
Primary School	**73,959**	**73,959**	**2**	**0.73**	**1**
Medium Office	**53,626**	**17,879**	**7**	**0.46**	**8**
Warehouse	**52,043**	**49,492**	**3**	**0.65**	**4**
Supermarket	**45,004**	**45,004**	**4**	**0.72**	**2**
Small Hotel	**43,206**	**10,796**	**8**	**0.37**	**9**
Retail	**24,692**	**24,692**	**5**	**0.66**	**3**
Strip Mall	**22,500**	**22,500**	**6**	**0.64**	**6**
Small Office	**5,500**	**5,500**	**9**	**0.46**	**8**
Restaurant	**5,500**	**5,500**	**9**	**0.55**	**7**

5.1.2 Overall Energy Consumption and Energy Intensity

Regardless of climate, the largest building, Secondary School, is also the largest consumer of energy at more than double the next largest consumer. Next, though, on the list of overall energy use is the fifth largest building, Supermarket, due to the large internal loads required for the refrigerators and freezers. The Small Office reflects its name by being the smallest energy building type, consuming less than 2 percent of the prototypical Secondary School.

Size is not at all a reliable indicator of energy intensity (energy/floor area) for buildings according to this analysis. Restaurant, consumes energy on an intensity basis many times greater than any other building type with Supermarket second, again due to the high internal load requirements of these two building uses. The semi-heated and low internal load nature of Warehouse puts it low on the list in terms of both overall energy and intensity. Figure 5.1.2 illustrates the widely varying energy consumption characteristics of these ten building types.

Figure 5.1.2: Overall Energy and Energy Intensity for Climate Zone 5



5.1.3 Energy Costs

Comparisons of the various building types in terms of operating costs are very similar to that of site energy. Total costs range from a few thousand dollars annually for Small Office to well over $400,000 for Secondary School. Restaurant is far and away the most costly building type to operate on a square footage basis.

5.2 Energy Consumption Characteristics by Climate Zones

5.2.1 Overall Energy Consumption and Energy Intensity

In general, energy usage is highest in the colder Climate Zones modeled (5 and 6). Climate Zones 2 and 4 are very similar in consumption rates and Zone 3 exhibits the lowest rate. These differences, though, are not nearly as wide as those seen between the different building types.

5.2.2 Energy Costs

The average annual utility rates established by the program calculations are listed below (Table 5.2.2) in ranges. The last column is intended to provide a general conclusion (although somewhat subjective) of the costs of operating existing buildings in these locations on a utility rate basis. Based on this analysis, the highest costs of operation are buildings located in California, followed by the highest cooling load regions of the south and the coldest locations are the least costly to operate.

Upon review of the overall operating costs of these existing buildings to include both utility rates and climate, this general picture looks only slightly different. Climate Zone 2 (Houston and Phoenix) has the highest costs, followed by Zone 3 (Atlanta, Los Angeles, Las Vegas and San Francisco), Zone 6 (Minneapolis and Helena), Zone 5 (Chicago and Boulder), and lastly, Zone 4 (Baltimore, Albuquerque and Seattle) with the lowest costs.

Table 5.2.2 Utility Rate Ranges

	Electricity	Natural Gas	Scale
	$/kWh	$/Therm	
Houston	$0.109 - 0.124	$0.849 – 0.865	High
Phoenix	$0.076 – 0.124	$0.852 – 0.908	Medium
Atlanta	$0.084 – 0.116	$0.989 – 1.064	High
Los Angeles	$0.123 – 0.136	$0.887 - 0.935	Highest
Las Vegas	$0.094 – 0.103	$0.796 – 0.861	High
San Francisco	$0.124 – 0.162	$0.889 – 0.934	Highest
Baltimore	$0.067 – 0.081	$1.016 – 1.059	Medium
Albuquerque	$0.037 – 0.075	$0.719 – 0.758	Lowest
Seattle	$0.071 – 0.079	$0.876 – 0.895	Medium
Chicago	$0.052 – 0.078	$0.867 – 0.930	Low
Boulder	$0.037 – 0.075	$0.722 – 0.756	Lowest
Minneapolis	$0.053 – 0.075	$0.831 – 0.839	Low
Helena	$0.068 – 0.077	$0.837 – 0.912	Low

5.2.3 Energy and Environmental Impacts

Section 6 explains in detail full life cycle energy and environmental benefits of energy efficient construction. In Section 6.1.2, the concept of "source versus site energy" is explained. In order to assess the full impact of resource depletion and Global Warming Potential (GWP), one must "consider the source". Table 5.2.3 illustrates the source energy and emissions involved in operating these buildings in Climate Zone 6. In the simulations, Zone 6 exhibited the highest levels of source impact. In order to illustrate the relative magnitude of emissions from the operation of each building type, the last two columns list the equivalent emissions from the annual energy used and the gasoline burned in the number of homes and vehicles, respectively. The data in these columns were obtained from the calculator on the Clean Energy page of the EPA website.[6]

Table 5.2.3: Building Type Source Energy and Emissions Comparisons - Zone 6

	Annual Source Energy	Annual Emissions	Annual Emissions Equivalent	
	Gigajoules, GJ	*Metric Tons, CO_2 equivalents*	*Homes*	*Vehicles*
Secondary School	**55,505**	**967**	**88**	**177**
Primary School	**20,059**	**341**	**31**	**63**
Medium Office	**9,771**	**167**	**15**	**31**
Warehouse	**3,906**	**67**	**6**	**12**
Supermarket	**24,911**	**424**	**39**	**78**
Small Hotel	**11,564**	**197**	**18**	**36**
Retail	**5,475**	**93**	**9**	**17**
Strip Mall	**5,359**	**91**	**9**	**17**
Small Office	**1,060**	**18**	**2**	**4**
Restaurant	**7,236**	**122**	**11**	**23**

Conversions: 948 kBtu/GJ; 2,205 LB/Metric Ton

5.3 Energy Savings from Energy Efficient Roof Construction

This sub-section of the report provides a comprehensive summary of the results of the comparative analysis of the energy performance upon upgrading a typical existing building with an “Energy Efficient Roof”. To review, a twenty to fifty year old building with a low-slope roof likely would have insulation above the roof deck amounting to R-12.4 or less. For this analysis, ten typical buildings with widely varying energy consumption characteristics have been modeled. The definition of the “Energy Efficient Roof” is that of a roof having roof insulation equal to or greater than R-20 for Climate Zone 1, equal to or greater than R-25 for Zones 2, 3, 4 and 5, equal to or greater than R-30 for Zone 6 and equal to or greater than R-35 for Zones 7 and 8. This study includes the comparative analysis of buildings located in Zones 2 – 6. Please note that the simulations were modeled with R-30.5 in Zones 4 and 5 as opposed to R-25. The reason for this is that when the boundaries of this study were established, ASHRAE and the Industry set this minimum level at R-30 for these Zones and have since adjusted to R-25.

[6] www.epa.gov/cleanenergy/energy-resouces/calulator.html

5.3.1 Retail Benchmark

Figure 5.3.1: Retail Building

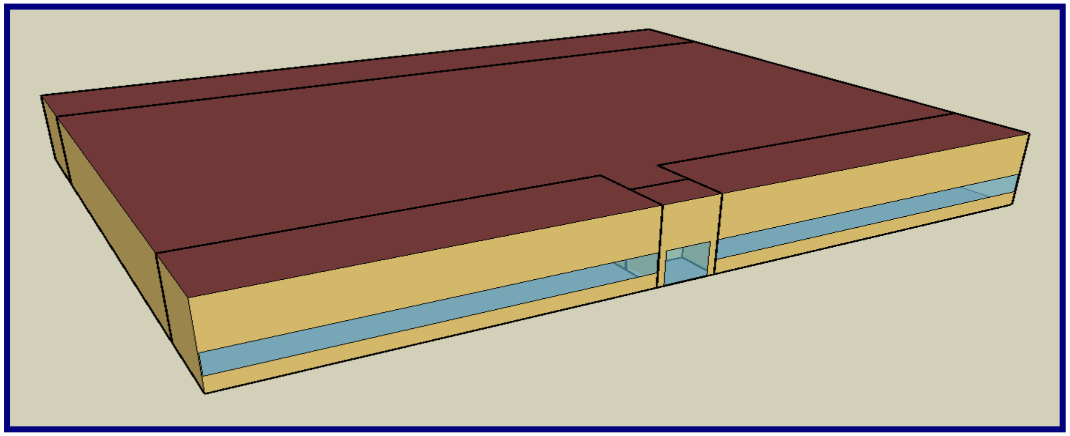


Table 5.3.1: Retail Building

		Zone	2	3	4	5	6
Energy Savings							
Site	Annual	% Savings	4.2 %	4.0 %	6.4 %	8.8 %	9.1 %
		MM Btu	73	57	111	180	221
		$kBtu/ft^2$	3.0	2.3	4.5	7.3	9.0
Source	30 Yrs.	$kBtu/ft^2$	254	161	229	383	470
Emissions		kg CO_2-eq/ft^2	18.3	11.6	16.2	27.0	33.2
Dollar Savings							
First Year		% Savings	4.1 %	3.3 %	5.2 %	7.4 %	8.0 %
		$	$2,173	$1,416	$1,375	$1,642	$2,723
		$/$ft^2$	$0.09	$0.06	$0.06	$0.07	$0.11
30 Yrs.		$	$89,510	$58,879	$59,169	$71,368	$116,675

5.3.2 Strip Mall Benchmark

Figure 5.3.2: Strip Mall Building

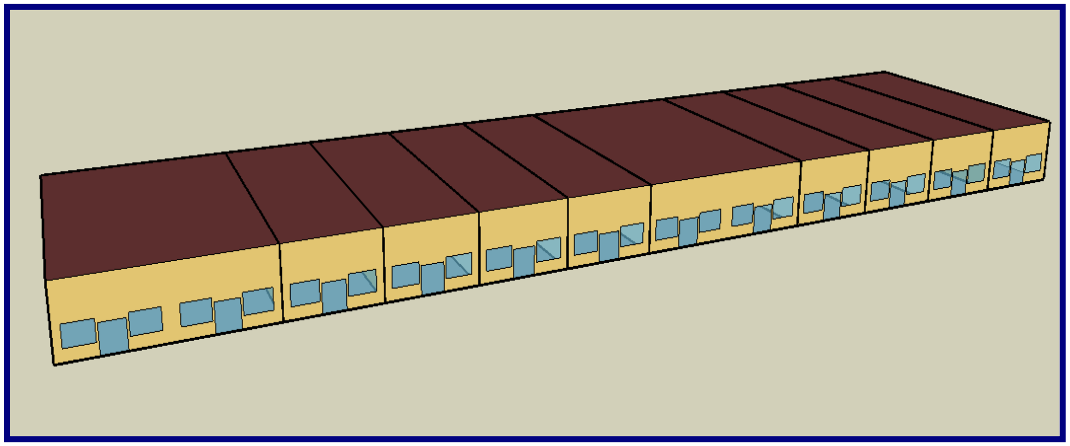


Table 5.3.2: Strip Mall Building

		Zone	2	3	4	5	6
Energy Savings							
Site	Annual	% Savings	5.5 %	6.4 %	8.1 %	9.6 %	9.8 %
		MM Btu	84	86	139	194	241
		kBtu/ft^2	3.7	3.8	6.2	8.6	10.7
Source	30 Yrs.	kBtu/ft^2	310	323	400	437	558
Emissions		kg CO_2-eq/ft^2	22.4	23.3	28.6	30.8	39.4
Dollar Savings							
First Year		% Savings	5.4 %	6.7 %	7.4 %	8.1 %	8.4 %
		$	$2,487	$2,660	$1,909	$1,756	$2,811
		$/ft^2	$0.11	$0.12	$0.08	$0.08	$0.12
30 Yrs.		$	$102,804	$109,387	$80,624	$76,368	$121,092

5.3.3 Warehouse Benchmark

Figure 5.3.3: Warehouse Building

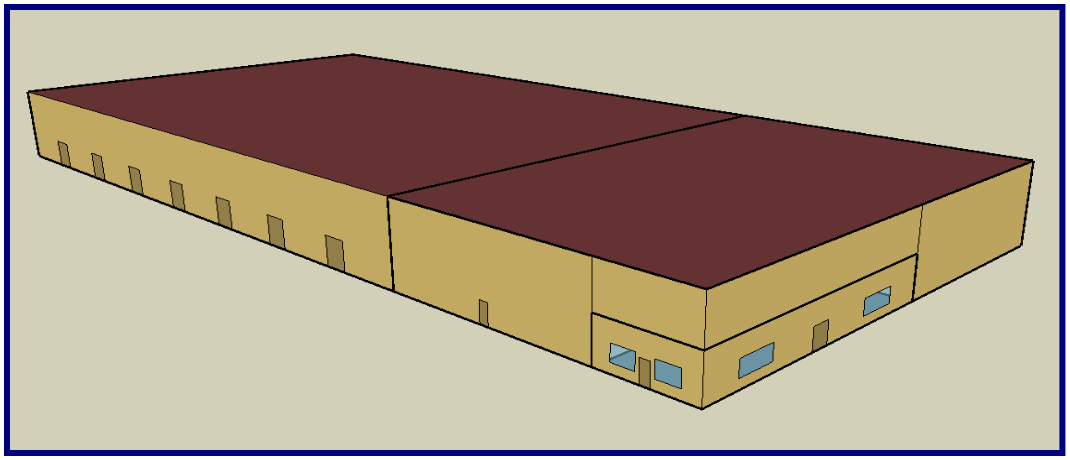
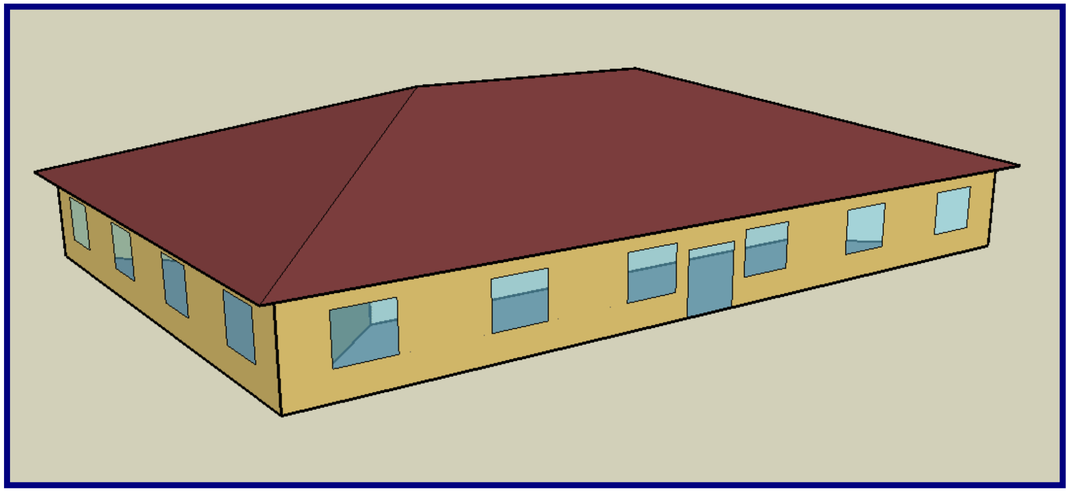


Table 5.3.3: Warehouse Building

			Zone	2	3	4	5	6
Energy Savings								
Site	Annual		% Savings	5.5 %	3.3 %	5.1 %	5.7 %	8.2 %
			MM Btu	51	29	54	71	126
			$kBtu/ft^2$	1.0	0.6	1.0	1.4	2.4
Source	30 Yrs.		$kBtu/ft^2$	92	51	58	78	151
Emissions			kg CO_2-eq/ft^2	6.7	3.7	4.1	5.5	10.7
Dollar Savings								
First Year			% Savings	6.0 %	3.2 %	3.9 %	4.7 %	7.8 %
			$	$1,789	$931	$677	$677	$1,982
			$/ft^2$	$0.03	$0.02	$0.01	$0.01	$0.04
30 Yrs.			$	$73,579	$38,496	$29,064	$28,935	$83,319

5.3.4 Small Office Benchmark

Figure 5.3.4: Small Office Building



Note: Attic converted to flat roof for modeling

Table 5.3.4: Small Office Building

		Zone	2	3	4	5	6
Energy Savings							
Site	Annual	% Savings	8.0 %	8.5 %	8.4 %	8.8 %	9.6 %
		MM Btu	27	23	25	30	37
		$kBtu/ft^2$	4.8	4.2	4.6	5.5	6.8
Source	30 Yrs.	$kBtu/ft^2$	458	380	359	356	392
Emissions		kg CO_2-eq/ft^2	33.2	33.6	35.1	39.2	44.9
Dollar Savings							
First Year		% Savings	7.8 %	8.4 %	7.6 %	6.7 %	7.3 %
		$	$874	$755	$443	$393	$508
		$/$ft^2$	$0.16	$0.14	$0.08	$0.07	$0.09
30 Yrs.		$	$35,803	$31,088	$18,352	$16,755	$21,650

5.3.5 Medium Office Benchmark

Figure 5.3.5: Medium Office Building

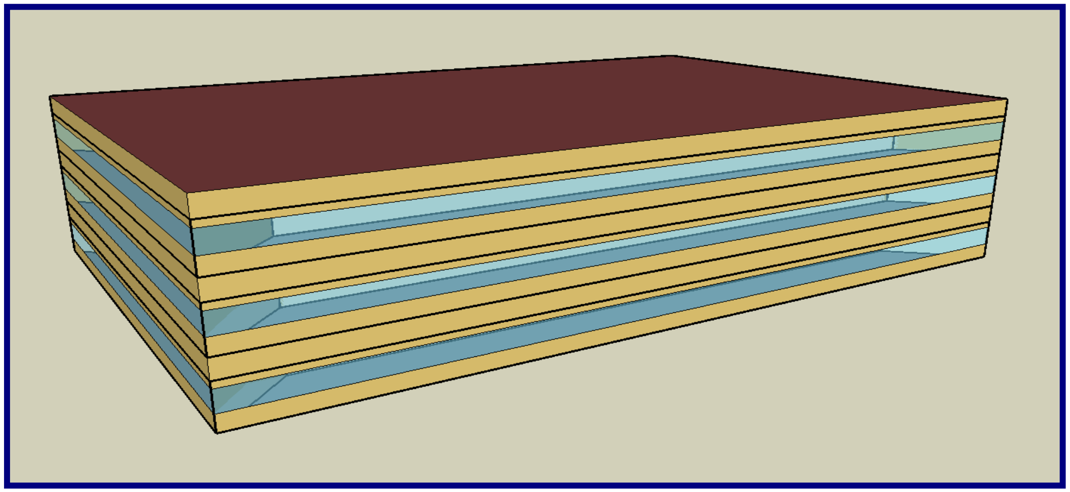
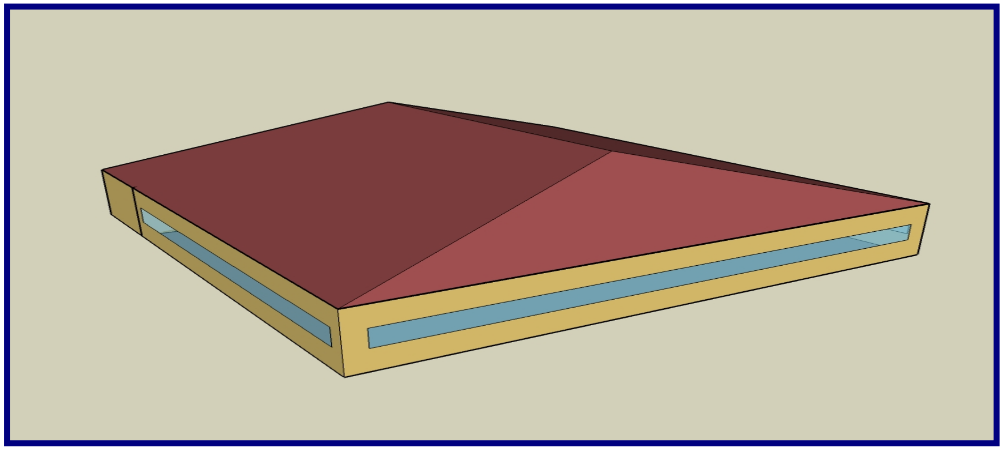


Table 5.3.5: Medium Office Building

		Zone	2	3	4	5	6
Energy Savings							
Site	Annual	% Savings	2.0 %	1.4 %	1.8 %	2.9 %	3.3 %
		MM Btu	62	40	57	97	125
		kBtu/ft^2	1.2	0.7	1.1	1.8	2.3
Source	30 Yrs.	kBtu/ft^2	100	63	65	102	120
Emissions		kg CO_2-eq/ft^2	7.2	4.5	4.6	7.3	8.4
Dollar Savings							
First Year		% Savings	2.3 %	1.5 %	1.5 %	2.1 %	2.5 %
		$	$2,068	$1,246	$781	$1,096	$1,520
		$/ft^2	$0.04	$0.02	$0.01	$0.02	$0.03
30 Yrs.		$	$85,108	$51,650	$32,870	$47,679	$64,599

5.3.6 Restaurant Benchmark

Figure 5.3.6: Restaurant Building



Note: Attic converted to flat roof for modeling

Table 5.3.6: Restaurant Building

		Zone	2	3	4	5	6
Energy Savings							
Site	Annual	% Savings	1.4 %	0.9 %	1.1 %	1.3 %	1.6 %
		MM Btu	43	27	33	42	59
		$kBtu/ft^2$	7.9	4.8	6.1	7.7	10.7
Source	30 Yrs.	$kBtu/ft^2$	753	463	487	546	631
Emissions		kg CO_2-eq/ft^2	54.7	33.6	35.1	39.2	44.9
Dollar Savings							
First Year		% Savings	2.1 %	1.4 %	1.3 %	1.3 %	1.8 %
		$	$1,313	$883	$521	$450	$761
		$/$ft^2$	$0.24	$0.16	$0.09	$0.08	$0.14
30 Yrs.		$	$53,835	$36,216	$21,680	$19,043	$32,390

5.3.7 Supermarket Benchmark

Figure 5.3.7: Supermarket Building

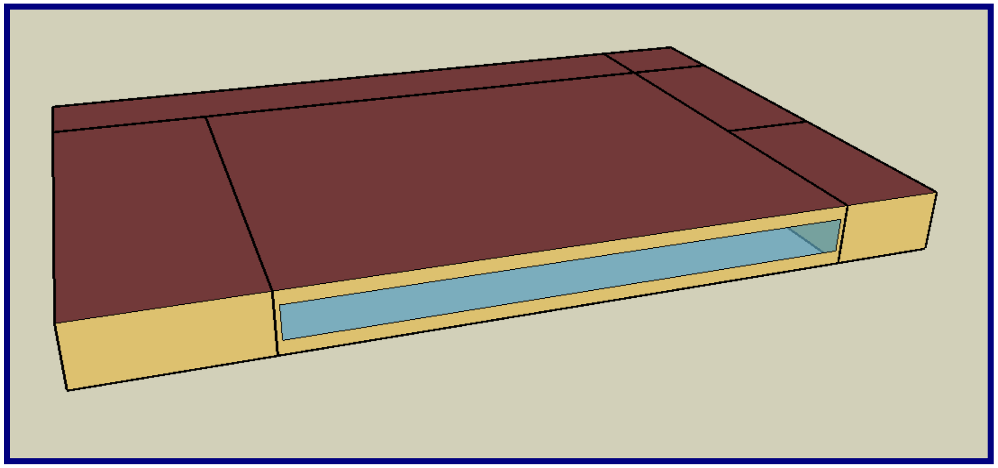


Table 5.3.7: Supermarket Building

		Zone	2	3	4	5	6
Energy Savings							
Site	Annual	% Savings	1.4 %	1.2 %	3.2 %	3.8 %	4.3 %
		MM Btu	118	91	272	350	425
		kBtu/ft^2	2.6	1.7	6.1	7.8	8.8
Source	30 Yrs.	kBtu/ft^2	245	171	353	402	416
Emissions		kg CO_2-eq/ft^2	17.8	12.3	25.1	28.4	29.1
Dollar Savings							
First Year		% Savings	1.9 %	1.1 %	2.6 %	2.9 %	3.2 %
		$	$3,888	$2,519	$3,317	$4,181	$4,495
		$/ft^2	$0.09	$0.06	$0.07	$0.09	$0.10
30 Yrs.		$	$159,781	$104,006	$141,714	$178,322	$195,056

5.3.8 Primary School Benchmark

Figure 5.3.8: Primary School Building

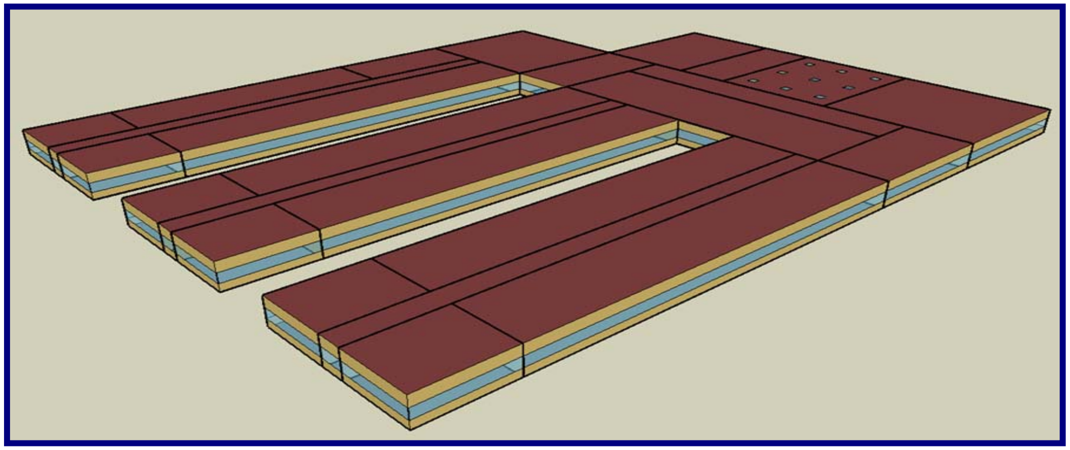


Table 5.3.8: Primary School Building

		Zone	2	3	4	5	6
Energy Savings							
Site	Annual	% Savings	12.2 %	11.3 %	14.3 %	14.2 %	12.7 %
		MM Btu	814	696	943	1,046	1,073
		kBtu/ft^2	11.0	9.4	12.8	14.1	14.5
Source	30 Yrs.	kBtu/ft^2	848	685	832	904	887
Emissions		kg CO_2-eq/ft^2	61.0	49.2	59.5	64.5	63.2
Dollar Savings							
First Year		% Savings	8.1 %	9.7 %	12.3 %	12.5 %	11.8 %
		$	$13,948	$17,040	$12,574	$13,261	$14,567
		$/ft^2	$0.19	$0.23	$0.17	$0.18	$0.20
30 Yrs.		$	$580,851	$708,143	$531,727	$560,103	$616,752

5.3.9 Secondary School Benchmark

Figure 5.3.9: Secondary School Building

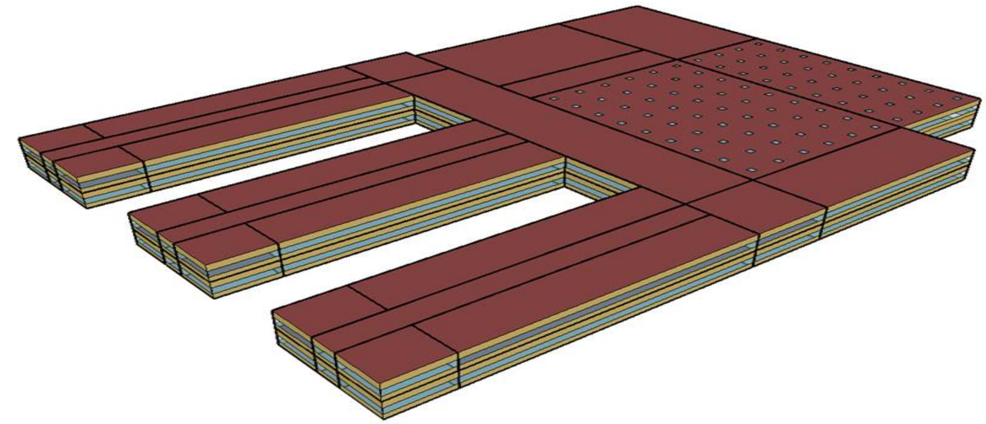


Table 5.3.9: Secondary School Building

		Zone	2	3	4	5	6
Energy Savings							
Site	Annual	% Savings	8.7 %	7.6 %	9.5 %	9.4 %	9.0 %
		MM Btu	1,501	1,190	1,695	1,925	2,180
		$kBtu/ft^2$	7.1	5.6	8.0	9.1	10.3
Source	30 Yrs.	$kBtu/ft^2$	602	455	573	630	652
Emissions		kg CO_2-eq/ft^2	43.5	32.8	41.1	45.1	51.0
Dollar Savings							
First Year		% Savings	7.9 %	6.9 %	8.6 %	9.0 %	8.7 %
		$	$35,266	$31,920	$22,923	$25,763	$29,878
		$/ft^2$	$0.17	$0.15	$0.17	$0.12	$0.14
30 Yrs.		$	$1,454,406	$1,318,566	$961,400	$1,081,580	$1,262,887

5.3.10 Small Hotel Benchmark

Figure 5.3.10: Small Hotel Building

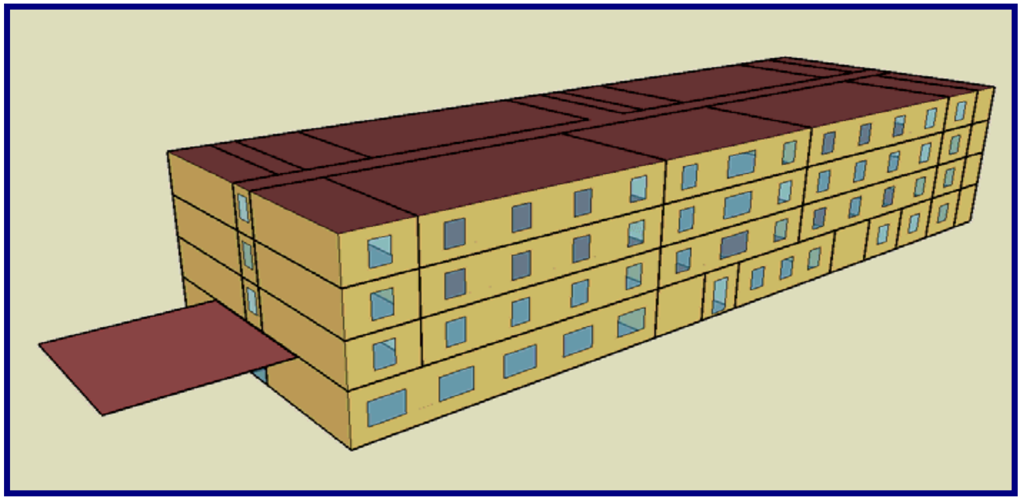


Table 5.3.10: Small Hotel Building

		Zone	2	3	4	5	6
Energy Savings							
Site	Annual	% Savings	0.8 %	0.3 %	0.3 %	0.6 %	0.8 %
		MM Btu	30	11	14	26	39
		$kBtu/ft^2$	0.6	0.3	0.3	0.6	1.0
Source	30 Yrs.	$kBtu/ft^2$	59	31	23	35	54
Emissions		kg CO_2-eq/ft^2	4.3	2.3	1.7	2.5	3.9
Dollar Savings							
First Year		% Savings	0.8 %	0.5 %	0.3 %	0.5 %	0.9 %
		$	$783	$482	$187	$321	$662
		$/$ft^2$	$0.02	$0.01	$0.004	$0.01	$0.02
30 Yrs.		$	$31,331	$19,392	$7,336	$13,156	$25,584

5.3.11 Results Compilation

In order to provide a side-by-side comparison of the benefits of upgrading to an energy efficient roof, Figure 5.3.11a shows all the savings on an energy intensity basis (i.e. decrease in energy consumption on a square foot basis) and Figure 5.3.11b shows cost savings on a dollar-per-square-foot basis. From a second perspective, Tables 5.3.11a and b lists all of the decreased energy consumption results.

Figure 5.3.11a: Energy Savings – Energy Intensity Basis, kBtu/ft^2

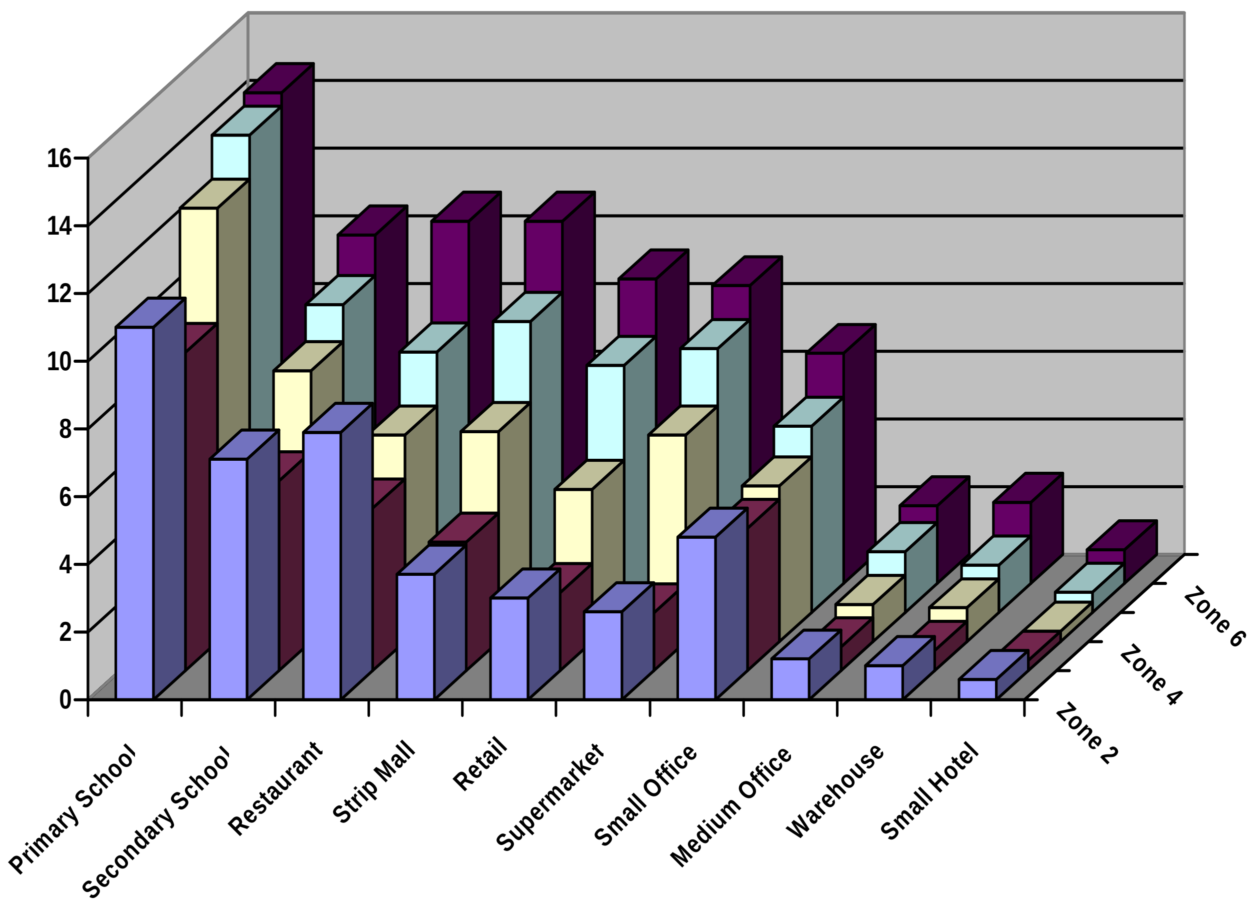


Table 5.3.11a: Energy Savings – MM Btu

	Primary School	Secondary School	Restaurant	Strip Mall	Retail	Supermkt	Small Office	Med. Office	Warehse	Small Hotel
Zone 2	814	1,501	43	84	73	118	27	62	51	30
Zone 3	696	1,190	27	86	57	91	23	40	29	11
Zone 4	943	1,695	33	139	111	272	25	57	54	14
Zone 5	1,046	1,925	42	180	180	350	30	71	71	26
Zone 6	1,073	2,180	59	241	221	425	37	125	126	39

Figure 5.3.11b: Energy Savings – Cost Intensity Basis, cents/ft^2

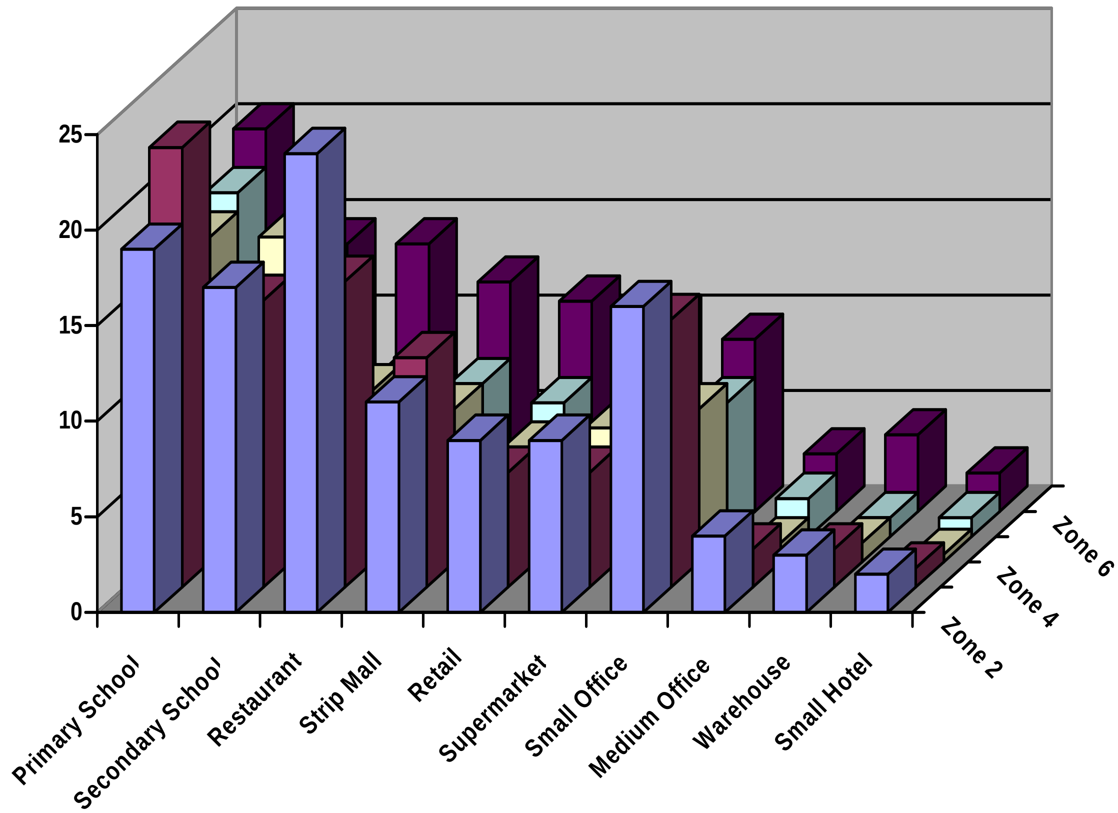


Table 5.3.11b: Lifetime Energy Savings – Cost Basis

	Primary School	Restaurant	Retail	Small Office	Warehouse
Zone 2	$580,851	$53,835	$89,510	$35,803	$73,579
Zone 3	$708,143	$36,216	$58,879	$31,088	$38,496
Zone 4	$531,727	$21,680	$59,169	$18,352	$29,064
Zone 5	$560,103	$19,043	$71,368	$16,755	$28,935
Zone 6	$616,752	$32,390	$116,675	$21,650	$83,319
	Secondary School	Strip Mall	Supermarket	Medium Office	Small Hotel
Zone 2	$1,454,406	$102,804	$159,781	$85,108	$31,331
Zone 3	$1,318,566	$109,387	$1054,006	$51,650	$19,392
Zone 4	$961,400	$80,624	$141,714	$32,870	$7,336
Zone 5	$1,081,580	$76,368	$178,322	$47,679	$13,156
Zone 6	$1,262,887	$121,092	$195,056	$64,599	$25,584

6.0 ENERGY AND ENVIRONMENTAL IMPACT

6.1 Energy Impacts

6.1.1.1 Life Cycle Energy

The entire insulation life cycle consists of cradle to end-of-life processes for making, processing, transporting, installing, using and finally disposing of insulation at end-of-life. Since polyiso is generally recognized as effective and durable, and is the most common type of insulation used in commercial roofing, each phase or process of the polyiso insulation life cycle was analyzed to determine energy consumption. These processes included: 1) Chemical Raw Materials Manufacturing; 2) Facer Manufacturing; 3) Plastic Packaging Manufacturing; 4) Polyiso Raw Materials Transportation; 5) Polyiso Manufacturing; 6) Polyiso Product Transportation; 7) Installation; 8) Use and 9) End-of-life.

Processes 1 to 7 and 9 consume energy associated with essentially making, installing and disposing of polyiso. Energy consumed in these life cycle processes is commonly called the embodied energy of a product. Standard life cycle inventory methods described in ISO 14040[7] were used to estimate the energy for a specified quantity of insulation.

Based on a previous study[8] for selected cities, Table 6.1.1 below summarizes the embodied energy for polyiso insulation installed on a one-story retail building roof.

Table 6.1.1: Estimated Embodied Energy for Polyiso Insulation based on Installation on a One-Story 125,000 ft^2 Commercial Building Roof

Building Location	R15 to R25.4 (2.2 inches extra)		R15 to R30.5 (3.0 inches extra)	
	MJ/kg	MJ/BF	MJ/kg	MJ/BF
Chicago	79.0	6.9	82.6	6.8
Los Angeles	83.6	7.3	87.2	7.2
Houston	78.7	6.9	82.3	6.8

Notes: MJ = Megajoules, based on installed kg or BF = Boardfoot (1 ft^2 insulation 1 inch thick)

Thus, a complete and balanced picture of the insulation life cycle must subtract the additional embodied energy associated with the insulation from the energy savings, thereby yielding a net energy savings. It is also worth emphasizing that the embodied energy, i.e. the energy used to make, install and transport the polyiso insulation product is negligible compared to the energy saved in using the insulation over its lifetime. These aspects are discussed in detail under Impact Assessment, section 8.

[7] ISO 14040:2006 – Environmental Management, Life Cycle Assessment, Principles & Framework

[8] Phelan, J and G. Pavlovich, Energy & Environmental Benefits of Insulating Commercial Buildings with Polyiso, Center for the Polyurethanes Industry 2008 Proceedings

Embodied energy also includes the total life cycle from energy sources used throughout steps 1 to 7 and 9. This total life cycle from energy sources such as electric power, natural gas, diesel fuel, etc. is often referred to as “source” energy, as discussed below.

6.1.2 Source Energy Versus Site Energy

When estimating energy consumption, it is not sufficient to measure the energy metered at a building or production unit or consumed as transportation fuel. These measurements only include the energy actually measured at a specific location or site, such as a building electricity meter, an orifice meter on a natural gas feed line into a manufacturing unit, or a fuel gauge on a truck using diesel fuel. Actual energy consumption includes the life cycle or “source energy” needed to produce the energy delivered to a specific location or user (i.e. site).

“Source energy” can be thought of as the “energy to make the energy”. Using electrical energy as an example, 3.24 kilowatt hour (kWh) of electricity are needed to generate 1 kWh of electricity delivered to a consumer (based on an average U.S. electric power grid mix). The 3.24 kWh is normally called the “source energy” and the 1 kWh is really the “site energy”. The total source energy of 3.24 kWh per kWh may also be thought of as the life cycle “cradle-to-plug” energy.

In other words, for each kWh of electricity measured at the meter of the building, 3.24 kWh is needed to supply this energy. This energy is required to extract coal, natural gas crude from the earth, refine these fuels as needed, deliver the fuels to the power plant, generate steam in the boilers to drive the turbines and generators, deliver the electricity throughout the grid with transformers, all of which includes efficiency and line losses.

Similarly, based on an average U.S. natural gas mix, 1.156 Mega joules (MJ) of “source energy” are needed for one MJ of natural gas “site energy” delivered to a consumer. The same concept applies to all sources of energy used in embodied energy calculations as well as energy consumed to heat, cool and light a building. Using transportation by a diesel-fueled truck as an example, the energy from combustion (lower heating value) is 128,450 Btu/gallon. However, the total energy associated with the diesel fuel life cycle must include the “pre-combustion energy” (energy for extracting, transporting, refining crude etc), which is 23 percent greater than the combustion energy. Thus, it takes 1.23 MJ of energy to produce one MJ of diesel fuel.

Table 6.1.2(a) shows the source energy factors used to adjust the metered building electricity and natural gas consumption from site energy to source energy in Simulation Results, Section 5. The “metered” values estimated from Whole Building Energy Analysis are multiplied by these source energy factors to obtain the “source” or “total life cycle” energy.

Table 6.1.2(a): Source-Site Ratios for Electricity and Natural Gas[9]

Type of Energy	Source-Site Ratio
US Electric Power Grid Mix (2002)	3.24
US Thermal Energy from Natural Gas (2002)	1.156

Note: Data from GaBi Life Cycle Engineering database (2006), lower heating value

These factors are relatively consistent with the factors published by the Environmental Protection Agency (EPA) on their Energy Star website[10], as the US EPA site-source ratio for electricity is 3.34 (3 percent greater than the electricity factor used in this report) and for natural gas the factor is 1.047 (9 percent lower than the natural gas factor used in this report).

The factors in Table 6.1.2(a) were chosen for this study since the authors are familiar with the rigorous life cycle methodology upon which the calculations are based. The methodology considers, for example: 1) The entire "cradle-to-plug" (electricity) or "cradle-to-valve" (natural gas) life cycle, i.e., the data considers the entire supply chain of fuels from exploration to extraction, processing and transport; 2) Life cycle inventory methods in conformance with ISO 14040 and 14044; 3) Cut-off rule coverage for unit processes includes 95 percent of mass and energy for input/output flows and 98% for environmental, with coverage for exploration (crude oil etc) at 90 percent of mass and energy and 95 percent for environmental aspects; 4) Grid mix data based on national US statistics, and power plant models according to US combustion technology mix; 5) All relevant transport processes used in the energy production are included; 6) US-specific boundary conditions and sources for a base year of 2002 (within the 2001 to 2005 averaged range used as the base years for the EPA data).

Table 6.1.2(b) shows source-site energy ratios for common fuels used in the embodied energy calculations, where diesel is used for truck and rail transportation, and lifting equipment such as cranes, and propane is used for fork-lift trucks.

Table 6.1.2(b): Source-Site Ratios for Some Petroleum Refinery Fuels[11]

Type of Energy	Source-Site Ratio
US Diesel from Refinery	1.23
US Propane from Refinery	1.24

Note: Data from GaBi Life Cycle Engineering database (2006), lower heating value

These factors were used, as the EPA site-source ratios for diesel and propane (both 1.01) do not appear to account for the pre-combustion energy required to extract, refine and transport these fuels. Also, similar to the justification provided for the electricity and natural gas, the factors in Table 6.1.2(b) were chosen for this study since the authors are familiar with the rigorous life cycle methodology upon which the calculations are based (ISO 14040/14044 methodology, comprehensive life cycle approach, etc).

[9] GaBi 4 Life Cycle Engineering Software and Database (2008), PE International
[10] http://www.energystar.gov
[11] GaBi 4 Life Cycle Engineering Software and Database (2008), PE International

6.2 Global Warming Potential (GWP) Impacts

6.2.1 Life Cycle GWP Emissions

Similar to embodied energy calculations, GWP associated with making, installing and disposing of polyiso was based on a "cradle to end-of-life" analysis that includes all GWP associated with the final polyiso product. The GWP generated during these phases also included GWP associated with pre-combustion and combustion of fuels such as natural gas, diesel, propane, etc. GWP is normally measured in kg CO_2-equivalents (kg CO_2-eq.), as different types of emissions (e.g. methane, nitrous oxides) have a greater global warming impact than CO_2 and must be adjusted to express the emissions on a common basis.

The TRACI model from US EPA was used to estimate the GWP emissions to air from all of the processes used to make polyiso insulation, i.e. processes 1 to 7 and 9 noted in Section 6.1.1. Standard life cycle inventory methods described in ISO 14040 were used to estimate the GWP for a specified quantity of insulation.

Based on a previous study for selected cities, Table 6.1.1 below summarizes the GWP associated with all of the polyiso insulation life cycle phases except for the use phase, when polyiso is installed on a one-story retail building roof.

Table 6.1.1: Estimated GWP Emissions from Increased Polyiso Insulation on a One-Story 125,000 ft^2 Commercial Building Roof

Building Location	R15 to R25.4 (2.2 inches extra)		R15 to R30.5 (3.0 inches extra)	
	kg CO_2-eq./kg	kg CO_2-eq./BF	kg CO_2-eq./kg	kg CO_2-eq./BF
Chicago	4.96	0.43	5.18	0.43
Los Angeles	5.35	0.47	5.58	0.46
Houston	4.99	0.43	5.21	0.43

Notes: kg CO_2-equivalents = kg CO_2-eq., BF = Boardfoot or 1 ft^2 insulation 1 inch thick

Thus, a complete and balanced picture of the insulation life cycle must subtract the additional GWP emissions generated from making, installing and transporting the insulation from the GWP emissions prevented in the use phase, thereby yielding a net GWP emissions prevented. It is also worth emphasizing that the GWP emissions generated to make, install, transport etc the polyiso insulation product is negligible compared to GWP prevented when using the insulation over its lifetime. These aspects are discussed in detail under Impact Assessment, Section 8.

6.2.2 GWP Life Cycle Emissions Factors

When estimating GWP emissions, it is not always sufficient to measure the GWP associated with combustion at a building, production unit or from internal combustion engines used for transportation. Actual GWP emissions generated include the life cycle GWP associated with life cycle processes for producing electricity, natural gas and other diesel fuels (extraction, refining, distribution, etc.) as well as GWP emissions generated from combustion of fuels.

Table 6.2.2 shows the GWP life cycle factors used to estimate kg CO_2-equivalents associated with electricity and natural gas consumption for the various building types/locations shown in the Simulation Results, Section 5. The metered energy values estimated from Whole Building Energy Analysis are multiplied by these life cycle GWP emissions factors to obtain the "total life cycle" kg CO_2-equivalents associated with energy use at the buildings.

Table 6.2.2: Life Cycle GWP Emissions Factors for Electricity and Natural Gas[12]

Type of Energy	/MJ kg CO_2-eq./MJ
US Electric Power Grid Mix (2002)	0.223
US Thermal Energy from Natural Gas (2002)	0.0749

Note: Data from GaBi Life Cycle Engineering database (2006), lower heating value, MJ = Megajoules

These factors differ considerably from the EPA AP42 factors published in the Energy Plus simulation model guidance[13], as the EPA factor for electricity is 0.1691 kg CO_2-eq./MJ (24 percent lower than the electricity factor used in this report) and for natural gas the factor is 0.0503 kg CO_2-eq./MJ (33 percent lower than the natural gas factor used in this report). It appears that these AP42 factors are based mainly on combustion, as it is not clear that GWP emissions associated with life cycle CO_2-eq. are considered.

Therefore, the factors in Table 6.2.2 were chosen for this study since the authors are familiar with the rigorous life cycle methodology upon which the calculations are based, as described in Section 6.1.2 (ISO 14040/14044 methodology, comprehensive life cycle approach etc).

Similarly, calculations made for common fuels (diesel for truck and rail transportation, propane for fork-lifts, etc.) in life cycle phases for insulation manufacture, installation, transportation, etc. also include the GWP emissions associated with both the pre-combustion and combustion stages.

[12] GaBi 4 Life Cycle Engineering Software and Database (2008), PE International
[13] U.S. Department of Energy (2007), EnergyPlus Engineering Reference

6.3 Other Environmental Aspects

Since the scope of this study is energy and cost reductions associated with increased levels of insulation, other environmental benefits have not been quantified with the exception of more commonly discussed GWP emissions.

For example, for every kWh (3.6 Megajoules) of electricity reduced at a building, there is a corresponding 0.803 kg CO_2-eq./kWh (0.223 kg CO_2-eq./MJ) reduction based on the average U.S. power grid (see Section 6.1.2). In this study, GWP reductions in private and public sector buildings over 30 years total 76,904,634 thousand metric tons of kg CO_2-eq., or approximately 77 billion metric tons of kg CO_2-eq. (equivalent to 76,904,634,000,000 or almost 77 trillion kg, i.e. 170,000,000,000,000 or 170 trillion pounds of kg CO_2-eq.). Since a significant portion of the kg CO_2-eq. reduction is associated with electricity generation at power plants, it is apparent from analogy that other environmental aspects associated with electric power generation are also significantly reduced.

Besides the global warming impact measured in kg CO_2-eq. (includes green house gases such as methane and nitrous oxide), additional environmental aspects associated with burning fossil/other fuels and electric power plants include, but are not limited to:

- Nitrogen oxides (NO_x) emissions, ozone
- Sulfur dioxide (SO_x) emissions
- Mercury, other heavy metals and pollutants from burning coal
- Coal mining including strip mining
- Particulate matter emissions
- Water usage
- Wastewater discharges
- Solid waste

The EPA publishes a regularly updated inventory of environmental attributes related to air emissions (greenhouse gases, criteria pollutants) of electric power systems on their "eGRID" webpage[15]. The data provide an indication of the magnitude of such emissions associated with electric power generation.

Since quantification of these other environmental aspects is beyond the scope of this report, these issues are mentioned to promote awareness that reduction in building energy use from increased insulation has benefits far more extensive than energy and greenhouse gas reductions. Quantification of these other environmental benefits will be the subject of future studies by the authors of this report.

[15] www.epa.gov/cleanenergy/energy-resources/egrid

7.0 COMMERCIAL BUILDING MARKET ANALYSIS

The Energy Information Administration's (EIA) Commercial Building Energy Consumption Survey (CBECS) is generally recognized as providing the most complete data regarding existing commercial buildings. The CBECS Survey is essential for relating the extensive and rigorous energy modeling results performed in this study to commercial building market data. Therefore, data from the most recent available survey, CBECS 2003, were utilized as the basis for the impact assessment (Section 8) of the energy modeling results. The information from the report entitled "DOE Commercial Building Benchmark Models for Energy Simulation" also was very useful in linking the modeling results to the market data.

7.1 CBECS 2003

The CBECS is a national-level sample quadrennial survey of buildings greater than 1,000 square feet in size that devote more than 50 percent of their floor space to commercial activity. The CBECS 2003 reports that the commercial market comprises more than 71.6 billion square feet of floor space in nearly 4.9 million buildings. In addition, it reports that these commercial buildings consume more than 6,500 trillion Btu of energy, with electricity accounting for 55 percent and natural gas 32 percent. Space heating, cooling and ventilation consume more than half of this energy.

7.2 Building Type and Climate Zone Weighting Methodologies

7.2.1 Roof Area Correlation and Weighting by Building Type

As stated in Section 3.1, Model Building Types, the ten DOE benchmark prototype models listed in Table 3.1 are believed to adequately represent the energy performance of buildings with low-slope roofs. This conclusion was established based on CBECS 2003 data and the use of a mapping methodology developed by Crawley and his colleagues.[16] This methodology was used to connect the CBECS data, which lists floor area by Principal Building Type (PBT) with the roof area of the DOE benchmark models. The commercial building roofing area was calculated using building floor space and numbers of floors. Table 7.2.1a provides a detailed analysis of the commercial building market by Principal Building Activity (PBA) as well as a correlation to roof area. The selected ten prototypes for this study account for nearly 54 percent and 60 percent of the total floor and roof area, respectively. The individual percentages are prorated in order to calculate the distribution of floor and roof area among the ten prototypes. These are summarized in Table 7.2.1b.

[16] " DOE Commercial Building Benchmark Models for Energy Simulation", NREL: Michael Deru, Brent Griffith, Kyle Benne, Paul Torcellini; PNNL: Mark Halversion, Dave Winiarski, Bing Liu; LBNL: Joe Huang and Mehry Yazdanian; DOE: Drury Crawley, December, 2008

Table 7.2.1a: Commercial Building Market Analysis

CBECS[1]		DOE Benchmark Models[2,3]				Roof Area Distribution[4]	
PBA	*Floor Area MM Ft²*	*Prototypes*	*Distri-bution*	*Floor Area MM Ft²*	*No. of Floors*	*Roof Area MM Ft²*	*% Roof Area*
Office	12,208	Large	0.39	4,761	12	397	0.7%
		1. Medium	0.41	5,005	3	1,668	3.1%
		2. Small	0.20	2,442	1	2,442	4.6%
Education	9,874	3. Primary	0.55	5,431	1	5,431	10.2%
		4. Secondary	0.45	4,443	2	2,222	4.2%
Lodging	5,096	5. Small	0.36	1,835	4	459	0.9%
		Large	0.64	3,261	6	544	1.0%
Warehouse	10,078	6. Warehouse	1.0	10,078	1	10,078	18.9%
Health Care	3,163	Hospital	0.6	1,898	5	380	0.7%
		Outpatient	0.4	1,265	2	633	1.2%
Retail	4,317	7. Retail	1.0	4,317	1	4,317	8.1%
Malls	6,875	Mall	0.66	4,538	2	2,269	4.3%
		8. Strip Mall	0.34	2,338	1	2,338	4.4%
Food Sales	1,255	9. Supermarket	1.0	1,255	1	1,255	2.4%
Food Service	1,654	Fast Food	0.18	298	1	298	0.6%
		10. Restaurant	0.82	1,356	1	1,356	2.5%
All Other	17,138	All Other	1.0	17,138	1	17,138	32.2
Total	**71,658**			**71,658**		**53,222**	
		Ten Model Totals				**31,566**	**59.3%**

Table references and notes:

(1) "2003 Commercial Buildings Energy Consumption Survey", Energy Information Administration

(2) " DOE Commercial Building Benchmark Models for Energy Simulation", NREL: Michael Deru, Brent Griffith, Kyle Benne, Paul Torcellini; PNNL: Mark Halversion, Dave Winiarski, Bing Liu; LBNL: Joe Huang and Mehry Yazdanian; DOE: Drury Crawley, December, 2008

(3) Mall: 2 floors; Public Assembly, Public Order and Safety, Religious Worship, Other and Vacant: 1 floor

(4) Roofing (MM SF) = Benchmark model floor area (MM SF)/# of Floors

Table 7.2.1b: Weighting Factors for Model Building Type

	Building Type Distribution	
	By Floor Area	***By Roof Area***
Retail	**0.112**	**0.137**
Strip Mall	**0.061**	**0.074**
Warehouse	**0.262**	**0.304**
Small Office	**0.063**	**0.077**
Medium Office	**0.130**	**0.053**
Restaurant	**0.035**	**0.043**
Supermarket	**0.033**	**0.040**
Primary School	**0.141**	**0.172**
Secondary School	**0.115**	**0.085**
Small Hotel	**0.048**	**0.015**
Total	**1.0**	**1.0**

7.2.2 Climate Zone Weighting Factors

The key assumption in the distribution of the benchmark models by climate zones is that it is the same for both existing and new buildings. The new construction benchmark building weighting factors, the allocation of new construction value by type of construction and the climate zone and square foot cost model (developed by Crawley et al, 2008) are utilized to generate the "New Construction BB Model Climate Zone Distribution".

The 13 locations included in this study represent every Climate Zone and Sub-zone in the country with the exceptions of 1A (Miami), 7 (northern continental U.S.) and 8 (northern Alaska). These omitted climate zones account for 1.6 percent, 0.6 percent and 0.5% of the total floor area, respectively. Considering these are a minor portion of the overall weighting, they were combined with the results of the nearest climate zone. In other words, the 1.6 percent for 1A is combined with Climate Zone 2 and the 0.6 percent for 7 and the 0.5 percent for 8 are combined with Climate Zone 6. Considering these are the three most extreme climates, the energy savings results can be assumed to be at least as high as the modeled location. The weightings by climate zone used for the impact assessment are compiled in Table 7.2.2.

Table 7.2.2: Distribution of Existing Buildings by Climate Zone for Impact Assessment

Zone	1, 2	3	4	5	6, 7, 8
Weighting Factors	0.140	0.252	0.245	0.264	0.099

7.3 The Commercial Roof Replacement Market

Roofing industry consensus data indicates that the 2006 North American Low-Slope Roofing market was four billion square feet. This market size is divided between new construction and re-roofing as one and three billion square feet, respectively. [9] It is reasonable to assume that a portion of this roof replacement market has little or no potential for insulation requirements.

From the perspective of the CBECS data on roofing materials, the conclusion can be drawn that approximately 65 percent of the 72 billion square feet of existing floor area (or just less than 50 billion square feet) is in low-slope roof buildings with insulation above the deck. Assuming that this roof area requires replacement approximately every twenty years, and a similar amount is replaced each year, then an estimated two to two and one-half billion square feet are replaced annually.

Finally, the Polyisocyanurate Insulation Manufacturers Association (PIMA) compiles member production data that estimates approximately four and one-half billion board feet of Polyiso produced annually. It is common knowledge in the industry that on average the vast majority of this board footage goes into re-roof applications. Concluding that this amounts to about two-thirds of the market or three billion board feet and assuming an average thickness of two inches means that Polyiso is used in roughly one and one-half billion square feet of re-roofing jobs annually. The National Roofing Contractors Association's (NRCA) market survey for 2006-2007 concludes that Polyiso has a 66 percent share of insulation used in low-slope re-roofing projects.[10] Thus, considering the remainder of the insulation types used, 1.5 billion square feet /0.66 = 2.3 billion square feet. This also supports a conclusion of the size of the annual insulated low-slope re-roofing market in the neighborhood of 2.2 to 2.5 billion square feet.

Therefore, for use in the impact assessment (Section 8) portion of this study, the re-roof market size of 2.25 billion square feet is used.

7.4 Private Versus Public Existing Commercial Buildings

One of the intents of conducting this study is to provide a resource for substantiating evidence to support potential tax incentive legislation. Therefore, an effort was made to separate private and public buildings in the impact assessment. Once again, the exercise of accurately portraying the very complex and uncontrollable variable driven nature of energy consumption in buildings can be a monumental task. However, the wide energy performance variety of the selected ten prototype models is believed to highly aid in this endeavor. Table 7.4 summarizes the weightings utilized for the breakdown of private versus public buildings in the impact assessment. Note that the overall distribution of existing floor area between private and public is 72 percent and 28 percent, respectively.

Table 7.4: Distribution of Private and Public Floor Area in Existing Buildings

	Floor Area Distribution	
	Private	***Public***
Retail	**1.0**	**0**
Strip Mall	**1.0**	**0**
Warehouse	**0.9**	**0.1**
Small Office	**0.9**	**0.1**
Medium Office	**0.9**	**0.1**
Restaurant	**1.0**	**0**
Supermarket	**1.0**	**0**
Primary School	**0.1**	**0.9**
Secondary School	**0.1**	**0.9**
Small Hotel	**0.9**	**0.1**
Aggregate Floor Area Distribution*	**0.72**	**0.28**

* Using the floor area weighting factors of Table 7.2.1b

8.0 IMPACT ASSESSMENT

As explained in Section 7.2, the basis for the initial impact assessment is two and one-quarter billion square feet of re-roofing (two and three-quarter billion square feet of floor area), representing the entire average annual square footage potential market for the installation of an energy efficient roof. However, a side by side comparison of results as is done in Section 5.3.11 could provide a different conclusion of the potential market. Specifically, Figures 5.3.11 a and b illustrate quite clearly that the benefits achieved with the first seven listed building types in all climate zones could easily motivate a building owner to install an energy efficient roof. On the other hand, based on these results, owners of the other three building types (i.e. Small Hotel, Warehouse and Medium Office) could conclude otherwise. Therefore, in order to provide the reader with separate perspectives, the impact assessments conducted below are based on two market potential scenarios as described in Table 8.0.

Table 8.0: Basis Scenarios for Impact Assessment

	Description	Building Types	Roof Area billion ft^2	Floor Area billion ft^2
Scenario 1	Insulated Re-roof Market	All	2.25	2.75
Scenario 2	Limited portion of Re-roof Market: Savings >4 kBtu/ ft^2	All except: Small Hotel, Warehouse & Medium Office	1.53	1.54

8.1 Validation of Modeling Results

The results of the state-of-the art EnergyPlus simulation modeling performed in this study correlate closely with results of US commercial building energy consumption published by the EIA in their CBECS 2003 survey.[17] Using energy intensity as a parameter, Table 8.1.1 shows that the commercial building energy consumption reported for all buildings in the U.S. in 2003 is very similar to the modeling results of this study. As explained in Section 7.2, the basis for the initial impact assessment is two and one-quarter billion square feet of re-roofing (two and three-quarter billion square feet of floor area). In Section 8.2.1.1

This close correlation indicates how realistic modeling results can be achieved applying the rigorous simulation models for Whole Building Energy Analysis developed by the DOE, and also demonstrates the validity of the results used for this impact assessment.

Table 8.1.1: Energy Intensity - CBECS 2003 and Modeling Results

Data Source	Floor Area	Annual Energy Consumed	Energy Intensity
	billion ft^2	billion Btu	kBtu/ft^2
CBECS 2003	**71.6**	**6,500,000**	**90.8**
Modeling Results	**2.75**	**230,113**	**83.7**

[17] www.eia.doe.goc/emeu/cbecs/cbecs2003

8.2 Annual Energy Savings – Site

8.2.1 Scenario 1 - All Building Types (2.75 billion ft^2 of floor area)

Table 8.2.1 shows the site (i.e. metered) energy savings for additional insulation levels by both private and public sector for all buildings modeled in this study. The percent energy savings are based on the ratio of the annual energy savings due to increased insulation versus the total annual building energy consumption.

The annual site energy savings realized nationally under Scenario 1 are as follows:

5.7%
13.1 trillion Btu
4.8 kBtu/ft^2

8.2.1.1 Private Sector

Significant points of interest regarding site energy savings under Scenario 1 from the private sector:

- **6.4 trillion Btu of energy saved or just under half of national savings.**
    - **Majority from Zones 3 & 4 (3.7 trillion Btu).**
- **3.8% savings.**
    - **Highest in Zones 6, 7 & 8 (5.3%)**
    - **Lowest in Zone 3 (2.6%)**
- **Intensity savings of 3.3 kBtu/ft^2.**
    - **Range in Zones between 1.9 kBtu/ft^2 (3) and 5.4 kBtu/ft^2 (6, 7, & 8).**

8.2.1.2 Public Sector

Significant points of interest regarding site energy savings under Scenario 1 from the public sector:

- **6.7 trillion Btu of energy saved or over half of national savings.**
    - **Majority from Zones 4 & 5 (3.8 trillion Btu).**
- **10.6% savings.**
    - **Highest in Zone 4 (11.4%)**
    - **Lowest in Zone 3 (9.1%)**
- **Intensity savings of 8.7 kBtu/ft^2.**
    - **Range in Zones between 6.5 kBtu/ft^2 (3) and 10.9 kBtu/ft^2 (6, 7, & 8).**

Table 8.2.1: Annual Energy Savings Scenario 1 - All Building Types

Private Sector

	Floor Area	Energy Savings Site	
	MM ft²	*%*	*kBTU/ft²*
Zone 1, 2	277	3.2%	2.54
Zone 3	498	2.6%	1.92
Zone 4	484	3.7%	3.07
Zone 5	522	4.6%	4.23
Zone 6, 7, 8	196	5.3%	5.44
Total U.S.	1,976	3.8%	3.25

Public Sector

	Floor Area	Energy Savings Site	
	MM ft²	*%*	*kBTU/ft²*
Zone 1, 2	108	10.1%	7.87
Zone 3	195	9.1%	6.52
Zone 4	189	11.4%	8.98
Zone 5	204	11.3%	10.10
Zone 6, 7, 8	76	10.5%	10.87
Total U.S.	773	10.6%	8.69

Total

	Floor Area	Energy Savings Site	
	MM ft²	*%*	*kBTU/ft²*
Zone 1, 2	385	5.1%	4.04
Zone 3	693	4.4%	3.21
Zone 4	673	5.8%	4.73
Zone 5	726	6.5%	5.88
Zone 6, 7, 8	272	6.7%	6.97
Total U.S.	2,748	5.7%	4.78

8.2.2 Scenario 2 – 7 Building Types (1.54 billion ft^2 Floor area)

Table 8.2.2 shows the site (i.e. metered) energy savings for additional insulation levels by both private and public sector for all buildings modeled in this study. The percent energy savings are based on the ratio of the annual energy savings due to increased insulation versus the total annual building energy consumption.

The annual site energy savings realized nationally under Scenario 2 are as follows:

6.5%
11.8 trillion Btu
7.7 kBtu/ft^2

8.2.2.1 Private Sector

Significant points of interest regarding site energy savings under Scenario 2 from the private sector:

- **5.2 trillion Btu of energy saved or 44% of national savings.**
  - **Majority from Zones 4 & 5 (3.0 trillion Btu).**
- **4.2% energy savings.**
  - **Highest in Zones 6, 7 & 8 (5.6%)**
  - **Lowest in Zone 3 (3.0%)**
- **Intensity savings of 5.9 kBtu/ft^2.**
  - **Range in Zones between 3.6 kBtu/ft^2 (3) and 9.4 kBtu/ft^2 (6, 7, & 8).**

8.2.2.2 Public Sector

Significant points of interest regarding site energy savings under Scenario 2 from the public sector:

- **6.6 trillion Btu of energy saved or over half of national savings.**
  - **Majority from Zones 4 & 5 (3.7 trillion Btu).**
- **11.2% energy savings.**
  - **Highest in Zone 4 (12.1%).**
  - **Lowest in Zone 3 (9.7%).**
- **Intensity savings of 10.1 kBtu/ft^2.**
  - **Range in Zones between 7.6 kBtu/ft^2 (3) and 10.5 kBtu/ft^2 (6, 7, & 8).**

Table 8.2.1: Annual Energy Savings Scenario 2 - 7 Building Types

Private Sector

	Floor Area	Energy Savings Site	
	MM ft²	*%*	*kBTU/ft²*
Zone 1, 2	124	3.3%	4.43
Zone 3	224	3.0%	3.55
Zone 4	218	4.1%	5.64
Zone 5	235	5.1%	7.68
Zone 6, 7, 8	88	5.6%	9.37
Total U.S.	889	4.2%	5.85

Public Sector

	Floor Area	Energy Savings Site	
	MM ft²	*%*	*kBTU/ft²*
Zone 1, 2	91	10.7%	9.14
Zone 3	164	9.7%	7.62
Zone 4	160	12.1%	10.47
Zone 5	172	12.0%	11.71
Zone 6, 7, 8	65	11.0%	12.47
Total U.S.	652	11.2%	10.09

Total

	Floor Area	Energy Savings Site	
	MM ft²	*%*	*kBTU/ft²*
Zone 1, 2	216	5.6%	6.43
Zone 3	388	5.1%	5.27
Zone 4	377	6.7%	7.68
Zone 5	407	7.3%	9.39
Zone 6, 7, 8	153	7.3%	10.68
Total U.S.	1,541	6.5%	7.65

8.2.3 Annual Energy Savings Compared to US Total

The impact of adding additional roofing insulation on total US commercial building energy consumption can be seen in Table 8.2.3 below. If insulation were added to all buildings (2.75 billion ft^2 of floor area or Scenario 1) in this study, annual energy savings total 13.1 trillion Btu. This savings is divided by 6,500 trillion Btu, which is the total energy consumed at all US commercial buildings, to obtain the 0.2 percent impact.

Adding additional roof insulation to small hotels, medium offices and warehouses may not be as financially attractive compared to other types of buildings, as hotels and offices are typically multi-storied (i.e. roof insulation has less energy savings impact relative to total square footage) and warehouses are generally not conditioned to comfortable temperatures since their function is storage of goods. However, even if small hotels, medium offices and warehouses were not insulated, the significant impact of additional insulation compared to the U.S. total energy consumption remains about the same. As shown in Scenario 2 below, excluding these buildings means increasing roofing insulation on just 2 percent of existing commercial buildings based on floor area (1.54 billion ft^2/71.6 billion ft^2), still resulting in approximately 0.2 percent energy savings versus the entire US commercial energy consumption.

Table 8.2.3: Impact of More Insulation on Annual US Commercial Building Energy

Scenario	Portion of US Total Commercial Building Floor Area	Floor Area (billion ft^2)	Annual Energy Saved (billion Btu)	Impact: Energy Saved vs. US Commercial Total
1	3.8%	2.75	13,128	0.20 %
2	2.1%	1.54	11,781	0.18 %

8.2.4 Net Cumulative Energy Savings

As discussed in section 6.2.1, when estimating energy consumption, it is not sufficient to measure the energy metered at a building. These measurements only include the energy actually measured at a specific building site, whereas actual energy consumption includes the life cycle or “source energy” needed to produce the energy delivered to a specific site.

Moreover, it is also important from a life cycle perspective to consider the total life cycle energy of materials installed to save energy on the building. Thus, one must estimate the so called "embodied energy" that goes into making, installing, transporting etc the insulation, and then subtract this embodied energy from the energy savings to obtain a net energy savings, i.e.

Net Energy Saved equals Energy Saved at Buildings minus Embodied Energy of Installed Insulation

For the case of all buildings insulated in this study, for example, the source energy saved over 30 years is 888 trillion Btu, and for the subset excluding warehouses, small hotels and medium offices the 30 year source energy saved is 799 trillion Btu. Based on embodied energy estimates for polyiso insulation discussed in section 6.1.1, a conservative (higher) value for the embodied energy of 90 Megajoules/kg or approximately 7.5 Megajoules/BF (7.1 kBtu/BF) is assumed.

Since 2.25 billion ft^2 of roof area (Scenario 1) and 1.53 billion ft^2 of roof area (Scenario 2) are insulated, the Boardfeet (BF) are estimated using an of average insulation thicknesses modeled in this study, i.e. 2.6 inches, which yields BF values ranging from 5.85 to 3.98 billion BF, respectively. These values are multiplied by the embodied energy factor of 7.1 kBtu/BF to estimate the embodied energy of both scenarios.

These results are shown in Table 8.2.4, where the building energy saved far exceeds the embodied energy. In fact, the embodied energy ranges from only 3.6 percent to 4.7 percent of the energy saved over the 30 years of insulation use. In other words, the incremental energy saved by adding additional insulation is 20 to 28 times greater than the energy that went into making, installing, transporting etc insulation. Thus, from a total life cycle energy perspective, insulation pays energy dividends many times over compared to the one time energy used to make it.

Table 8.2.4: Net Cumulative Energy Saved and Embodied Energy Impact

Scenario	Roof Area (billion ft^2)	Energy Saved at Buildings (trillion Btu)	Embodied Energy of Insulation (trillion Btu)	Net Cumulative Energy Saved (trillion Btu)	Ratio: Embodied to Saved Energy	Ratio: Energy Saved to Embodied Energy
1	2.25	888	41.5	846	4.7%	20
2	1.53	799	28.2	787	3.6%	28

8.3 First Year Energy Cost Savings

8.3.1 Scenario 1 - All Building Types (2.75 billion ft^2 of floor area)

Table 8.3.1 shows the energy cost savings for additional insulation levels by both private and public sector for all buildings modeled in this study. The percent energy cost savings are based on the ratio of the first year utility cost savings due to increased insulation versus the total first year building utility costs.

The first year costs savings realized nationally under Scenario 1 are as follows:

5.1%
$217,000,000
$0.079/$ft^2$

8.3.1.1 Private Sector

Significant points of interest regarding energy cost savings under Scenario 1 from the private sector:

- **$107,100,000 of energy cost saving or nearly half of national savings.**
  - **$20-$29,000,000 per Zone.**
- **3.5% energy cost savings.**
  - **Highest in Zones 6, 7 & 8 (4.9%).**
  - **Lowest in Zone 3 (2.9%).**
- **Intensity cost savings of $0.054/$ft^2$.**
  - **Range in Zones between $0.042/$ft^2$ (4) and $0.076/$ft^2$ (1, 2).**

8.3.1.2 Public Sector

Significant points of interest regarding energy cost savings under Scenario 2 from the public sector:

- **$109,900,000 of energy cost saving or just over half of national savings.**
  - **A wide range of $11,400,000-$32,300,000 per Zone.**
- **8.9% energy cost savings.**
  - **Highest in Zones 5 (10.2%).**
  - **Lowest in Zone 1, 2 (7.6%).**
- **Intensity cost savings of $0.142/$ft^2$.**
  - **Range in Zones between $0.121/$ft^2$ (4) and $0.166/$ft^2$ (3).**

Table 8.3.1: Annual Energy Cost Savings Scenario 1 - All Building Types

Private Sector

	Floor Area	Cost Savings			
		First Year			30 Years
	MM ft^2	*%*	*MM $*	*\$/*ft^2	*\$/*ft^2
Zone 1, 2	277	3.6%	$21.1	$0.076	$3.14
Zone 3	498	2.9%	$28.6	$0.057	$2.37
Zone 4	484	3.5%	$20.4	$0.042	$1.78
Zone 5	522	3.9%	$23.2	$0.044	$1.90
Zone 6, 7, 8	196	4.9%	$21.1	$0.071	$3.01
Total U.S.	1,976	3.5%	$107.1	$0.054	$2.27

Public Sector

	Floor Area	Cost Savings			
		First Year			30 Years
	MM ft^2	*%*	*MM $*	*\$/*ft^2	*\$/*ft^2
Zone 1, 2	108	7.6%	$16.9	$0.156	$6.46
Zone 3	195	8.0%	$32.3	$0.166	$6.88
Zone 4	189	9.9%	$22.9	$0.121	$5.09
Zone 5	204	10.2%	$26.5	$0.130	$5.48
Zone 6, 7, 8	76	9.8%	$11.4	$0.149	$6.28
Total U.S.	773	8.9%	$109.9	$0.142	$5.96

Total

	Floor Area	Cost Savings			
		First Year			30 Years
	MM ft^2	*%*	*MM $*	*\$/*ft^2	*\$/*ft^2
Zone 1, 2	385	4.7%	38.0	$0.099	$4.07
Zone 3	693	4.4%	60.9	$0.088	$3.64
Zone 4	673	5.3%	43.3	$0.064	$2.71
Zone 5	726	5.8%	49.7	$0.068	$2.91
Zone 6, 7, 8	272	6.3%	25.2	$0.092	$3.93
Total U.S.	2,748	5.1%	$217.0	$0.079	$3.31

8.3.2 Scenario 2 – 7 Building Types (1.54 billion ft^2 Floor area)

Table 8.3.2 shows the energy cost savings for additional insulation levels by both private and public sector for all buildings modeled in this study. The percent energy cost savings are based on the ratio of the first year utility cost savings due to increased insulation versus the total first year building utility costs.

The first year costs savings realized <u>nationally</u> under Scenario 2 are as follows:

5.9%
$193,000,000
$0.125/$ft^2$

8.3.2.1 Private Sector

Significant points of interest regarding energy cost savings under Scenario 1 from the private sector:

- **$85,800,000 of energy cost saving or nearly half of national savings.**
  - **A wide range of $10,300,000-$23,500,000 per Zone (6, 7, 8 - Lowest; 3 – Highest).**
- **4.0% energy cost savings.**
  - **Highest in Zones 6, 7 & 8 (5.1%).**
  - **Lowest in Zone 3 (3.4%).**
- **Intensity cost savings of $0.097/$ft^2$.**
  - **Range in Zones between $0.079/$ft^2$ (4) and $0.128/$ft^2$ (1, 2).**

8.3.2.2 Public Sector

Significant points of interest regarding energy cost savings under Scenario 2 from the public sector:

- **$107,500,000 of energy cost saving or just over half of national savings.**
  - **A wide range of $11,000,000-$31,800,000 per Zone (6, 7, 8 - Lowest; 3 – Highest).**
- **9.5% energy cost savings.**
  - **Highest in Zone 5 (10.9%).**
  - **Lowest in Zone 1, 2 (8.0%).**
- **Intensity cost savings of $0.165/$ft^2$.**
  - **Range in Zones between $0.141/$ft^2$ (4) and $0.193/$ft^2$ (3).**

Table 8.3.2: Annual Energy Cost Savings Scenario 2 (7 Building Types)

Private Sector

	Floor Area	Cost Savings			
		First Year			30 Years
	MM ft²	*%*	*MM $*	*$/ft²*	*$/ft²*
Zone 1, 2	124	3.8%	$15.9	$0.128	$5.28
Zone 3	224	3.4%	$23.4	$0.105	$4.33
Zone 4	218	4.0%	$17.1	$0.079	$3.32
Zone 5	235	4.5%	$19.0	$0.081	$3.47
Zone 6, 7, 8	88	5.1%	$10.3	$0.117	$5.00
Total U.S.	889	4.0%	$85.8	$0.097	$4.05

Public Sector

	Floor Area	Cost Savings			
		First Year			30 Years
	MM ft²	*%*	*MM $*	*$/ft²*	*$/ft²*
Zone 1, 2	91	8.0%	$16.3	$0.178	$7.40
Zone 3	164	8.5%	$31.8	$0.193	$8.01
Zone 4	160	10.6%	$22.5	$0.141	$5.93
Zone 5	172	10.9%	$26.1	$0.151	$6.38
Zone 6, 7, 8	65	10.3%	$11.0	$0.170	$7.19
Total U.S.	652	9.5%	$107.5	$0.165	$6.91

Total

	Floor Area	Cost Savings			
		First Year			30 Years
	MM ft²	*%*	*MM $*	*$/ft²*	*$/ft²*
Zone 1, 2	216	5.2%	32.2	$0.149	$6.17
Zone 3	388	5.2%	55.2	$0.142	$5.89
Zone 4	377	6.2%	39.6	$0.105	$4.42
Zone 5	407	6.8%	45.0	$0.111	$4.70
Zone 6, 7, 8	153	7.0%	21.2	$0.139	$5.93
Total U.S.	1,541	5.9%	$193.3	$0.125	$5.26

8.4 GWP Emissions Prevented

8.4.1 GWP Prevented Compared to Buildings Modeled in this Study

Similar to the significant energy reductions resulting from increased insulation, there is an associated significant quantity of GWP emissions prevented. GWP emissions associated with energy consumption for all buildings in Scenario 1 is estimated at 40,834,510 metric tons CO_2-eq./yr. This is calculated from the annual energy consumption in all buildings of 230,113 billion Btu/yr for Scenario 1. The split is electricity accounting for 55 percent and natural gas accounting for 32 percent of this energy[17]. For estimation purposes using readily available factors, the electricity to natural gas split was scaled up to 63 percent and 37 percent respectively, and the total annual GWP was obtained by multiplying the respective energy consumptions by the factors previously noted, i.e. 0.223 kg CO_2-eq./MJ for electricity and 0.0749 kg CO_2-eq./MJ for natural gas. The same estimation method was used for Scenario 2 to obtain 32,327,180 metric tons CO_2-eq./yr.

The impact of adding additional roofing insulation on commercial building GWP generation modeled in this study can be seen in Table 8.4.1 below. If insulation were added to all buildings (Scenario 1) in this study, annual GWP prevented totals 2.12 million metric tons CO_2-eq.

This is divided by 40,834,510 metric tons CO_2-eq./yr., which is the total GWP generated at all Scenario 1 buildings, to obtain the 5.2 percent impact. The same estimation method was used for Scenario 2.

As previously mentioned, additional roof insulation for small hotels, medium offices and warehouses may not be as financially attractive compared to other types of buildings. However, even if small hotels, medium offices and warehouses were not insulated, the significant impact of additional insulation compared to the total GWP generation is in the same range, and somewhat higher since there annual GWP prevented is only slightly less (2.12 versus 1.91 million metric tons CO_2-eq.) but the total GWP generation is reduced from 40,834,510 to 32,327,180 metric tons CO_2-eq./yr.

Table 8.4.1: Impact of Insulation on Annual GWP Generation

Scenario	Portion of US Total Commercial Building Floor Area	Floor Area (billion ft^2)	Annual GWP Prevented (million metric tons CO_2-eq.)	Impact: GWP Prevented vs. All Buildings in this Study
1	3.8%	2.75	2.12	5.2 %
2	2.1%	1.54	1.91	5.9 %

As expected, the ratio of GWP prevented by additional insulation compared to the total GWP generated at the buildings is in the same range as the ratio of energy saved by additional insulation compared to the total energy consumed.

8.4.2 Annual GWP Prevented Compared to US Total

The impact of additional roofing insulation on total GWP emissions related to US commercial building energy use can be seen in Table 8.4.2 below. If insulation were added to all buildings (2.75 billion ft^2 of floor area or Scenario 1) in this study, annual GWP emissions prevented total 2.12 million metric tons CO_2-eq. This value is divided by 1153 million metric tons CO_2-eq., which is the total estimated GWP associated with energy consumption at all US commercial buildings, yielding a ratio of 0.18 percent as shown in Table 8.4.2 below. The GWP associated with all US commercial building energy consumption is estimated based on CBECS 2003 data indicating that 6500 trillion Btu of energy are consumed at all commercial buildings annually, with electricity accounting for 55 percent and natural gas for 32 percent of this energy. For estimation purposes using readily available factors, the electricity to natural gas split was scaled up to 63 percent and 37 percent respectively, and the total annual GWP was obtained by multiplying the respective energy consumptions by the factors previously noted, i.e. 0.223 kg CO_2-eq./MJ for electricity and 0.0749 kg CO_2-eq./MJ for natural gas.

As previously noted under the energy impact section, additional roofing insulation on small hotels, medium offices and warehouses may not be as financially attractive compared to other types of buildings. However, even if small hotels, medium offices and warehouses were not insulated, the significant impact of additional insulation compared to the US total GWP associated with commercial buildings remains about the same. As shown in Scenario 2 below, excluding these buildings results in 0.17 percent GWP emissions prevented versus the GWP emissions associated with all U.S. commercial building energy consumption.

Table 8.4.2: Impact of Insulation on Annual GWP Emissions Associated with US Commercial Building Energy Consumption

Scenario	Portion of US Total Commercial Floor Area	Floor Area (billion ft^2)	GWP Prevented (million metric tons CO_2-eq.)	Impact: GWP Prevented vs. US Commercial Total
1	3.8%	2.75	2.12	0.18 %
2	2.1%	1.54	1.91	0.17 %

8.4.3 Net Cumulative GWP Prevented (Total Life Cycle GWP)

As discussed previously, it is important from a life cycle perspective to consider the total life GWP emissions of materials installed to save energy on the building. Thus, one must estimate the GWP emissions resulting from making, installing, transporting etc the insulation, and then subtract these GWP emissions from the GWP prevented during insulation use to obtain a net cumulative GWP prevented, i.e.

Net Cumulative GWP Prevented *equals* ***GWP Prevented at Buildings*** *minus* ***GWP from Making, Installing, Transporting, etc. Insulation***

For the case of all buildings insulated in this study, for example, the GWP prevented over 30 years is 63.69 million metric tons CO_2-eq., and for the subset excluding warehouses, small hotels and medium offices the 30 year source energy saved is 57.31 million metric tons CO_2-eq. Based on GW emissions estimates for polyiso insulation discussed in section 7.1.1, a conservative (higher) value for the GWP emissions from making, installing, transporting, etc. the insulation is 0.5 kg CO_2-eq./BF is assumed.

Since 2.25 billion ft^2 of roof area (Scenario 1) and 1.53 billion ft^2 of roof area (Scenario 2) are insulated, the Boardfeet (BF) are estimated using an of average insulation thicknesses modeled in this study, i.e. 2.6 inches, which yields BF values ranging from 5.85 to 3.98 billion BF, respectively. These values are multiplied by the GWP emissions factor of 0.5 kg CO_2-eq. /BF to estimate the GWP emissions from making the insulation in both scenarios.

These results are shown in Table 8.4.3, where the GWP emissions prevented during insulation use far exceed the GWP emissions from making the insulation. In fact, the GWP emissions from making insulation range from only 3.5 percent to 4.6 percent of the GWP emissions prevented over the 30 years of insulation use. In other words, the incremental GWP prevented by adding additional insulation is 22 to 29 times greater than the GWP emissions from making, installing, transporting etc insulation. Thus, from a total life cycle energy perspective, insulation pays GWP dividends many times over compared to the one time GWP emissions generated when it was made.

Table 8.4.3: Net Cumulative GWP Prevented from a Life Cycle Perspective

Scenario	Roof Area (billion ft^2)	Cumulative GWP Prevented (million metric tons CO_2-eq.)	GWP from Making Insulation (million metric tons CO_2-eq.)	Net Cumulative GWP Prevented (million metric tons CO_2-eq.)	Ratio: GWP from Making Insulation vs. GWP Prevented in Use	Ratio: GWP Prevented in Use vs. GWP from Making Insulation
1	2.25	63.69	2.93	60.76	4.6%	22
2	1.53	57.31	1.99	55.32	3.5%	29

8.5 Cumulative Impact Assessment

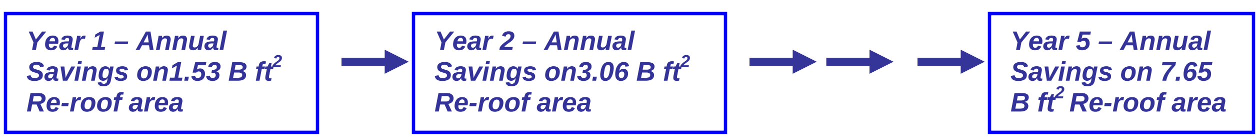
Throughout this report, the focus for the analysis and impact assessment of the research conducted utilizes a boundary limit of a single year of potential energy efficient roof replacements. The purpose for doing this is to produce clear and concise conclusions that can be useful for decision-makers involved with improving the energy efficiency of buildings. As stated in Section 8.2.3, “Annual Energy Savings Compared to US Total”, the conclusion was made that the amount of floor area involved in Scenario 2 represents only 2 percent of the total floor area for existing buildings. These roofs would be installed over many consecutive years and, therefore, the actual market potential is multiples of the annual boundary evaluated in this study. In this section, this boundary will be expanded to evaluate the impact of replacing existing roofs in this fashion year after year. For this exercise, Scenario 2 (See Table 8.0 for description) will provide the market potential basis.

8.5.1 Cumulative Impact Parameters

In order to represent the cumulative benefits, four parameters were established and are described below:

- **Annual energy savings and emissions prevention after five years.**
- **Annual energy savings and emissions prevention after ten years.**

Under Scenario 2, 1.53 billion square feet of existing low-slope roofs are replaced through the installation of an energy efficient roofing system in any given year. The key assumption used in this assessment is that this potential market will be available every year for many years. Therefore, linear growth in annual energy savings and GWP emissions is achieved each year.



- **Accumulation of energy savings and emissions prevention through five years.**
- **Accumulation of energy savings and emissions prevention through ten years.**

As is evident by the data presented regarding the cumulative savings calculations, the opportunity for energy consumption reductions in roof replacements of existing buildings is dramatic.

8.5.1.1 Annual Benefits after 5 Years

Table 8.5.1.1a: Annual Cost Savings after 5 Years

Sector	*Floor Area* billion ft^2		*Annual Cost Savings*	
	First Year	*Fifth Year*	*First Year*	*Fifth Year*
Private	0.9	4.4	$86 MM	$471 MM
Public	0.7	3.3	$108 MM	$589 MM
Total	1.5	7.7	$193 MM	$1,100 MM

Table 8.5.1.1b: Annual Site Energy Savings after 5 Years

Sector	*Annual Site Energy Savings* trillion Btu	
	First Year	*Fifth Year*
Private	5.2	26
Public	6.6	33
Total	11.8	59

Table 8.5.1.1c: Annual Source Energy Savings after 5 Years

Sector	*Annual Source Energy Savings* trillion Btu	
	First Year	*Fifth Year*
Private	11.4	57
Public	15.2	76
Total	26.6	133

Table 8.5.1.1d: Annual Emissions Prevention after 5 Years

Sector	*Annual Emissions Prevention* million metric tons CO_2-eq.	
	First Year	*Fifth Year*
Private	0.8	4.1
Public	1.1	5.5
Total	1.9	9.6

8.5.1.2 Annual Benefits after 10 Years

Table 8.5.1.2a: Annual Cost Savings after 10 Years

Sector	Floor Area billion ft^2		Annual Cost Savings	
	First Year	Tenth Year	First Year	Tenth Year
Private	0.9	8.9	$86 MM	$1,100 MM
Public	0.7	6.5	$108 MM	$1,300 MM
Total	1.5	15.4	$193 MM	$2,400 MM

Table 8.5.1.2b: Annual Site Energy Savings after 10 Years

Sector	Annual Site Energy Savings trillion Btu	
	First Year	Tenth Year
Private	5.2	52
Public	6.6	66
Total	11.8	118

Table 8.5.1.2c: Annual Source Energy Savings after 10 Years

Sector	Annual Source Energy Savings trillion Btu	
	First Year	Tenth Year
Private	11.4	114
Public	15.2	152
Total	26.6	266

Table 8.5.1.2d: Annual Emissions Prevention after 10 Years

Sector	Annual Emissions Prevention million metric tons CO_2-eq.	
	First Year	Tenth Year
Private	0.8	8.2
Public	1.1	10.9
Total	1.9	19.1

8.5.1.3 Accumulation of Benefits through 5 Years

Table 8.5.1.3a: Cumulative Cost Savings through 5 Years

Sector	Floor Area billion ft^2		Cumulative Cost Savings	
	First Year	Fifth Year	First Year	Fifth Year
Private	0.9	4.4	$86 MM	$1,400 MM
Public	0.7	3.3	$108 MM	$1,700 MM
Total	1.5	7.7	$193 MM	$3,100 MM

Table 8.5.1.3b: Cumulative Site Energy Savings through 5 Years

Sector	Cumulative Site Energy Savings trillion Btu	
	First Year	Fifth Year
Private	5.2	78
Public	6.6	99
Total	11.8	177

Table 8.5.1.3c: Cumulative Source Energy Savings through 5 Years

Sector	Cumulative Source Energy Savings trillion Btu	
	First Year	Fifth Year
Private	11.4	171
Public	15.2	228
Total	26.6	399

Table 8.5.1.3d: Cumulative Emissions Prevention through 5 Years

Sector	Cumulative Emissions Prevention million metric tons CO_2-eq.	
	First Year	Fifth Year
Private	0.8	12.2
Public	1.1	16.4
Total	1.9	28.6

8.5.1.4 Accumulation of Benefits through 10 Years

Table 8.5.1.4a: Cumulative Cost Savings through 10 Years

Sector	Floor Area billion ft^2		Cumulative Cost Savings	
	First Year	Tenth Year	First Year	Tenth Year
Private	0.9	8.9	$86 MM	$5,400 MM
Public	0.7	6.5	$108 MM	$6,800 MM
Total	1.5	15.4	$193 MM	$12,200 MM

Table 8.5.1.4b: Cumulative Site Energy Savings through 10 Years

Sector	Cumulative Site Energy Savings trillion Btu	
	First Year	Tenth Year
Private	5.2	286
Public	6.6	362
Total	11.8	648

Table 8.5.1.4c: Cumulative Source Energy Savings through 10 Years

Sector	Cumulative Source Energy Savings trillion Btu	
	First Year	Tenth Year
Private	11.4	628
Public	15.2	836
Total	26.6	1,464

Table 8.5.1.4d: Cumulative Emissions Prevention through 10 Years

Sector	Cumulative Emissions Prevention million metric tons CO_2-eq.	
	First Year	Tenth Year
Private	0.8	45
Public	1.1	60
Total	1.9	105

9.0 PAYBACK ANALYSIS

As reviewed in Economic Analysis, Section 4, first-year utility costs were calculated by the EnergyPlus model and annual inflation rates of 2.2 percent and 2.8 percent were applied for sequential years to electricity and natural gas, respectively. In addition, the current costs for the required rigid insulation were obtained from RS Means CostWorks Online Construction Estimator software. These data provide the basis for the simple payback calculations that are reviewed in this section.

9.1 Overall Results

As is the case with the energy analysis results, payback calculations show widely varying results by building type and climate. Please note that all results were rounded up to the first full year following exact payback occurrence.

9.1.1 Payback by Building Type

It comes as no surprise that the most favorable payback results are exhibited by the two school models. Warehouse, on the other hand, does not show payback during the thirty-year lifetime in any case except one. Table 9.1.1 lists the payback range results for each location.

Table 9.1.1 Payback Results by Building Type

	Payback Range
	Less than, Yrs.
Secondary School	4 - 10
Primary School	5 - 10
Restaurant	4 - 18
Small Office	6 - 17
Supermarket	9 - 21
Strip Mall	7 - 19
Retail	11 - 29
Medium Office	8 - >30
Small Hotel	12 - >30
Warehouse	22 - >30

9.1.2 Payback by Climate Zone

Variables affecting payback by climate zone include regional installation costs and the mildness of the climate. Consistently, the mildest Climate Zones of 4 and 5 exhibits the lengthiest payback results. The shortest payback periods are always achieved in the Zone 2 simulations.

9.2 Market Weighted Findings

In Impact Assessment, Section 8, energy savings results are not favorable with Warehouse, Small Hotel and Medium Office. Payback results further confirm this conclusion. Therefore, market weighted results calculated here are based on Scenario 2 described in Table 8.0. Payback periods are summarized in Table 9.2. Please note that figure is rounded up to the first full year above payback.

Table 9.2: Full Insulation Cost Market Weighted Payback Results

(Note: All payback results are rounded up to first full year, therefore exact payback can be up to 1 year less than indicated)

Zone	1, 2	3	4	5	6, 7, 8	National Average
Private Sector	8.8	12.7	16.1	16.5	11.7	13.9
Public Sector	5.2	5.1	8.2	7.8	7.3	6.8
Total	7.7	10.1	13.6	13.7	10.5	11.6

9.3 Tax Incentive Impact

This study confirms that substantial energy consumption reduction opportunities exist with energy efficient roof replacements on existing buildings. In light of the current economic conditions, these opportunities are lost due to the tendency to eliminate, or at least delay, capitol projects. The implementation of a tax incentive could reverse this tendency dramatically. The PIMA/CEIR proposed Federal tax credit of 30 per cent for the installation of an energy efficient roof would highly reduce first costs as well as payback fulfillment periods. This credit will apply to the costs associated with the installation of the insulation and applies to Private Sector buildings only. Table 9.3 illustrates the benefit of this tax credit proposal to accelerate energy saving activity for existing buildings. This incentive will serve to reduce the payback period on energy efficient roof replacements by nearly four years in the private sector and over three years on the national average.

Table 9.3: Payback Results with 30% Tax Credit for Private Sector Buildings

(Note: All payback results are rounded up to first full year, therefore exact payback can be up to 1 year less than indicated)

Zone	1, 2	3	4	5	6, 7, 8	National Average
Private Sector	6.4	9.3	12.0	12.3	8.9	10.3
Public Sector	5.2	5.1	8.2	7.8	7.3	6.8
Total	5.6	7.5	10.1	10.1	8.0	8.6

10.0 CONCLUSIONS

Representing eighteen percent of all U.S. annual energy use at 91 $kBtu/ft^2$ based on floor area, existing commercial buildings play an important role in the challenge to achieve substantial reductions in consumption of energy and impact on the environment. A key lies in the fact that the vast majority of building stock will require roof replacement over the next fifteen to twenty five years providing a practical opportunity to improve the thermal performance of buildings. From the research conducted and the results presented in this report, the following conclusions have been established:

- One and one half billion square feet of existing floor area is a viable annual potential for installation of low-slope energy efficient roofing systems. Clearer and more stringent energy code language as well as increased enforcement specific to re-roofing projects could enhance this potential.
- After ten years, fifteen billion square feet or greater than 20 percent of today's existing floor area will be saving 6.5 percent of total site energy consumption or 118 billion Btu and 266 billion Btu of source energy annually. It is presumed that during this period, a portion of non-retrofitted buildings will be demolished, further contributing to the relative impact of energy efficient roofing systems in lowering the energy intensity level of buildings. Lastly, from a life cycle perspective, the total embodied energy involved in the insulation is recovered in the first year of its use through the energy saved.
- The economic impact includes a cumulative savings of $12.2 billion and annual savings of $2.4 billion which, of course, continues throughout the lifetime of the insulation. The total capitol required (installed cost of additional insulation) over this ten year period is approximately $23 billion. Please note that the economic impact in this study is limited to the site utility costs and the installed costs of the insulation. There are other potential economic benefits associated with reductions in energy generation and use as well as reduction in emissions and other environmental impacts that are beyond the scope of this research.
- Energy savings realized with energy efficient roof systems vary significantly between climate zones and vary dramatically between building types. Of the ten building types studied, seven exhibit substantial savings in all climate zones with schools reaping the greatest benefits.
- With respect to GWP, this practical means of thermal performance improvement prevents nearly 0.2 percent of the total building stock emissions in the first year alone. The compounding impact provides a GWP emissions prevention benefit of greater than 100 million metric tons CO_2-equiv. after ten years. Again, comparing this to the life cycle emissions involved in the additional insulation shows that the net zero emissions period is roughly one year.

Biographies

Jerry Phelan

Jerry Phelan holds a B. S. degree in Chemical Engineering from the University of Rochester. He has been with Bayer MaterialScience in Pittsburgh for 29 years. For much of that time, Jerry has been, and continues to be, engaged in Bayer's business with polyurethane and polyisocyanurate insulation in Construction. Jerry has been very active in PIMA (Polyisocyanurate Insulation Manufacturers Association) for the last 14 years, where he is currently serving a third term on the Board of Directors, participates on the Industry Promotion Committee, the ASHRAE Task Force and with colleague Pavlovich, manages PIMA's Life Cycle Inventory Program. He also actively participates on the Building and Construction Market Team of ACC (American Chemistry Council), participates in CPI (Center for the Polyurethanes Industry) and member of both ASHRAE and NRCA. Alongside many respected colleagues in PIMA and the Polyurethane Industry, Jerry has been deeply involved in and committed to the advancement of polyisocyanurate/polyurethane insulation products for many years. Much of this involvement in recent years has been in the fields of Life Cycle Assessment and Whole Building Energy Analysis.

George Pavlovich

George Pavlovich works for Bayer MaterialScience in Pittsburgh focusing on Life Cycle Assessments. He has worked with chemical processes at Bayer since 1987, implementing pollution prevention programs, conducting environmental impact analyses, and developing global EH&S management systems and Product Stewardship programs. This included several years in Europe and Asia, as well as assignments in China, India, Japan, Belgium, Mexico, Brazil and many plants in the U.S.A. He has an MS in Civil Engineering from Carnegie Mellon University and BS degrees in Chemical Engineering and Biology from the University of Pittsburgh.

Eric Ma

Eric Ma has over 26 years experience in merger and acquisition, sales and marketing, consulting, business development, strategic planning and technology with Bayer MaterialScience. Eric has 11 publications and patents.