

# The Important Role of the Polyurethane Industry in Deep Reductions of Energy and Environmental Impact

**JERRY PHELAN**

*Bayer Material Science  
100 Bayer Road  
Pittsburgh, PA 15205*

**GEORGE PAVLOVICH**

*Bayer Material Science  
100 Bayer Road  
Pittsburgh, PA 15205*

## **ABSTRACT**

Advances in the energy efficiency and environmental impact of constructing and operating buildings play a vital role in achieving the aggressive energy use and emissions reduction goals of this country. The prompt transformation of energy standards and codes for new and retrofit construction that capitalize on the “negative costs” and persuasive life cycle characteristics of existing and proven technologies are essential. This study demonstrates that spray polyurethane and boardstock and metal faced polyisocyanurate insulation products can support this transformation by providing credible evidence of their energy savings, emissions prevention and durability attributes. It does this through the utilization of recognized technical tools, as the study combines life cycle principles contained in ISO 14040 with rigorous building energy simulation modeling. The scope of the research conducted incorporates the energy efficiency and green building standards under development by the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE 90.1-2010 and ASHRAE 189.1). In addition, the scope included the development of a comprehensive market analysis for new construction of commercial buildings and the potential application of the polyurethane industry’s products. The multifaceted aspects of this project described above were then utilized to establish a complete impact assessment for the use of polyurethane/polyisocyanurate materials at the levels required to comply with the standards that are currently being scrutinized by proponents and opponents of advanced energy codes. The authors believe that this study, along with our previous efforts in this field as well as the work of others, such as McKinsey and Company and the International Council of Chemical Associations (ICCA), can be effectively leveraged to help drive forward the short term goals (i.e. thirty percent and fifty percent reductions by 2010 and 2015, respectively) of policy makers and their supporters.

## **DISCLAIMER**

The authors of this report have compiled detailed information provided by internal and external sources, and have generated technical data, engineering calculations and conclusions to the best of their knowledge and belief at the time of this writing. Since limited information for estimating life cycle impacts was available or could not be verified in some instances, the results contained in this report should be considered preliminary. No representation is made or warranty given, either expressly or tacitly, for the completeness or correctness of the information in this study. Neither Bayer MaterialScience nor third parties involved in providing information for this study may be held liable for use or misuse of information provided in this report. This report contains references to non-Bayer MaterialScience companies, services and websites. By providing these references, Bayer MaterialScience is not endorsing or approving their products, services and websites, and cannot confirm the accuracy or completeness of the information or services provided therein. Access and use of these references is at the user's risk. Bayer MaterialScience will not be liable for any harm resulting from the use of non-Bayer MaterialScience products, services or websites. It is the responsibility of the user of non-Bayer MaterialScience products, services and information to comply with all applicable laws and regulations.

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## EXECUTIVE SUMMARY

Polyurethane insulation products for new commercial buildings play a vital role in significantly reducing U.S. energy consumption and preventing greenhouse gas emissions. Vast energy and greenhouse gas reductions can be realized through implementation of the continuous insulation requirements in the proposed ASHRAE 90.1-2010P and 189.1P standards. It is essential that these enhanced standards be implemented now, or substantial energy savings and greenhouse gas emissions prevention opportunities will be lost. A delay in implementing the ASHRAE 90.1-2010P requirements until 2015 will result in losing 1,900 trillion Btu in energy savings (equivalent of 328 million barrels of crude oil) and releasing of 134 million metric tons of CO<sub>2</sub>-eq. (equivalent to annual CO<sub>2</sub> emissions from 29 coal-fired power plants). By 2030, new commercial building floor space is projected to increase by 35 billion ft<sup>2</sup>, with an additional 21 billion ft<sup>2</sup> replacing existing demolished buildings. If the proposed continuous insulation requirements of ASHRAE 90.1-2010P are adopted, the market potential would increase by 87% for roof insulation, and 270% for wall insulation. This increase in market size for new low-slope roof and exterior wall insulation for new commercial buildings amounts to approximately 3 to 5.7 billion board feet. As quantitatively demonstrated with rigorous Whole Building Energy Analysis and Life Cycle Assessment methodology in this study, prompt adoption and enforcement of the enhanced standards will greatly benefit the polyurethane/polyisocyanurate insulation industry. More importantly, implementation of these enhanced insulation requirements will significantly reduce U.S. energy consumption and benefit the environment through avoidance of greenhouse gas emissions. Polyurethane insulation technology is tried and tested: now is the time to put it in place.

### 1.0 INTRODUCTION

Faced with the challenges of energy dependence and climate change, aggressive goals have been established in the United States. In order to achieve deep reductions in energy consumption and greenhouse gas emissions, well coordinated policies involving stricter standards and innovation incentives must be implemented in the near future. The actions taken must strike a balanced approach for removing barriers to optimal utilization of existing technology and motivation for development of new technologies, while maintaining the global competitiveness. The economic crisis that we are now dealing with certainly creates an added challenge to the effective and timely implementation of these policies, but in no way lessens the need to do so.

The polyurethane industry has a strong history of innovation and responsibility at times of demand for new technologies and in facing challenges that threaten its markets. There is no question that the need to further develop technologies, such as in the area of renewable energy, provides opportunities to new applications for polyurethanes through innovation.

The focus of this study and paper, though, is the long proven and durable polyurethane insulation products, specifically polyisocyanurate boardstock insulation, spray polyurethane foam, and polyisocyanurate insulated metal panels. With the highest commercially available insulation properties and with widespread flammability approvals in wall and roof applications, the manufacturers of polyurethane raw materials, systems and finished foam insulation products are positioned to immediately participate in and contribute to addressing the issues of energy and emissions. However, in order for the industry to turn potential market growth opportunity into reality, it is essential that we provide policy makers, those who implement and enforce the policies, specifiers and building owners with credible substantiation of impact benefits of polyurethane insulation materials.

The purpose of this study is two-fold:

1. To quantify potential opportunities for polyurethane/polyisocyanurate (PUR/PIR) insulation products created by the market transformation as a result of the aggressive energy and emissions reduction goals of the country.
2. To provide thorough and credible representation of the energy and environmental impact benefits of PUR/PIR insulation from a life cycle perspective. This incorporates the data from the first purpose in order to draw conclusions regarding the potential impact assessment within the boundaries of the defined scope of the project.

In fulfilling these purposes, the authors hope to provide the industry with a valuable tool to help drive the growth of our markets through effective advocacy.

#### 1.1 Scope and Functional Units

New construction or substantial additions to existing structures of commercial building floor space represent the scope of research conducted in this study, serving as the boundary for relating the Whole Building Energy Modeling performed in this analysis to available commercial building market information. The variable for comparison is the continuous insulation level of the opaque above grade area of the building envelope. The baseline building is modeled to comply with Section 5.5, "Prescriptive Building Envelope Option" of ASHRAE 90.1-2004. This standard establishes the minimum

level for energy efficiency in commercial buildings and is the most frequently applied energy code in the U.S. today. The anticipated future model energy code specific to prescriptive wall and roof continuous insulation requirements sets the basis for the “ultimate” market potential under Purpose 1 above. Therefore, the functional units for this study include a series of new construction prototypical commercial buildings set in all ASHRAE sub-climate zones with exterior wall and roof designs modified to reflect the future expected minimum standards. These design modifications match of two important preliminary standards: ASHRAE 90.1-2010 and ASHRAE 189.1. A comparison of the proposed continuous insulation minimum requirements for these two standards to the ASHRAE 90.1-2004 basis is provided in Chapter 2.

Note: As a point of clarification, this analysis is based on continuous insulation requirements and therefore, does not include market quantification for insulation application in the cavity wall. However, compliance with cavity wall insulation requirements is established in the input file for each energy simulation.

Also within the scope of this project is the calculation of the life cycle inventory (LCI) for the embodied energy and global warming potential (GWP) in the PUR/PIR insulation. Included in the functional units described above are the PUR/PIR wall and roof insulation products of specific thermal resistances required for each of the ASHRAE standards, in each of the sixteen sub-climate zones and for the type of constructions included in the design. Chapter 3 explains the LCI calculations and provides the tables of embodied energy per Board Foot and GWP per Board Foot for each of the insulation products included in the study. For each use-phase comparison, the appropriate results for the additional insulation are subtracted from the energy savings and GWP prevention for the additional insulation. This provides the net energy and environmental impact benefit or described in equation form as follows:

$$\text{Net Energy Saved} \underline{\text{equals}} \text{Energy Saved at Buildings} \\ \underline{\text{minus}} \text{Embodied Energy of Additional Installed Insulation} \quad (1)$$

$$\text{Net Cumulative GWP Prevented} \underline{\text{equals}} \text{GWP Prevented at Buildings} \\ \underline{\text{minus}} \text{GWP from Making, Installing, Transporting, etc. Additional Insulation} \quad (2)$$

The calculation of the LCI embodied energy and emissions can be effectively used to demonstrate the benefits of additional PUR/PIR insulation. In a side-by-side comparison of the energy saved/GWP prevented and the embodied energy/ GWP in the complete life cycle it is clear that the impact of the additional insulation is minimal relative to the achieved benefits.

## 1.2 Objectives

Whether it is generated by the policy-makers, the officials responsible for compliance with the policies, the design community or the building owners, there is a strong demand for information that describes the energy and environmental impact of the life cycle and use of building products. It is the hope of the authors that the polyurethane industry is the source and support for this information as it relates to our products. The overall goal of this study as well as previous studies by the authors [1, 2], is that thorough, credible, transparent and effectively useable data be established on the sustainability of PUR/PIR insulation materials. Expanding upon this overall goal are the following specific objectives:

1. Further develop and improve upon cradle to end-of-life energy and emissions ISO 14040 compliant data for PUR/PIR insulation materials.
2. Expand and organize the data collected to support manufacturers and suppliers to the polyurethane industry in advocacy efforts.
3. Establish primary LCI data that can be utilized by industry trade groups PIMA, SPFA and MCA for their specific product LCA (Life Cycle Assessment) programs.
4. Contribute to efforts to replace outdated and inaccurate data that is currently available and represents PUR/PIR materials in LCA tools.
5. Compile extensive energy modeling results to support energy efficiency goals and stricter standards and codes.
6. Compile complete and reliable market data on commercial buildings for polyurethane industry raw material suppliers and manufacturers to allocate resources and rationalize investments appropriately.
7. Combine market data and extensive energy modeling to generate a full impact assessment for the USA of the energy and environmental impact reduction potential as a result of the implementation of new and stricter standards.
8. Establish further justification to use in gathering additional congressional support for H.R. 2615: Energy Efficient Roof Systems; proposed legislation providing a 30% tax credit for added levels of insulation on roofs.

### 1.3 Target Audiences

What are clear are the magnitude of both the challenge and the opportunity of engaging, influencing and capitalizing on the market transformation created by the energy efficiency and green building movement. Achieving the full potential requires the concerted effort of the polyurethane industry (CPI), the downstream organizations of PIMA, SPFA and MCA as well as the American Chemistry Council and its Building and Construction Market Industry Team (ACC-BCMIT). It is the intention of Bayer MaterialScience and the authors of this paper that the purposes of this study as stated above serve to benefit the polyurethane/plastics industry. Therefore, the initial target audience is the participants of this Conference. A measure of success of this project is the level of dialogue that this paper generates in the form of comments, questions, means of improvement in the content and related activity following the conference.

The ultimate target audiences are far broader, and therefore, the effectiveness in delivering the messages from this research is reliant on the engagement of the industry. The results of this study are expected to be of particular interest to the following stakeholders:

- ASHRAE Standards Committee and Board of Directors where this information can provide valuable support behind their efforts to enhance the standards.
- Federal government agencies, such as the Department of Energy (DOE), National Laboratories, Government Service Administration (GSA), and others who have the potential of serving as a valuable asset with these efforts.
- Commercial building architects, designers, specifiers and owners who need to justify the cost/benefits of insulation, and better understand the relative environmental impact of various building assemblies.
- Life Cycle Assessment practitioners/consultants, academia and building scientists in serving as advisors and peer reviewers.
- And more...

## 2.0 ADVANCED MODEL CODE TARGETS

The level of support behind the quest for stricter and more advanced model energy codes is nothing short of monumental! From the Sierra Club to large chemical companies, the organizations, activist groups, agencies and companies have teamed up to encourage policy-makers take productive action to move the country towards these goals through enhanced codes and adoption processes. Despite the momentum, an onerous state and local code adoption process, a small yet effective opponent base and a low level of compliance following adoption, present formidable barriers to the transformation.

The intermediate and ultimate targets and their timing for energy efficiency in buildings through enhanced energy codes are consistent amongst the leadership organizations of ASHRAE, International Code Council (ICC), DOE and American Institute of Architects (AIA). These consistent targets were further solidified by the milestone event of the approval of the American Clean Energy and Security Act of 2009 by the House Committee on Energy and Commerce on May 26, 2009.

### 2.1 American Clean Energy and Security Act of 2009 (ACES) [3]

In its current form, ACES establishes a national building energy code. Aggressive provisions in this legislation mandate that the DOE ensure that state and local jurisdictions support building energy efficiency. The energy efficiency targets of the bill are summarized in Table 1. They are also consistent with those of the organizations cited in the previous paragraph reflecting the effectiveness of the efforts of the diverse coalition of advocates. **It is the first stage target (30% reductions) that serves to establish the scope of the energy modeling segment of this project.**

The bill addresses the critical issues of timing requirements for state adoption, DOE confirmation of state code severity and mandates state enforcement. Of particular importance to the latter point, is the requirement that compliance be at least ninety percent (90%) with all new and substantially renovated building space. With statistics showing that current compliance rates at well below this level, if this national model energy code is implemented and acted on effectively, this aspect alone will provide a substantial boost in energy efficiency in buildings.

Note: It is not clear to the author at the time of the writing of this report, what role that the current model energy codes of International Energy Conservation Code (IECC; Residential and Commercial construction) and ASHRAE 90.1

(Commercial construction only) will be if ACES is enacted. However, it is anticipated that the prescriptive insulation levels will be similar to ASHRAE 90.1-2010.

**Table 1: ACES Energy Efficiency Targets**

<b>Baseline code</b>	IECC-2006
	ASHRAE 90.1-2004
<b>30% below baseline</b>	Effective upon enactment of ACES
<b>50% below baseline</b>	Residential 1/1/2014
	Commercial 1/1/2015
<b>5% additional savings every three years</b>	Residential 1/1/2017 through 1/1/2029
	Commercial 1/1/2015 through 1/1/2030

**2.2 ASHRAE 90.1**

The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) is a standards writing organization with a focus on building performance. The ASHRAE Standing Standard Project Committee (SSPC) prepares a number of standards, including Standard 90, for member review and consensus agreement as defined by the American National Standards Institute (ANSI).

The purpose of ASHRAE 90.1 as stated in the standard is:

“...to provide minimum requirements for the energy-efficient design of buildings except low rise residential buildings.”

“Low rise residential” is any single family home or any multi-family building of three stories or less.

First published in 1975, new versions of Standard 90 are now published in its entirety every three years with the potential for updating several times a year by publishing approved addenda.

The first public review has closed on Addendum bb to ASHRAE 90.1-2007 which includes proposed changes to the building envelope requirements of the “Prescriptive Building Envelope Option” (Section 5.5). At some point, this addendum along with all of the other addenda to ASHRAE 90.1-2007 will be integrated into the release of ASHRAE 90.1-2010. Table 2 lists the current specific proposed building envelope requirements for ASHRAE 90.1-2010 that are pertinent to this project.

**2.3 ASHRAE 189.1P**

ASHRAE189.1P, Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings has completed its third public review and comment period. The general description and purpose taken directly from the standard are as follows:

*“Standard 189.1 addresses site sustainability, water use efficiency, energy efficiency, indoor environmental quality (IEQ), and the building’s impact on the atmosphere, materials and resources.*

*The purpose of this standard is to provide minimum requirements for the siting, design, construction, and plan for operation of high performance, green buildings to:*  
*a. balance environmental responsibility, resource efficiency, occupant comfort and well being, and community sensitivity, and*  
*b. support the goal of development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”*

This green building standard also has a prescriptive option including building envelope requirements. The envelope requirements pertinent to this project are listed side-by-side with ASHRAE 90.1-2004 and proposed ASHRAE 90.1-2010 requirements in Table 2.

<b>Table 2: Comparison of versions of ASHRAE 90.1 Nonresidential building envelope requirements – IP Units</b> <i>ci = continuous insulation IEAD = Insulation entirely above deck</i>								
<b>Climate Zone</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>
<b>Roofs IEAD</b>								
<b>90.1-2004</b>	R-15	15	15	15	15	15	15	20
<b>90.1-2010P</b>	R-20	25	25	30	30	30	35	35
<b>189.1P</b>	R-20	25	25	25	25	25	35	35
<b>Mass Wall Construction</b>								
<b>90.1-2004</b>	NR	NR	5.7ci	5.7ci	7.6ci	9.5ci	11.4ci	13.3ci
<b>90.1-2010P</b>	NR	5.7ci	7.6ci	9.5ci	11.4ci	19.5ci	19.5ci	19.5ci
<b>189.1P</b>	5.7ci	7.6ci	9.5ci	11.4ci	13.3ci	15.2ci	20.0ci	20.0ci
<b>Steel Frame Wall Construction</b>								
<b>90.1-2004</b>	R-13	13	13	13	13+3.8ci	13+3.8ci	13+7.5ci	13+7.5ci
<b>90.1-2010P</b>	R-13+7.5ci	13+7.5ci	13+7.5ci	13+7.5ci	13+15.6ci	13+18.8ci	13+18.8ci	13+18.8ci
<b>189.1P</b>	R-13+5.0ci	13+5.0ci	13+5.0ci	13+10.0ci	13+10.0ci	13+10.0ci	13+10.0ci	13+10.0ci

### 3.0 GLOBAL GREENHOUSE GAS (GHG) ABATEMENT

Top government leaders throughout the world have discussed aggressive plans for reducing global greenhouse gas emissions. In light of this interest, McKinsey & Company (McKinsey) along with other organizations have compiled US and global GHG abatement databases which include extensive lists of opportunities and implementation costs. The results from this study, which uses state-of-the-art life cycle and simulation modeling to quantify GHG avoided from improved insulation in new commercial buildings, are consistent with conclusions and recommendations outlined in recently published McKinsey and similar reports, including:

1. [Reducing U.S. Greenhouse Gas Emissions: How much at What Cost? \(McKinsey 2007\)](#) [4]
2. [Putting America on the Path to Solving Global Warming \(NRDC 2008\)](#) [5]
3. [Pathways to a Low-Carbon Economy \(McKinsey 2009\)](#) [6]
4. [Innovations for Greenhouse Gas Reductions \(ICCA 2009\)](#) [7]

The GHG abatement cost curve published by McKinsey in 2007 for the US provides an overall perspective highlighting “low hanging” fruit versus more costly abatement measures. As shown in Figure 1 below on the left lower section, “Commercial buildings-New shell improvements” is a significant abatement opportunity that includes improved insulation. This abatement has a negative marginal cost, meaning that building shell improvements such as better insulation would save significantly more money (i.e. reduced heating/cooling costs) over the building life cycle compared to the cost of installing insulation. This conclusion is consistent with results on net life cycle energy savings quantified by the authors, demonstrating that the energy saved over the building life is many times greater than the relatively minor one time embodied energy. These results, together with the short energy payback periods given in Chapter 7 and additional data in Chapter 9 of this report, further support the McKinsey analysis.



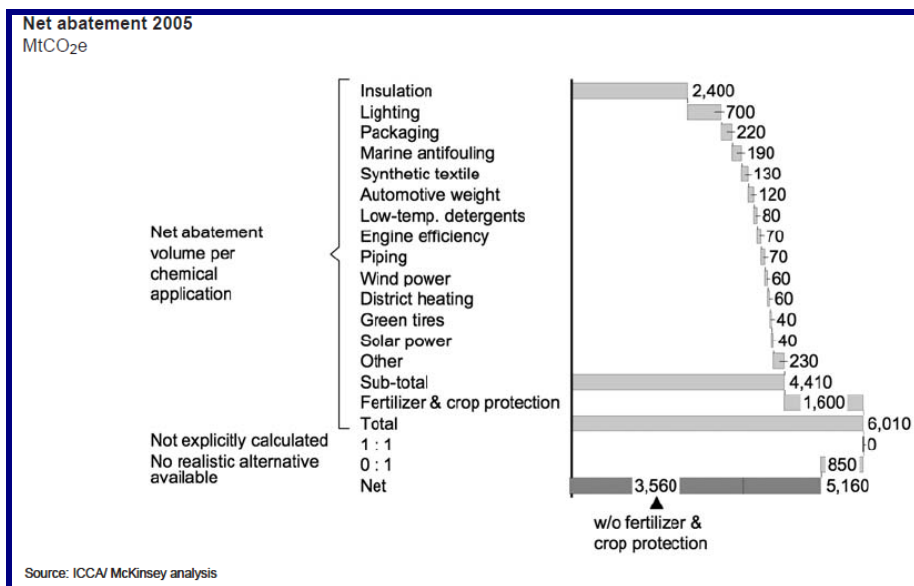
Based on a global study covering Asia, Europe and North America, the ICCA report estimated that the ratio of GHG prevented compared to GHG associated with making foam insulation is 233:1. In their study, the authors estimated different ratios of GHG prevented compared to GHG associated with making foam insulation. The ratios calculated in the authors' study and reasons for these differences are given in Chapters 7, 9 and 10 of this report. Nevertheless, the trends from the ICCA study and those given in this report are directionally similar. Both support the conclusion that GHG prevented in the building use phase from installing additional insulation is much greater than the relatively small GHG generated from all other life cycle phases, e.g. from manufacturing, installing and disposing of the insulation at end-of-life.

In summary, the McKinsey Initiative conducted a comprehensive analysis with the intent of identifying and fully evaluating any and all opportunities to reduce global GHG emissions. Each opportunity identified was assigned to one of several categories referred to as "clusters of abatement potential". Each of the clusters was extensively analyzed and conclusions were drawn regarding its quantification of abatement potential as well as the costs involved in implementing the actions taken in order achieve its potential.

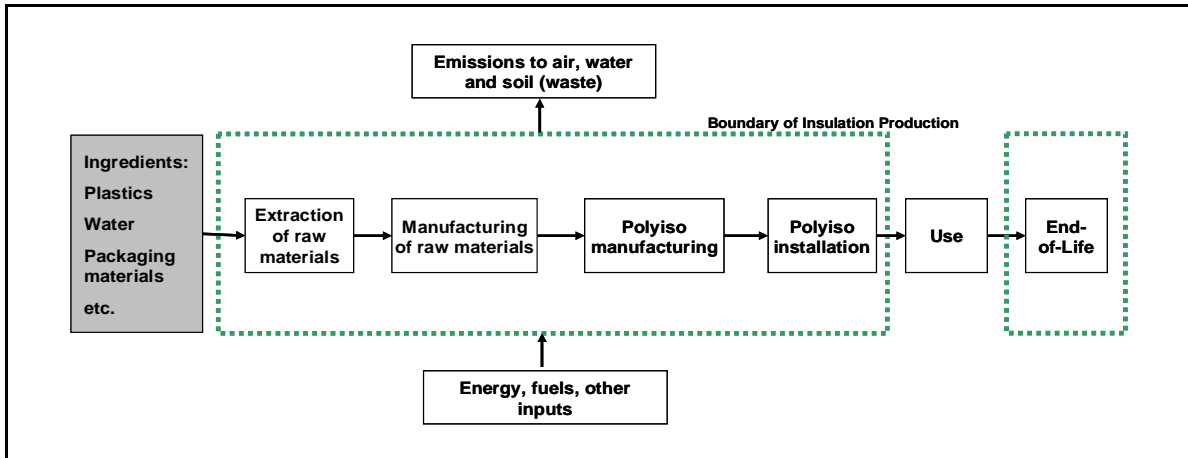
In the McKinsey report issued in December 2007 [4], five (5) clusters of opportunities were identified in which would create significant progress in GHG reductions in the U.S. provided that the initiatives involved are pursued. The cluster identified as the number one priority is "improving energy efficiency in buildings and appliances". As discussed above, the building shell is an option within this cluster and, of course, specifically insulation levels and air sealing effectiveness. The reasons why this is the top priority include the following:

- It provides a substantial portion of the total abatement potential.
- Its individual measures, including added and better insulation, are often negative-cost options.
- Its individual measures include available and proven technologies with virtually no investment of time and economic resources.
- Its individual measures include actions in which are considered to be "time-lost opportunities", meaning that the longer the actions are not taken, the smaller the impact of the of the abatement opportunity. An obvious example would be the delayed enactment of stricter energy codes for newly constructed and retrofitted buildings.

McKinsey has quantified the abatement potential of all options within each cluster which are estimated to have a cost attached of less than \$50 per ton of CO<sub>2</sub>-eq. For energy efficiency in buildings and appliances, this exercise has identified a mid-range total abatement potential of 710 to a high-range of 870 megatons of CO<sub>2</sub>-eq. per year by 2030. The report states that abatement potential specific to **building shells** amount to **a mid-range of 60 to a high-range of 72 megatons of CO<sub>2</sub>-eq. per year** by 2030 split evenly between residential and commercial. In Section 9.3, "Cumulative Impact Assessment", the quantification of the portion of this total potential directly achieved by the continuous insulation requirements of the proposed standards evaluated in this study will be calculated.



**Figure 2: Product Applications from the Global Chemical Industry Driving GHG Emissions Reductions**



**Figure 3: Phases Included in Embodied Energy and Associated GWP Estimates**

#### 4.0 EMBODIED ENERGY AND ASSOCIATED GWP

The entire insulation life cycle consists of cradle to end-of-life phases, including extraction of raw materials, manufacturing of raw materials, PUR/PIR manufacturing and installation, insulation use on buildings and end-of-life disposal. Transportation energy and associated GWP (Global Warming Potential) are also included, e.g. transportation of raw materials, product and waste. As shown Figure 3, this chapter focuses on energy consumed and GWP associated with all steps noted above except for the use phase.

Although energy consumed and GWP associated with the other phases are negligible compared to energy and GWP reductions during use, the entire PUR/PIR life cycle is considered in this study to obtain a complete balance. Thus, energy consumed and GWP generated in these other phases are subtracted from the energy saved and GWP prevented during use to obtain a net life cycle energy and GWP balance. This adjustment is further described in Chapters 7 and 9 of this report.

#### 4.1 Embodied Energy

The embodied energy used for insulation in this study includes all steps except the use phase. The estimates are based on methods and assumptions from a preliminary 2008 study for polyiso boardstock insulation [1]. This analysis covers all 29 polyiso plants in the USA and the authors are familiar with the methodology. The embodied energy estimates below are based on averages modeled for polyiso insulation installed on commercial buildings at 14 major cities distributed among US climates zones. Foam formulations are based on generally representative industry values and a wet density of 1.82 lb/ft<sup>3</sup>. The facer is based on Glass Reinforced Fiber (GRF) made primarily from recycled materials. Polyester polyol is based on data from two of three US plants with some raw material streams modeled as recycled. Recycled raw material streams are assumed burden-free, i.e. energy and GWP contributions are generally excluded except for energy and GWP associated with transporting materials. Results in Table 3 for roofing insulation and Table 4 for wall insulation show normalized embodied energy as a function of R-value (thermal resistance) for the three insulation standards used in this study.

ASHRAE Standard	R-value* (°F ft <sup>2</sup> hr/Btu)	Nominal Thickness (in)	Embodied Energy (kBtu/BF)	Comments
90.1-2004	15.0	2.45	6.69	Single-layer
	20.0	3.25	6.64	
90.1-2010 & 189.1	20.4	3.30	6.63	
	25.0	4.08	6.74	2 x 2.04 in. layers
	30.0	4.90	6.69	2 x 2.45 in. layers
	35.0	5.72	6.66	2 x 2.86 in. layers

\*Note: Normalized kBtu/BF for double-layer = kBtu/BF for single-layer, as values are energy per unit volume.  
 Absolute embodied energy, e.g. for 1 ft<sup>2</sup> covered by two 2.45 in. layers = 4.9 BF x 6.69 kBtu/BF=32.8 kBtu

**Table 4: Wall Insulation - Embodied Energy**

ASHRAE Standard	R-value* (°F ft <sup>2</sup> hr/Btu)	Nominal Thickness (in)	Embodied Energy (kBtu/BF)
90.1-2004	3.2	0.5	7.62
	4.8	0.75	7.23
	6.5	1.0	7.04
	8.1	1.25	6.92
	9.6	1.50	6.85
	11.2	1.75	6.79
90.1-2010	4.8	0.75	7.23
	6.5	1.0	7.04
	8.1	1.25	6.92
	16.0	2.5	6.69
	17.6	2.75	6.67
	19.2	3.0	6.65
189.1	4.8	0.75	7.23
	6.5	1.0	7.04
	8.1	1.25	6.92
	9.6	1.50	6.85
	11.2	1.75	6.79

\* Note: single-layer insulation in all cases

## 4.2 Global Warming Potential

Similar to the embodied energy, the GWP associated with polyiso insulation includes all phases except the use phase. Estimates are based on methods and assumptions from the preliminary 2008 study by the authors noted above. The GWP is calculated using the US EPA TRACI [8] model for polyiso insulation installed under the same building type and averaged across selected US cities as noted above for embodied energy. Results in Table 5 for roofing insulation and Table 6 for wall insulation show normalized GWP averaged across all cities as a function of R-value.

**Table 5: Roof Insulation – Global Warming Potential**

ASHRAE Standard	R-value* (°F ft <sup>2</sup> hr/Btu)	Nominal Thickness (in)	GWP (kg CO <sub>2</sub> eq/BF)	Comments
90.1-2004	15.0	2.45	0.425	Single-layer
	20.0	3.25	0.420	
90.1-2010 & 189.1	20.4	3.30	0.420	
	25.0	4.08	0.429	2 x 2.04 in. layers
	30.0	4.90	0.425	2 x 2.45 in. layers
	35.0	5.72	0.422	2 x 2.86 in. layers

\*Note: Normalized GWP for double-layer = GWP for single-layer, as values are kg CO<sub>2</sub> eq. per unit volume.  
Absolute GWP e.g. for 1 ft<sup>2</sup> covered by two 2.45 in. layers = 4.9 BF x 0.425 kg CO<sub>2</sub> eq/BF= 2.1 kg CO<sub>2</sub> eq

<i>Table 6: Wall Insulation – Global Warming Potential</i>			
<b>ASHRAE Standard</b>	<b>R-value* (°F ft<sup>2</sup> hr/Btu)</b>	<b>Nominal Thickness (in)</b>	<b>GWP (kg CO<sub>2</sub> eq/BF)</b>
<b>90.1-2004</b>	<b>3.2</b>	<b>0.5</b>	<b>0.497</b>
	<b>4.8</b>	<b>0.75</b>	<b>0.467</b>
	<b>6.5</b>	<b>1.0</b>	<b>0.452</b>
	<b>8.1</b>	<b>1.25</b>	<b>0.443</b>
	<b>9.6</b>	<b>1.50</b>	<b>0.437</b>
	<b>11.2</b>	<b>1.75</b>	<b>0.432</b>
<b>90.1-2010</b>	<b>4.8</b>	<b>0.75</b>	<b>0.467</b>
	<b>6.5</b>	<b>1.0</b>	<b>0.452</b>
	<b>8.1</b>	<b>1.25</b>	<b>0.443</b>
	<b>16.0</b>	<b>2.5</b>	<b>0.424</b>
	<b>17.6</b>	<b>2.75</b>	<b>0.423</b>
	<b>19.2</b>	<b>3.0</b>	<b>0.421</b>
<b>189.1</b>	<b>4.8</b>	<b>0.75</b>	<b>0.467</b>
	<b>6.5</b>	<b>1.0</b>	<b>0.452</b>
	<b>8.1</b>	<b>1.25</b>	<b>0.443</b>
	<b>9.6</b>	<b>1.50</b>	<b>0.437</b>
	<b>11.2</b>	<b>1.75</b>	<b>0.432</b>
Note: single-layer insulation in all cases			

### 4.3 Additional Information on Embodied Energy and GWP Factors

The factors above assume that GRF facer is used in both roofing and wall applications. In practice, GRF facer is used primarily in commercial roofing insulation, whereas aluminum craft paper facer is generally used for wall insulation. Since only factors based on GRF facer were available to the authors at the time of this writing, the embodied energy and associated GWP based on polyiso insulation with GRF facer are used to determine the net life energy and GWP. Since the GRF facer estimate is based on limited information and assumes recycled raw materials (waste paper, glass, old corrugated cardboard) carry no energy and GWP burden, and processes for aluminum craft paper manufacturing might be more energy and GWP intensive than GRF facer, it is possible that the factors above are underestimated.

The factors given in Tables 3 through 6 show the embodied energy and associated GWP per unit volume (BoardFoot) of insulation, as this is the typical unit used for insulation quantity in the USA. Since embodied energy and associated GWP of materials are normally expressed by convention as MJ/kg and kg CO<sub>2</sub>-equivalent/kg, curves have been generated using these energy and GWP units as a function of insulation thickness. Moreover, the factors in Tables 3 through 6 show that embodied energy and associated GWP decrease with increasing insulation R-value or thickness. This is opposite to the trend expected when embodied energy or associated GWP of insulation are expressed on a mass basis, as the embodied energy and associated GWP increase with greater insulation R-value or thickness. An explanation of the trends in embodied energy and associated GWP as a function of R-value/thickness along with illustrative curves are provided in Appendix A.

## 5.0 MODELING AND SIMULATION DESCRIPTIONS

### 5.1 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 predicting 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.

EnergyPlus Version 3-1 was WBEA tool utilized for the modeling conducted in this study. This 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 [9].

## **5.2 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 fifteen (15) separate building prototypes which, according to DOE analysis, represents approximately seventy percent of the commercial buildings in the U.S. For each building prototype, EnergyPlus files are generated with specific input data for sixteen (16) U.S. locations representing each of the ASHRAE sub-climates (See Figure 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 [10].

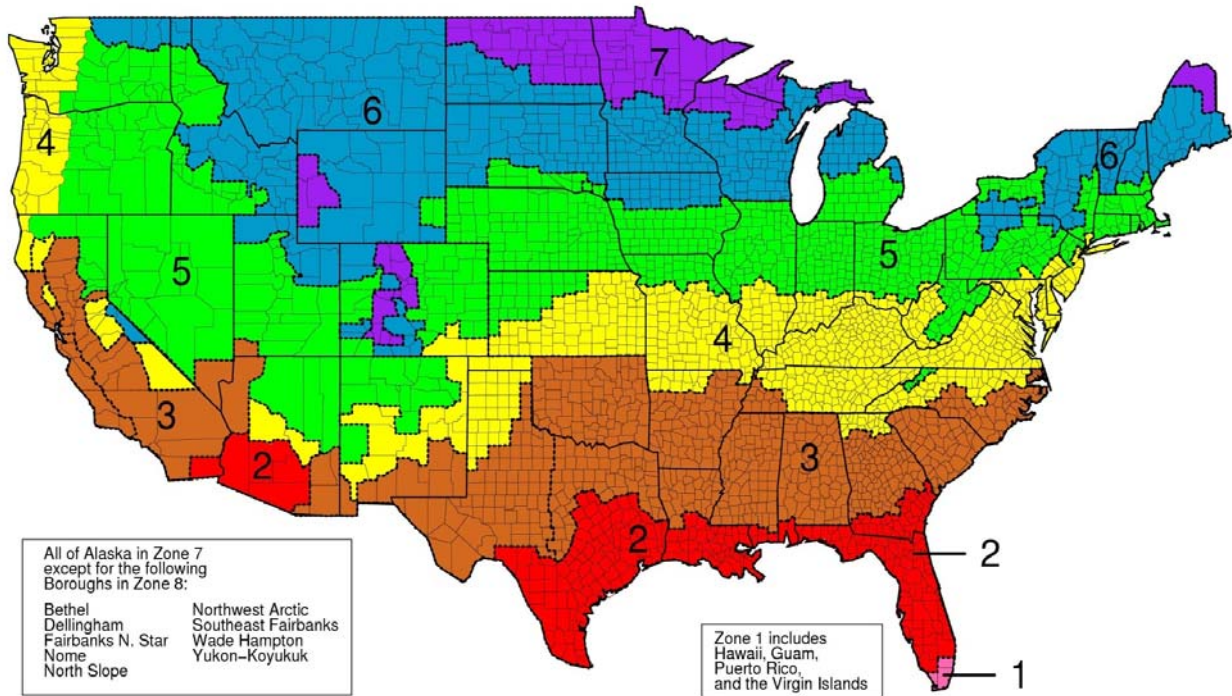
## **5.3 Simulation Descriptions**

### **5.3.1 MODEL BUILDING TYPES**

Of the fifteen (15) building types established in the DOE Commercial Building Benchmark Project, six (6) were used in this study:

- Strip Mall
- Retail
- Small Office
- Medium Office
- Primary School
- Secondary School

Analyses of existing commercial building data indicate that the modeling of these types would provide a sufficient representation of the energy performance of buildings. Chapter 8, “Commercial Building Market Analysis”, offers further explanation to substantiate this conclusion. Refer to Table 7 for building envelope descriptions of the six (6) models,



**Figure 4: ASHRAE Climate Zones**

**Table 7: Model Building Envelope Description**

Building Type	Floor Area	Roof Area	Opaque Wall Area	Wall Construction
	Ft <sup>2</sup>	Ft <sup>2</sup>	Ft <sup>2</sup>	
Strip Mall	22,497	22,497	10,907	Steel Frame
Retail	24,692	24,692	11,766	Mass
Small Office	5,500	5,500	2,390	Mass
Medium Office	53,626	17,879	14,431	Steel Frame
Primary School	73,959	73,959	17,431	Steel Frame
Secondary School	210,886	126,677	44,005	Steel Frame

**5.3.2 BUILDING LOCATIONS AND CLIMATE ZONES**

All sixteen (16) building locations for which EnergyPlus input files were developed in the DOE Commercial Building Benchmark Project were used in this study, representing each Climate Zone and all three Moist, Dry and Marine locations:

- |   |   |  |  |
|---|---|--|--|
| <u>Moist Climate</u>  | <u>Dry Climate</u>  | <u>Dry Climate</u>   | <u>Marine Climate</u>  |
| <ul style="list-style-type: none"> <li>• 1A Miami</li> <li>• 2A Houston</li> <li>• 3A Atlanta</li> <li>• 4A Baltimore</li> <li>• 5A Chicago</li> <li>• 6A Minneapolis</li> <li>• 7 Duluth</li> <li>• 8 Fairbanks</li> </ul> | <ul style="list-style-type: none"> <li>2B Phoenix</li> <li>3B Los Angeles</li> <li>4B Albuquerque</li> <li>5B Boulder</li> <li>6B Helena</li> </ul> | <ul style="list-style-type: none"> <li>3B Las Vegas</li> </ul> | <ul style="list-style-type: none"> <li>3C San Francisco</li> <li>4C Seattle</li> </ul> |

### 5.3.3 SUMMARY OF SPECIFIC SIMULATION INPUT PARAMETERS

When conducting Whole Building Energy Analysis for energy performance comparisons, consistent guidelines must be followed. The ASHRAE 90.1 Appendix G: Performance Rating Method is the most widely accepted procedural standard for conducting this type of evaluation. The author followed the guidelines of Appendix G for this study as closely as practical.

There are a few specific input parameters that should be expanded on for the reader to have a greater depth of understanding in evaluating the conclusions and assertions made as a result of this analysis. First, it should be noted that every effort was made to establish the boundaries of the modeling to be consistent with those of the commercial building market analysis presented in Chapter 7. Section 7.4, “Summary of Specific Market Potential Boundaries” is of particular importance in this regard. The specific simulation input parameters of note are as follows:

- Some benchmark model input files are designed with steep-slope roofs and attic spaces. In these cases, which were true of the Small Office model, for example, the author modified the input file to reflect the design of a flat roof with application of insulation by means of IEAD.
- As noted, the benchmark model input files were structured to comply with ASHRAE 90.1-2004. The proposed standards, though, address other improvements in energy efficiency besides insulation levels. It is intuitive that other improvements will have an interactive impact on the results of this of the modeling conducted in this study. As a result, efficiency improvement modifications were made in the baseline models, including a ten percent (10%) improvement in lighting efficiency, a ten percent (10%) improvement in HVAC equipment, and a ten percent (10%) decrease in the air infiltration rate. These modifications were consistent in the comparison models of ASHRAE 90.1-2010 and ASHRAE 189.1.
- In the prescriptive requirements, the standards provide the option of satisfying either the minimum R-value of the insulation or the maximum U-value of the assembly including air film. Consistently in all simulations, the lower R-value of the two calculations was utilized.

Refer to the tables in Appendix B for further details regarding the various PUR/PIR thicknesses and resulting board footage consistent with the simulation input values.

6.0 SIMULATION RESULTS

6.1 Strip Mall Simulation Results

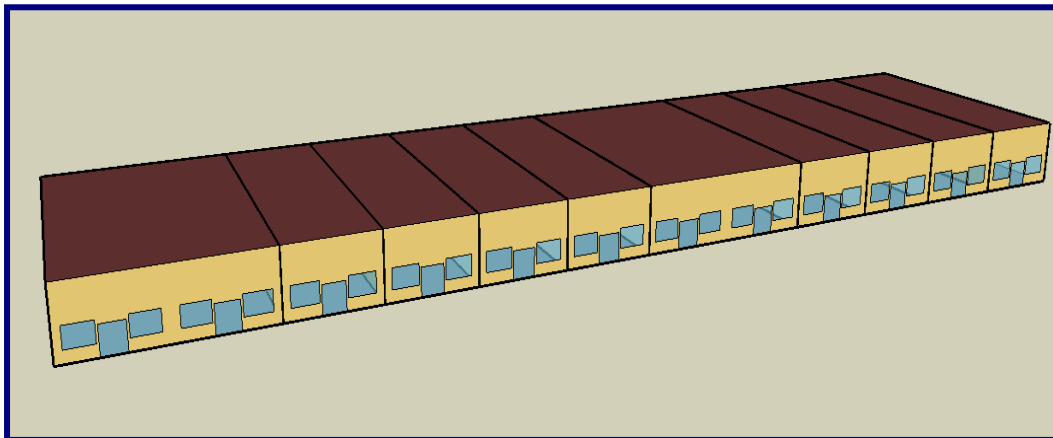


Figure 5: Strip Mall Benchmark Model

**Table 8: Strip Mall Annual Energy Savings and Emissions Prevention Summary**  
Baseline Model: 90.1-2004 modified to 10% improvement in HVAC & lighting efficiency & 10% decrease in infiltration

Climate Zone	1	2	3	4	5	6	7	8
Baseline Model, kBtu/ft <sup>2</sup>	58	58	54	69	81	96	113	162
<b>Site Annual Energy Savings, kBtu/ft<sup>2</sup>-yr</b>								
Roof Savings	-0.28	1.19	1.53	4.77	6.11	6.93	9.53	8.39
Wall Savings	0.49	1.33	1.40	3.08	3.16	4.17	2.89	4.66
90.1-2010P Total	0.21	2.52	2.93	7.85	9.27	11.10	12.43	13.05
189.1P	0.09	2.23	2.59	7.18	6.80	9.30	10.52	9.85
<b>Source Annual Energy Savings, kBtu/ft<sup>2</sup>-yr</b>								
Roof Savings	-1.08	1.75	1.38	7.77	7.53	12.02	15.53	12.83
Wall Savings	1.42	2.85	2.24	5.19	5.67	5.85	1.92	7.15
90.1-2010P Total	0.34	4.60	3.62	12.96	13.20	17.87	17.45	19.97
189.1P	0.02	4.00	3.00	12.07	8.92	14.68	17.08	15.02
<b>Annual Emissions Prevention, kg CO<sub>2</sub>-eq/ft<sup>2</sup>-yr</b>								
Roof Savings	-0.08	0.12	0.09	0.55	0.52	0.85	1.09	0.90
Wall Savings	0.10	0.21	0.16	0.36	0.40	0.40	0.12	0.50
90.1-2010P Total	0.02	0.33	0.25	0.91	0.92	1.25	1.21	1.40
189.1P	0	0.28	0.21	0.85	0.62	1.03	1.20	1.05

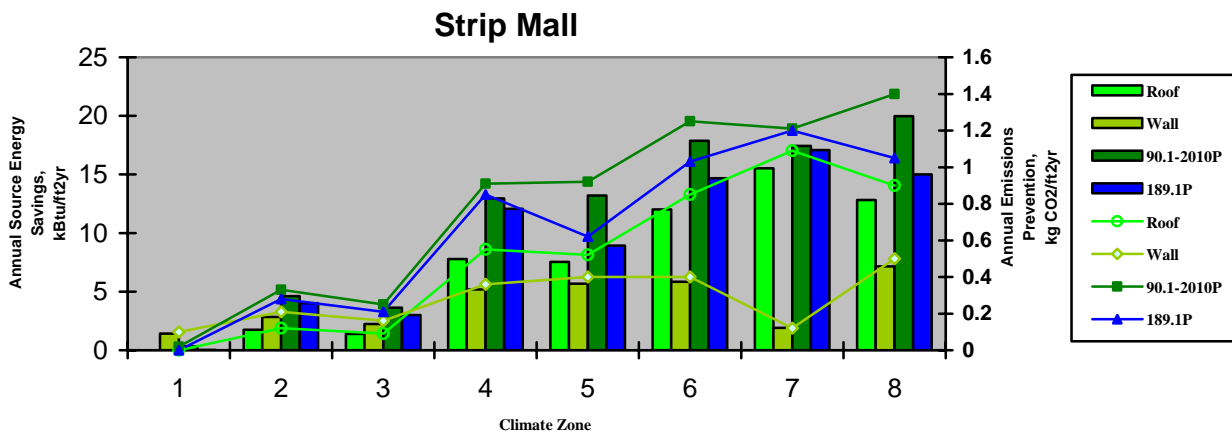


Figure 6: Strip Mall Annual Source Energy Savings & Emissions Prevention Savings

## 6.2 Retail Simulation Results

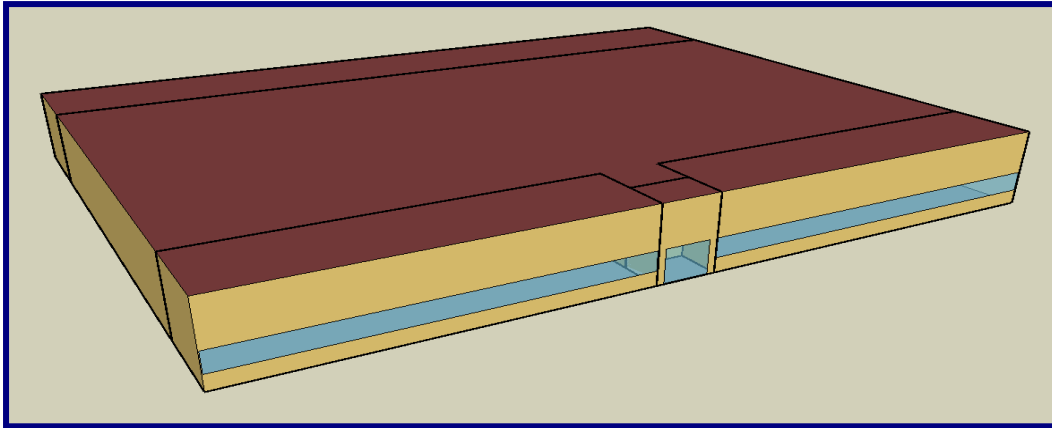


Figure 7: Retail Benchmark Model

Table 9: Retail Annual Energy Annual Savings and Emissions Prevention Summary								
Baseline Model: 90.1-2004 modified to 10% improvement in HVAC & lighting efficiency & 10% decrease in infiltration								
Climate Zone	1	2	3	4	5	6	7	8
Baseline Model, kBtu/ft <sup>2</sup>	62	62	52	64	74	85	102	144
<i>Site Annual Energy Savings, kBtu/ft<sup>2</sup>-yr</i>								
Roof Savings	-0.13	0.49	1.21	3.35	5.33	6.54	9.56	9.32
Wall Savings	0	6.96	1.62	2.52	2.48	3.33	3.26	4.33
90.1-2010P Total	-0.13	7.45	2.83	5.87	7.81	9.86	12.82	13.65
189.1P	5.30	8.12	3.19	5.64	7.14	8.46	12.82	13.65
<i>Source Annual Energy Savings, kBtu/ft<sup>2</sup>-yr</i>								
Roof Savings	-0.49	-0.12	0.93	3.01	6.23	11.11	14.85	17.96
Wall Savings	0	20.02	5.05	6.04	4.91	2.81	2.37	6.09
90.1-2010P Total	-0.49	19.90	5.98	9.06	11.13	13.92	17.22	24.04
189.1P	17.01	21.93	6.98	9.33	10.15	11.51	17.22	24.04
<i>Annual Emissions Prevention, kg CO<sub>2</sub>-eq/ft<sup>2</sup>-yr</i>								
Roof Savings	-0.04	-0.01	0.06	0.20	0.43	0.78	1.04	1.27
Wall Savings	0	1.45	0.37	0.43	0.35	0.19	0.15	0.42
90.1-2010P Total	-0.04	1.44	0.43	0.63	0.78	0.97	1.19	1.70
189.1P	1.23	1.58	0.50	0.66	0.71	0.80	1.19	1.70

### Retail

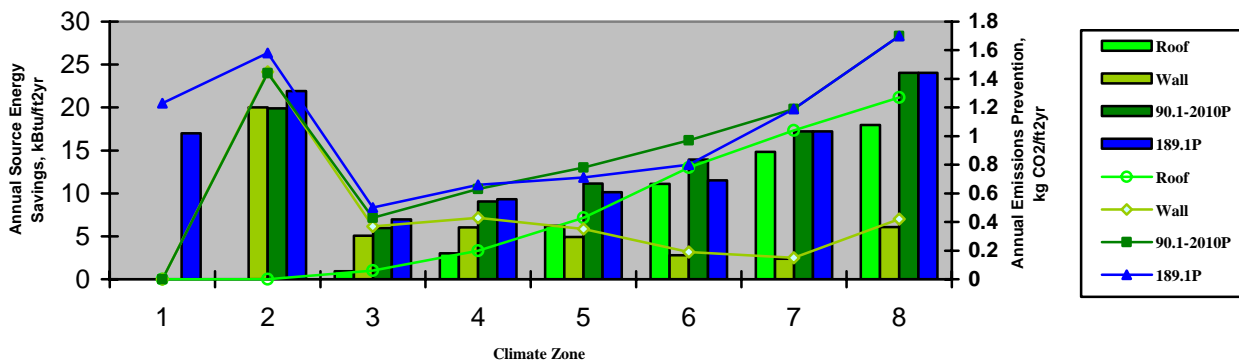
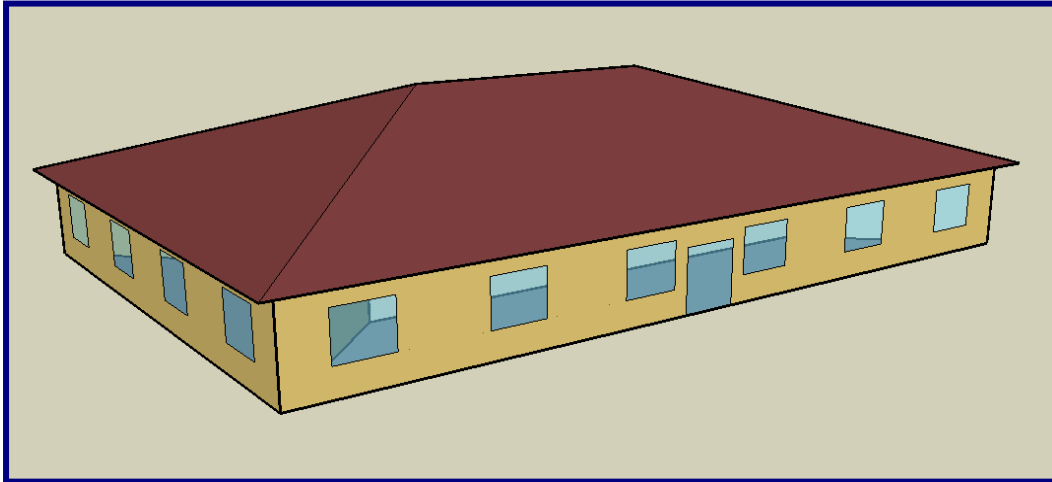


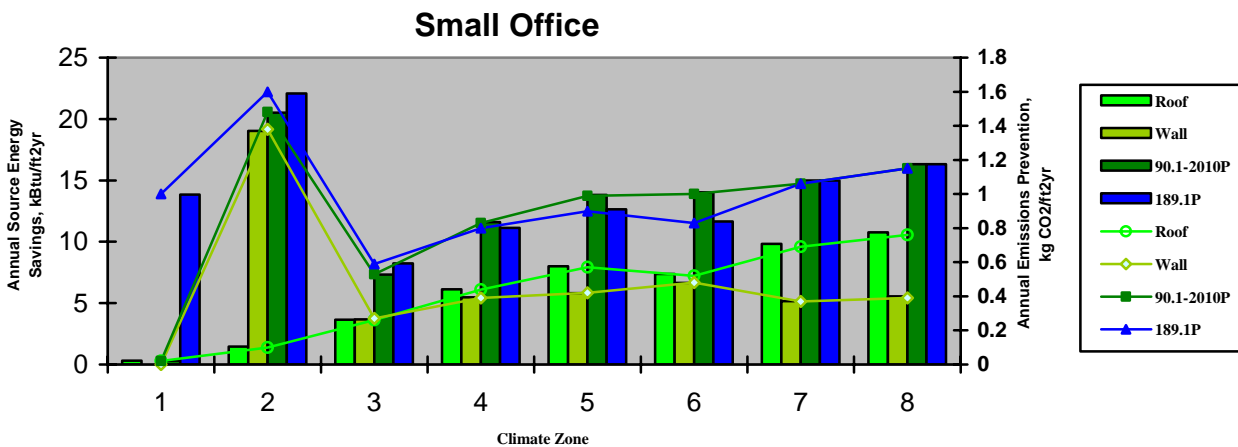
Figure 8: Retail Source Annual Energy Savings & Emissions Prevention Savings

### 6.3 Small Office Simulation Results



**Figure 9: Small Office Benchmark Model**  
 Note: For simulations, attic roof converted to flat roof

<b>Table 10: Small Office Annual Energy Savings and Emissions Prevention Summary</b>								
Baseline Model: 90.1-2004 modified to 10% improvement in HVAC & lighting efficiency & 10% decrease in infiltration								
Climate Zone	1	2	3	4	5	6	7	8
Baseline Model, kBtu/ft <sup>2</sup>	51	51	44	49	57	62	69	91
<b>Site Annual Energy Savings, kBtu/ft<sup>2</sup>-yr</b>								
Roof Savings	0.10	0.70	1.55	3.07	4.14	4.29	5.92	6.55
Wall Savings	0	6.35	1.26	2.11	2.23	3.06	2.56	2.98
90.1-2010P Total	0.10	7.05	2.81	5.18	6.37	7.35	8.48	9.53
189.1P	4.30	7.57	3.12	4.88	5.80	6.26	8.48	9.53
<b>Source Annual Energy Savings, kBtu/ft<sup>2</sup>-yr</b>								
Roof Savings	0.30	1.47	3.66	6.12	8.01	7.38	9.83	10.76
Wall Savings	0	19.04	3.67	5.48	5.81	6.65	5.15	5.56
90.1-2010P Total	0.30	20.51	7.33	11.60	13.82	14.02	14.98	16.32
189.1P	13.83	22.07	8.23	11.13	12.65	11.66	14.98	16.32
<b>Annual Emissions Prevention, kg CO<sub>2</sub>-eq/ft<sup>2</sup>-yr</b>								
Roof Savings	0.02	0.10	0.26	0.44	0.57	0.52	0.69	0.76
Wall Savings	0	1.38	0.27	0.39	0.42	0.48	0.37	0.39
90.1-2010P Total	0.02	1.48	0.53	0.83	0.99	1.00	1.06	1.15
189.1P	1.00	1.60	0.59	0.80	0.90	0.83	1.06	1.15



**Figure 10: Small Office Annual Source Energy Savings & Emissions Prevention Savings**

## 6.4 Medium Office Simulation Results

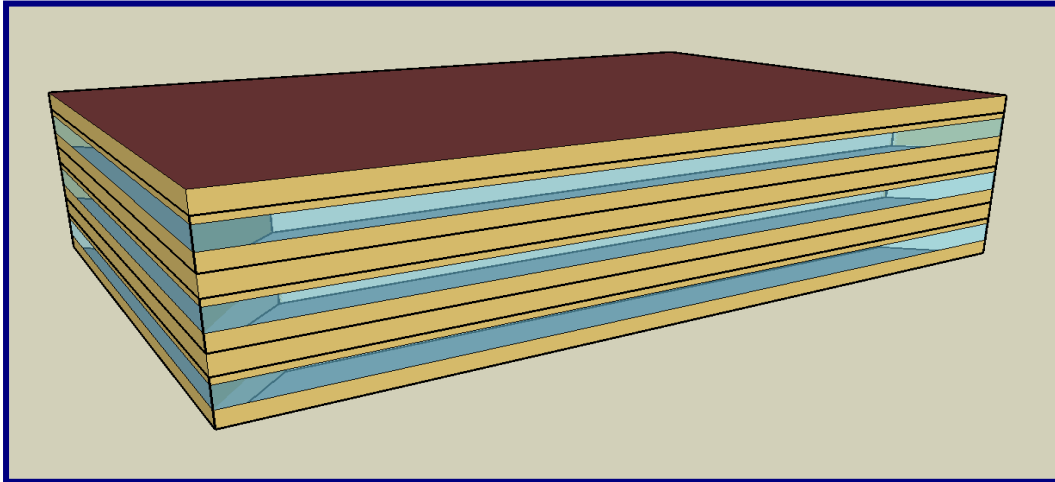


Figure 11: Medium Office Benchmark Model

Table 11: Medium Office Annual Energy Savings and Emissions Prevention Summary								
Baseline Model: 90.1-2004 modified to 10% improvement in HVAC & lighting efficiency & 10% decrease in infiltration								
Climate Zone	1	2	3	4	5	6	7	8
Baseline Model, kBtu/ft <sup>2</sup>	48	53	49	54	57	64	70	92
<b>Site Annual Energy Savings, kBtu/ft<sup>2</sup>-yr</b>								
Roof Savings	0.03	0.35	0.28	0.65	1.52	1.72	2.32	2.09
Wall Savings	0.66	1.30	1.29	1.95	1.58	2.40	1.61	2.48
90.1-2010P Total	0.69	1.65	1.57	2.60	3.10	4.12	3.94	4.56
189.1P	0.61	1.45	1.30	2.57	2.24	3.18	2.68	2.86
<b>Source Annual Energy Savings, kBtu/ft<sup>2</sup>-yr</b>								
Roof Savings	0.02	0.54	0.18	0.61	2.07	2.78	3.55	2.89
Wall Savings	1.92	2.97	2.48	3.22	2.33	3.63	2.18	3.33
90.1-2010P Total	1.93	3.51	2.66	3.83	4.40	6.41	5.73	6.23
189.1P	1.72	3.08	2.15	3.86	3.19	5.01	3.85	3.89
<b>Annual Emissions Prevention, kg CO<sub>2</sub>-eq/ft<sup>2</sup>-yr</b>								
Roof Savings	0	0.04	0	0.04	0.14	0.20	0.25	0.20
Wall Savings	0.14	0.21	0.16	0.23	0.16	0.25	0.15	0.23
90.1-2010P Total	0.14	0.25	0.16	0.27	0.31	0.45	0.40	0.43
189.1P	0.12	0.22	0.13	0.27	0.22	0.35	0.27	0.27

### Medium Office

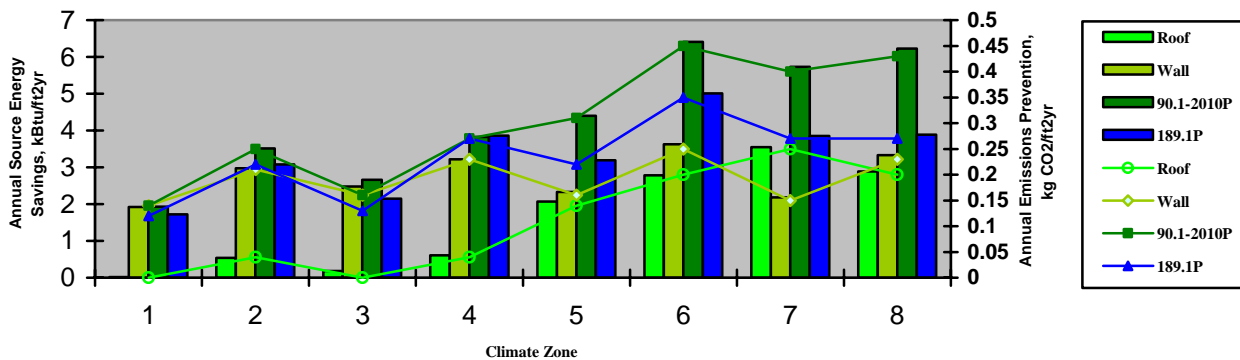
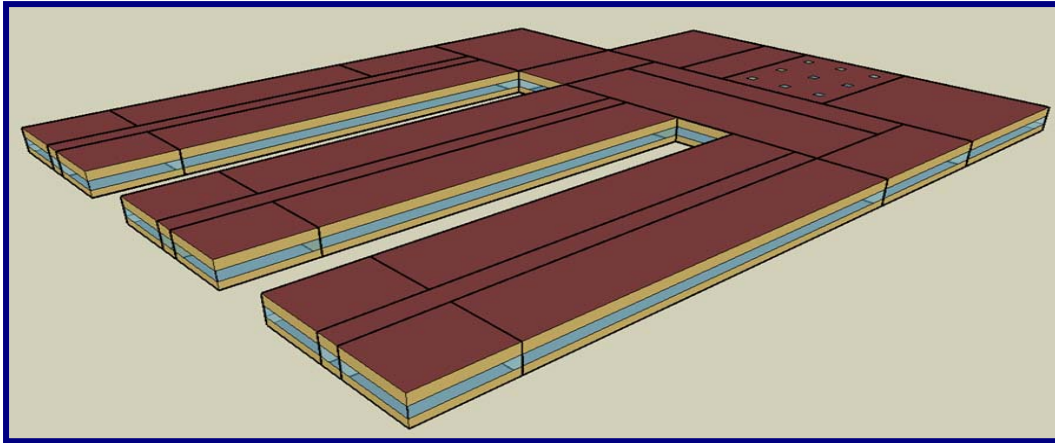


Figure 12: Medium Office Annual Source Energy Savings & Emissions Prevention Savings

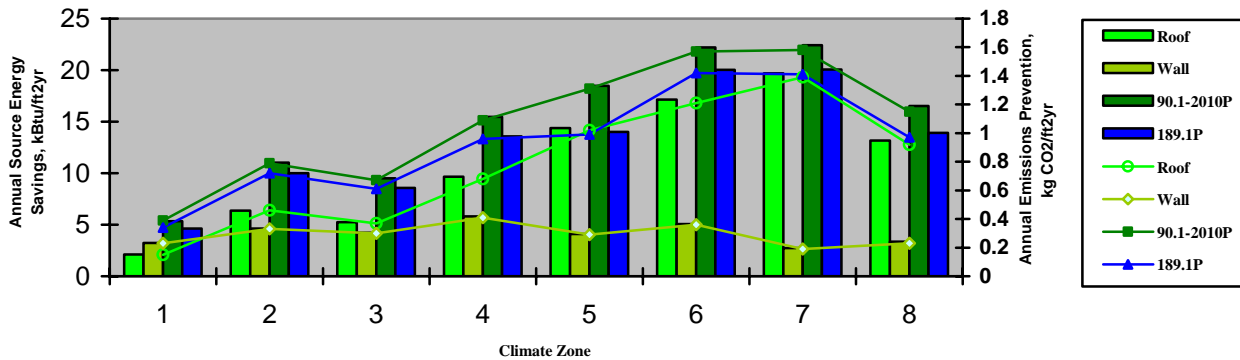
## 6.5 Primary School Simulation Results



**Figure 13: Primary School Benchmark Model**

<b>Table 12: Primary School Annual Energy Savings and Emissions Prevention Summary</b>								
Baseline Model: 90.1-2004 modified to 10% improvement in HVAC & lighting efficiency & 10% decrease in infiltration								
Climate Zone	1	2	3	4	5	6	7	8
Baseline Model, kBtu/ft <sup>2</sup>	72	76	72	77	88	104	118	163
<b>Site Annual Energy Savings, kBtu/ft<sup>2</sup>-yr</b>								
Roof Savings	0.76	3.04	2.90	5.79	8.10	9.52	11.70	8.85
Wall Savings	1.10	1.95	2.00	3.00	2.27	2.95	1.85	2.42
90.1-2010P Total	1.86	4.99	4.90	8.79	10.37	12.47	13.55	11.28
189.1P	1.62	4.56	4.46	7.66	7.89	11.35	12.09	9.57
<b>Source Annual Energy Savings, kBtu/ft<sup>2</sup>-yr</b>								
Roof Savings	2.12	6.38	5.26	9.66	14.37	17.14	19.68	13.17
Wall Savings	3.22	4.63	4.23	5.80	4.10	5.06	2.74	3.34
90.1-2010P Total	5.34	11.02	9.49	15.46	18.47	22.20	22.41	16.51
189.1P	4.64	10.01	8.57	13.57	14.00	20.02	20.07	13.90
<b>Annual Emissions Prevention, kg CO<sub>2</sub>-eq/ft<sup>2</sup>-yr</b>								
Roof Savings	0.15	0.46	0.37	0.68	1.02	1.21	1.39	0.92
Wall Savings	0.23	0.33	0.30	0.41	0.29	0.36	0.19	0.23
90.1-2010P Total	0.39	0.79	0.67	1.09	1.31	1.57	1.58	1.15
189.1P	0.34	0.72	0.61	0.96	0.99	1.42	1.41	0.97

### Primary School



**Figure 14: Primary School Annual Source Energy Savings & Emissions Prevention Savings**

## 6.6 Secondary School Simulation Results

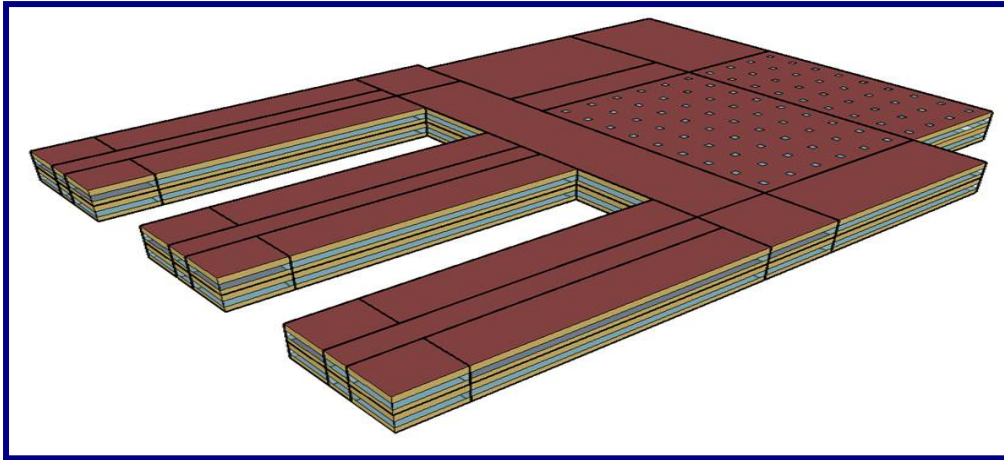


Figure 15: Secondary School Benchmark Model

Table 13: Secondary School Annual Energy Savings and Emissions Prevention Summary

Baseline Model: 90.1-2004 modified to 10% improvement in HVAC & lighting efficiency & 10% decrease in infiltration

Climate Zone	1	2	3	4	5	6	7	8
Baseline Model, kBtu/ft <sup>2</sup>	66	70	64	74	87	102	118	164
<b>Site Annual Energy Savings, kBtu/ft<sup>2</sup>-yr</b>								
Roof Savings	0.45	1.90	1.87	3.97	5.58	6.39	8.38	6.73
Wall Savings	1.00	1.88	1.54	2.63	2.07	2.66	1.82	2.31
90.1-2010P Total	1.45	3.78	3.41	6.60	7.65	9.05	10.20	9.04
189.1P	1.21	3.37	3.27	4.22	6.94	7.95	8.79	7.25
<b>Source Annual Energy Savings, kBtu/ft<sup>2</sup>-yr</b>								
Roof Savings	1.32	4.29	3.53	6.91	11.55	14.19	14.28	10.18
Wall Savings	3.10	4.94	3.50	5.55	4.12	2.75	2.76	3.27
90.1-2010P Total	4.42	9.23	7.03	12.46	15.66	16.94	17.03	13.45
189.1P	3.67	8.15	6.77	12.89	14.21	14.86	14.73	10.68
<b>Annual Emissions Prevention, kg CO<sub>2</sub>-eq/ft<sup>2</sup>-yr</b>								
Roof Savings	0.10	0.31	0.25	0.49	0.82	1.01	1.01	0.71
Wall Savings	0.22	0.36	0.25	0.40	0.29	0.19	0.19	0.23
90.1-2010P Total	0.32	0.66	0.50	0.88	1.12	1.20	1.20	0.94
189.1P	0.27	0.59	0.48	0.91	1.01	1.05	1.04	0.75

### Secondary School

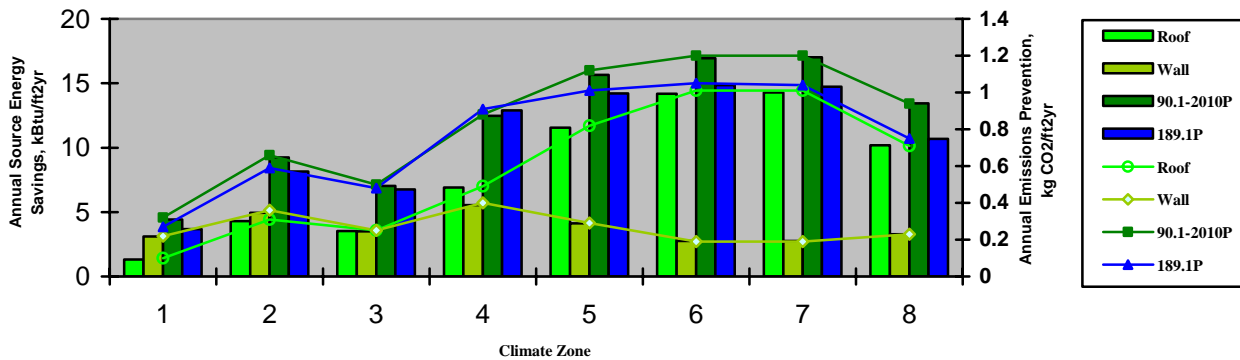


Figure 16: Secondary School Annual Source Energy Savings & Emissions Prevention Savings

## 7.0 THE NET LIFE CYCLE CONCEPT

### 7.1 Strip Mall Results – Energy (Example)

When estimating the energy savings as a result of additional insulation, both the energy saved from additional insulation during the use phase *and* the embodied energy of additional insulation installed to save energy must be considered. The embodied energy refers to energy consumed in all life cycle phases except the use phase, e.g. energy required for extracting raw materials, manufacturing raw materials, and making, installing, transporting and disposing of insulation at end-of-life. Thus, the net energy savings is calculated by:

Net Life Cycle Energy Saved = Energy Saved in Use Phase – Incremental Embodied Energy of Installed Insulation

Table 14: Energy Benefits of Insulation for a 60-Year Building Life								
Ratio: Use Phase Energy Savings vs. Incremental Embodied Energy								
Climate Zone	1	2	3	4	5	6	7	8
Roof	0	9	7	28	28	44	43	47
Wall	20	41	32	74	58	47	21	78
90.1-2010P Total	9	18	14	38	36	45	39	55
189.1P	0.1	17	13	45	39	46	46	52

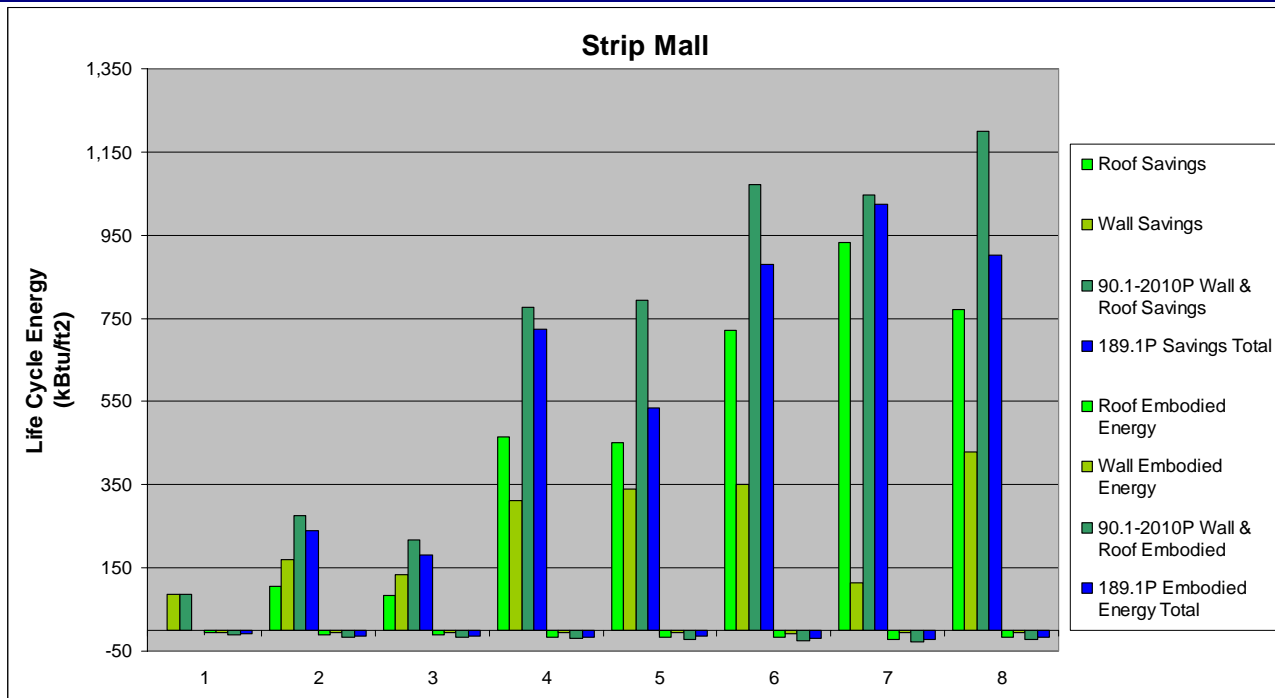


Figure 17: Strip Mall Lifetime Energy Saved & Embodied

Using the Strip Mall as an example to illustrate net life cycle savings and the extent of use phase savings compared to embodied energy, Table 14 shows the ratio of use phase energy savings to incremental embodied energy for each scenario in each climate zone. Both of these values consider the entire life cycle energy and were determined using consistent methodology, as the energy savings in the use phase are based on source energy savings, and the incremental embodied energy covers the entire life cycle for making, installing, transporting etc the insulation. The calculations are based on a 60 year life span, which is feasible for foam insulation installed on properly maintained roofs and within building walls.

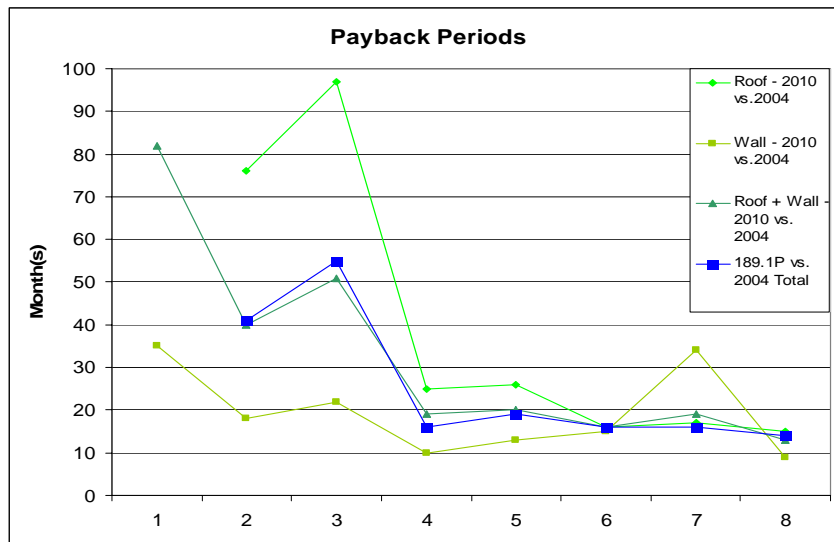
For instance, considering climate zone 5, energy savings from roof insulation for ASHRAE 90.1-2010P (4.9 inches, R-30) versus ASHRAE 90.1-2004 (2.45 inches, R-15) equal 458.1 kBtu/ft<sup>2</sup>. Energy savings from insulation on steel frame wall construction for ASHRAE 90.1-2010P (2.5 inches, R-16) versus ASHRAE 90.1-2004 (0.5 inches, R-3.2) equal 340.2 kBtu/ft<sup>2</sup>. The total savings from roof and wall for ASHRAE 90.1-2010P versus ASHRAE 90.1-2004 equal 792 kBtu/ft<sup>2</sup>.

These energy savings for each ASHRAE scenario were determined using the energy modeling simulation methods discussed in Chapter 5 of this report. The embodied energy for roof and wall are each estimated by using the life cycle embodied energy factors for the appropriate roof (6.69 kBtu/BF) and wall (6.69 and 7.62 kBtu/BF) R-values given in Chapter 4 of this report, which are then multiplied by installed BF for ASHRAE 90.1-2010P and 90.1-2004 respectively (for wall 110,223 BF vs. 55,117 BF, and for roof 27,267 BF vs. 6,476 BF) and then normalized on a ft<sup>2</sup> building basis. The incremental embodied energy is the difference of added embodied energy for ASHRAE 90.1-2010P vs. 90.1-2004, or 16.4 kBtu/ft<sup>2</sup> for the roof and 5.9 kBtu/ft<sup>2</sup> for the wall, or a total of 22.3 kBtu/ft<sup>2</sup> for roof plus wall. Thus, Net Life Cycle Energy Saved = 792 kBtu/ft<sup>2</sup> - 22.3 kBtu/ft<sup>2</sup> = 769.7 kBtu/ft<sup>2</sup>

Similarly, energy savings, incremental embodied energy, and net life cycle energy saved are determined for the 189.1P vs. ASHRAE 90.1-2004 standards. Except for a few cases in climate zones 1 to 3 with minimal insulation requirements, the ratio of energy saved in the use phase over the building life to incremental embodied energy ranges from values around 10 or 20:1 to almost 80:1, demonstrating just how negligible the energy “invested” by making, installing, transporting etc insulation is compared to the energy “earned” by the insulation during building use.

Figure 17 shows the embodied energy as negative values in each climate zone compared to the much larger use phase savings in the positive range, graphically depicting how much greater the savings are in the use phase vs. the one-time energy needed to make and install the insulation. As expected with generally temperate to more severe climate zones in the USA (zone 4 to 8), the energy savings from additional roof insulation on a building with such a roof (22,497 ft<sup>2</sup>) to opaque wall area (10,907 ft<sup>2</sup>) ratio of approx. 2:1 are relatively greater for the roof versus wall cases.

The payback periods shown in Figure 18 were determined by the breakeven point of embodied energy saved to the yearly energy savings. Consistent with the trend in significant energy savings noted for climate zones 4 to 8 above, the payback occurs within about one to two years, which is relatively early in the life of a product built to last 60 years. Except for the moist/marine and relatively mild zones 1 to 3 with less modeled energy savings, the payback is less than 30 months in most cases. The trend for the relatively attractive (10 to 35 month range) wall insulation payback for even climate zones 1 to 4 is related to the benefits achieved from relatively thin (i.e. low incremental embodied energy for 1.25 inch insulation versus no requirement for the ASHRAE 90.1-2010P vs. 90.1-2004, respectively) compared to the energy savings.



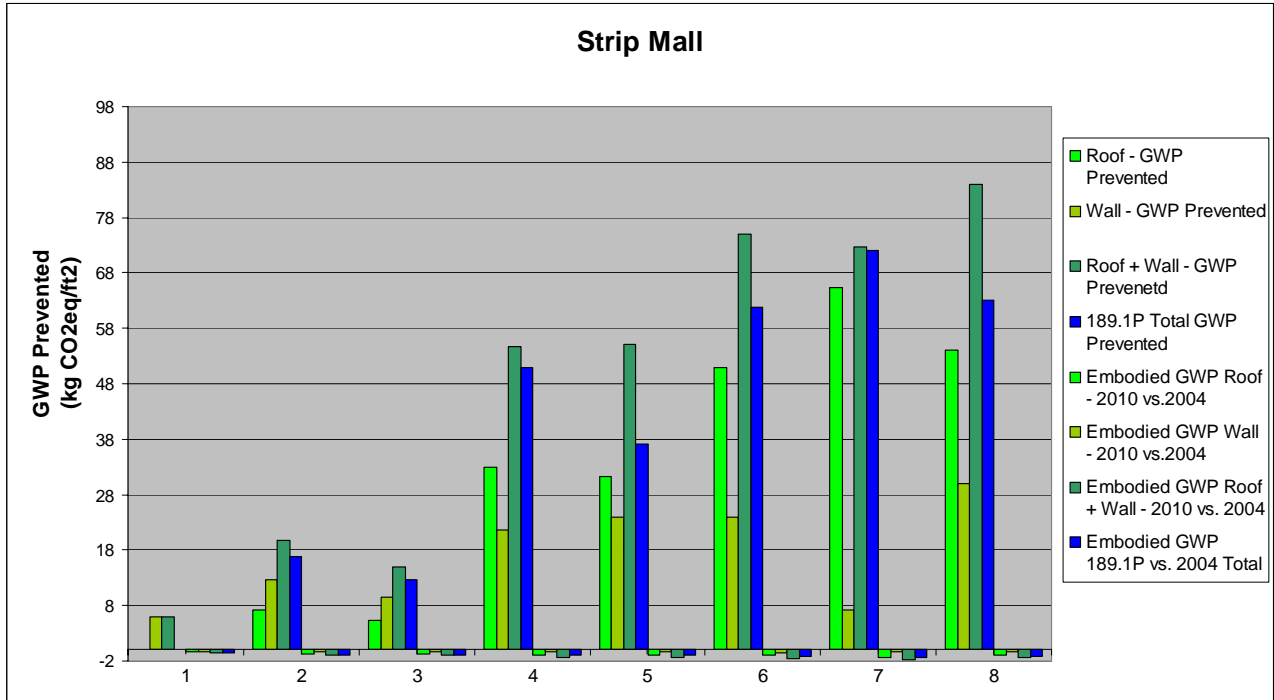
**Figure 18: Strip Mall Energy Payback Periods**

## 7.2 Strip Mall Results – GWP (Example)

The results for GWP emissions are given below. Since GWP prevented and GWP generated from phases other than use are approximately proportional to the energy saved and incremental embodied energy, the trends are similar to those discussed for net life cycle energy savings and associated ratios and payback periods above. Similar to life cycle energy, the net GWP prevented equals GWP prevented in the use phase minus the incremental GWP generated from installed insulation. Except for a few cases in climate zones 1 to 3 with minimal insulation requirements, the ratio of GWP prevented in the use phase over the building life to incremental GWP generated from other life cycle phases ranges from values around 10 or 20:1 to almost 90:1, demonstrating just how negligible the GWP “generated” by making, installing, transporting etc insulation is compared to the GWP “avoided” by the insulation during building use.

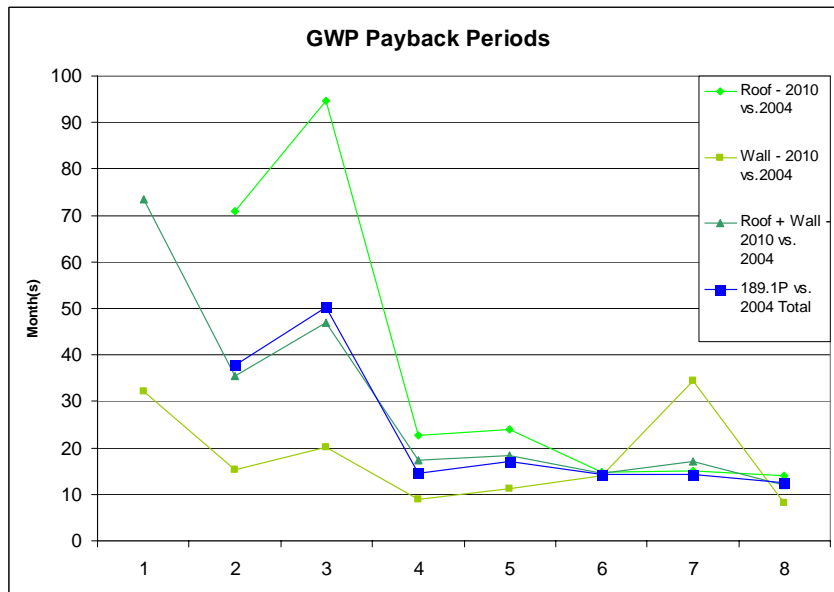
**Table 15: Environmental Benefits of Insulation for a 60-Year Building Life**  
**Ratio: Use Phase GWP Prevented vs. GWP Generated in all Other Life Cycle Phases**

Climate Zone	1	2	3	4	5	6	7	8
Roof	0	10	8	32	30	49	48	51
Wall	22	47	36	80	65	51	21	87
90.1-2010P Wall & Roof	10	20	15	42	39	50	42	60
189.1P	0	19	14	50	42	51	51	57



**Figure 19: Strip Mall Lifetime GWP Prevented & Embodied GWP**

Note: Embodied GWP refers to GWP emissions generated in all life cycle phases except use



**Figure 20: Strip Mall GWP Emissions Payback Periods**

## 8.0 COMMERCIAL BUILDING MARKET ANALYSIS

As stated in the Introduction (Chapter 1), the scope of this research includes the new construction of commercial buildings. Defining this scope further is “continuous insulation” applications of low-slope roofing with insulation entirely above deck (IEAD) along with above-grade exterior walls. In other words, this covers rigid foam insulation for complying with the prescriptive minimum levels for IEAD in low-slope roofing and the continuous insulation in exterior walls in the three ASHRAE standards (ASHRAE 90.1-2004, 2010P and ASHRAE 189.1P) for new construction. In this section, the market that envelopes this scope will be thoroughly evaluated. Completing this exercise should include the following benefits:

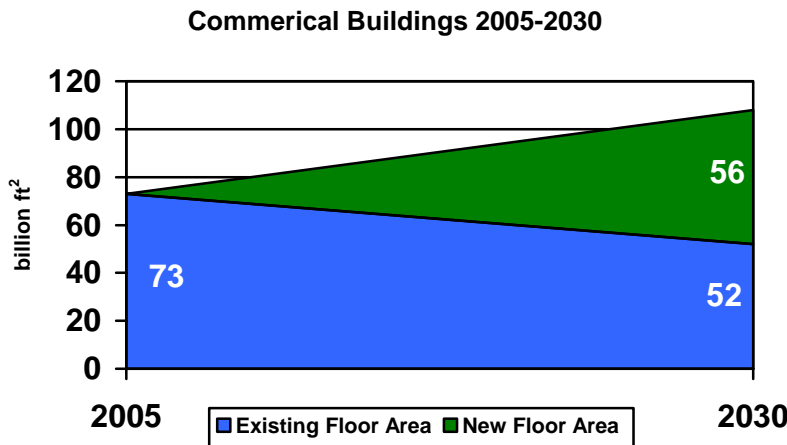
- Provide the basis in executing the energy and environmental impact assessment of the implementation of more stringent building envelope energy standards and codes.
- Provide a tool for interested parties of the polyurethane industry to better define the current market and its potential growth.

As is the case in any research, the boundary limits of this study were set as such in order keep the activity at a manageable level and maintain a focused approach in achieving the objectives and serving the purposes of the project. Of course, this defined scope does not include all applications for polyurethane insulation products. The one application that comes to mind that is not part of this work is framing and attic insulation. In addition, the retrofit market clearly provides a major opportunity for our industry, but is not within the scope of this study. In this regard, though, the authors of this report recently released a report entitled Energy and Environmental Impact Reduction Opportunities for Existing Buildings with Low-Slope Roofs [2]. The research, on which this report was written, was based on extensive energy analyses and life cycle energy and environmental impact of insulation for IEAD applications in re-roofing commercial buildings. The conclusions of this study included a market potential for this application of 1.5 billion square feet of roofing and 3.75 billion board feet of insulation annually.

### 8.1 Commercial Building Construction Forecast

Long range construction forecasts were required for this analysis, so in alignment with environmental targets, the period of current day to 2030 was selected for the projection period. Economic cycles, including the current recession, were ignored in this analysis. The reference source utilized for this information was the EIA Annual Energy Outlook 2007 [11].

The most recent commercial building data (2005) indicate that floor area of existing buildings in the U.S. total 73 billion square feet. This figure is projected to grow to 108 billion square feet by 2030. During this twenty five year period, 56 billion square feet of new commercial floor space is expected to be constructed, with 35 billion square feet for new buildings and the remaining 21 billion square feet being built in order to replace demolished structures. Therefore, **the estimated annual construction of floor area in commercial buildings used for this analysis is 2.24 billion square feet.**



**Figure 20: Projected construction and demolition of commercial building floor area**

## 8.2 Building Type and Climate Zone Weighting Methodologies

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. This survey data is utilized in the study for the market analysis. Therefore, data from the most recent available survey, CBECS 2003, were utilized as the basis for the impact assessment (Chapter 9) of the energy modeling results [12]. The information from the report entitled "DOE Commercial Building Benchmark Models for Energy Simulation" was also very useful for this analysis and in linking the modeling results to the market data [13].

The CBECS data is organized into numerous categories including listing floor area by "Principal Building Type" (PBT). In the above referenced DOE report, Crawley and his colleagues, explain the mapping methodology developed for the purpose of connecting the fifteen (15) commercial building benchmark models [10] to the PBT categories. In addition to linking each of the benchmark models to a PBT, this methodology uses Economic Census data in order to establish the relative importance of each model in each of the sixteen (16) sub-climate zones. This work developed weighting factors for each of the models in each of the sub-climates and therefore, provides an estimate of the geographical characterization of the new additions to the commercial building stock. This methodology is used as the basis for this market analysis.

## 8.3 Types of Construction

ASHRAE 90.1 lists minimum prescriptive requirements in four types of above-grade wall construction: Mass, Metal Building, Steel-Framed and Wood Framed and Other. In order to simplify this effort somewhat, Metal Building construction was not included in this analysis. Data that could be used to estimate the distribution of new construction activity between these three means of wall construction was unavailable. The weighting of each type used for the market analysis calculations are reflective of the type selected for each of the benchmark model input files and is roughly as follows:

Steel-Frame – 70%

Mass – 25%

Wood Frame – 5%

### 8.3.1 ROOFS

Again, the scope of this project in terms of the roof design of the building envelope is limited to low-slope. Therefore, an effort was made to estimate the typical portion of annual new construction activity associated with low-slope roofing. The CBECS 2003 includes data on frequency of application of the various roofing materials. It was from this data that the breakdown between low and steep-slope roofing was estimated to be 68% and 32%, respectively. Only roof area associated with low-slope construction is included in the calculation for the market potential comparisons of the advanced building standards to the current prevalent standard of ASHRAE 90.1-2004.

## 8.4 Summary of Market Potential Boundaries

The following list serves to define the boundary limits for the market analysis:

- All new construction and major additions at an annual projected rate of 2.24 billion square feet is included.
- All above grade exterior wall area is included. Total wall area is calculated from weighted distribution of the 15 benchmark buildings and sub-climate zones.
- Low-slope roof area where application of insulation is considered IEAD. Total low-slope area is calculated from the low-slope factor of 68% and the weighted distribution of the 15 benchmark buildings and sub-climate zones.
- Above grade insulation applications that comply with the ASHRAE criteria of continuous insulation, ci. Framing insulation, below grade and floor insulation and attic insulation are not included.
- The warehouse benchmark building model is predominately associated with "semi-heated" floor space and lower insulation standards apply to this type of building. As a result, a factor of 50% of the calculated ci insulation potential is used for this model.

Based on the prescriptive minimum building envelope insulation levels required through ASHRAE 90.1-2004 (current market), ASHRAE 90.1-2010P and ASHRAE 189.1P, the market potentials for ci applications are estimated using the above boundaries. Table 21 shows the breakdown of the estimated annual new construction by weighted average of floor and building envelope areas for the benchmark model buildings.

**Table 16: Estimated Annual New Construction by Model Building Type**

Building Type	Floor Area	Flat Roof Area*	Opaque Wall Area
	Million Ft <sup>2</sup>	Million Ft <sup>2</sup>	Million Ft <sup>2</sup>
Primary School	513	349	121
Strip Mall	265	180	129
Medium Office	226	51	60
Secondary School	215	88	45
Large Office	215	11	32
Warehouse	202	131	56
Retail	144	98	69
Small Office	110	75	48
Hospital	104	12	20
Large Hotel	81	7	23
Outpatient Care	69	24	34
Restaurant	46	31	20
Supermarket	31	21	11
Fast Food	10	7	7
Small Hotel	5	1	2
<b>Total</b>	<b>2240</b>	<b>1087</b>	<b>677</b>
<b>Total of Modeled Buildings</b>	<b>1474</b>	<b>842</b>	<b>471</b>
<b>% of Total</b>	<b>66%</b>	<b>77%</b>	<b>70%</b>

\* The roof square foot for each building type was multiplied by a factor of 0.68 as an estimate of low-slope roof area only.

### 8.5 Building Envelope and Continuous Insulation Market Analyses

The basis for this analysis is the annual new construction estimate of 2.24 billion square feet along with the configuration of the fifteen (15) benchmark models. The weighting factors described in Section 8.2 are used to calculate the number of each type of building model located in each climate zone as well as the break down of the total floor areas. Table 16 lists the results by building model on a nation-wide total. The six prototypes modeled for this study are amongst the top eight buildings represented 66% of the total estimated floor area of new construction. It is believed that the weighted averages of the energy performance of these six models closely represent that of all buildings.

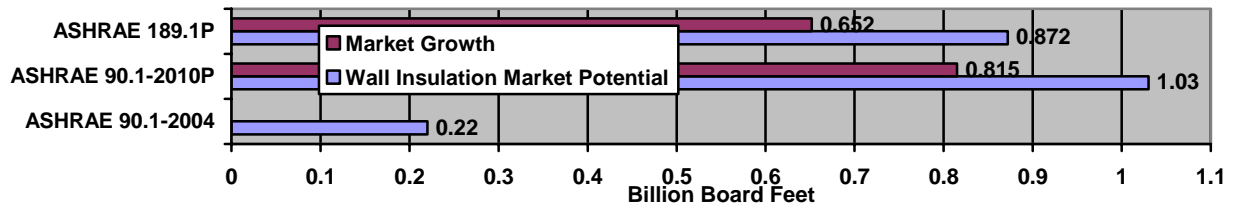
Of course, buildings are designed in an infinite array of shapes and envelope designs, such as fraction of window to opaque wall area, creating an impossible task of accurately pinpointing the building envelope market. However, this analysis could be useful to provide the relative comparison of the current market potential for PUR/PIR products in continuous insulation applications versus the future potential following the adoption of upgraded energy standards and codes.

The exterior opaque wall and roof areas are calculated for each model in each climate zone. However, the roof area results are then multiplied by a factor of 0.68 in order to incorporate only that which is estimated to be low-slope (Section 8.3.2). The nation-wide results are included in Table 16. The market potentials on a board foot basis were derived by the product of the raw sub-climate for each building and its appropriate insulation board footage (listed in Appendix B for the six models simulated).

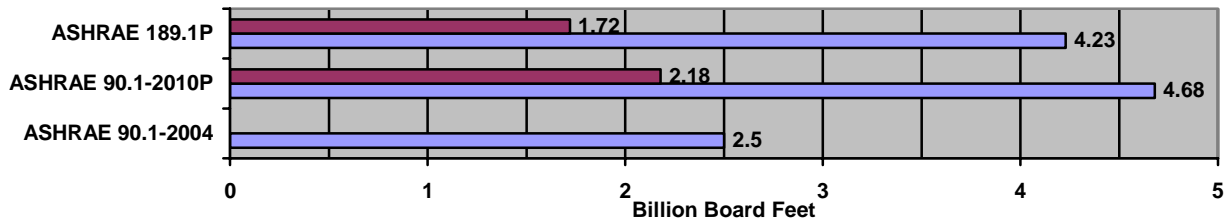
Table 17 and Figure 21 illustrate the market potential of the advanced standards relative to that of the current market under ASHRAE 90.1-2004. The opportunity of market growth for the Polyurethane Industry as a result of the probable adoption of energy codes is remarkable. The wall market for continuous insulation, ci, has the potential of growth at a factor of almost five from the current size of just 220 million board feet to 1 billion board feet if ASHRAE 90.1-2010 is implemented nation-wide. In terms of absolute board feet, PUR/PIR in the roof market could benefit the most with over two (2) billion board feet of market size growth. The total market for rigid foam in ci applications could potentially increase by 2.3 to 3 billion board feet to over 5 billion, more than doubling the size of the market.

<i>Table 17: Market Potential Comparisons</i>			
	ASHRAE Standard	Market	% Growth VS 90.1-2004
		Billion Board Ft	
Wall	90.1-2004	0.2	
	90.1-2010P	1.0	470%
	189.1P	0.9	396%
Roof	90.1-2004	2.5	
	90.1-2010P	4.7	87%
	189.1P	4.2	67%
Total	90.1-2004	2.7	
	90.1-2010P	5.7	110%
	189.1P	5.0	85%

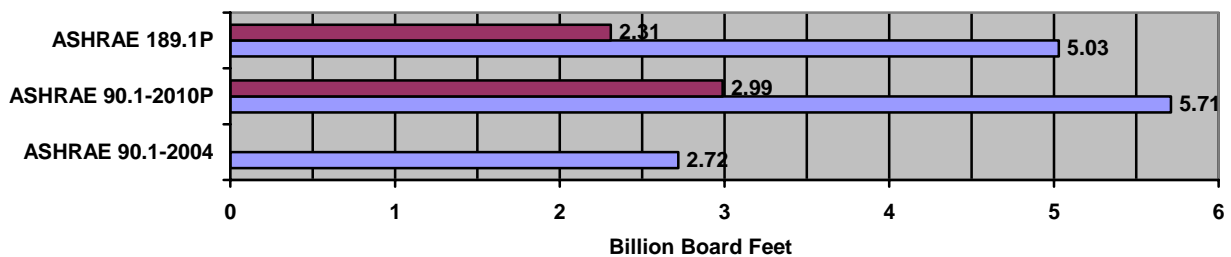
**Wall Insulation Market Potential**



**Roof Insulation Market Potential**



**Continuous Insulation Market Potential**



**Figure 21: Comparison of Market Potential Estimates**



## 9.0 IMPACT ASSESSMENT

This study modeled the energy savings for six (6) buildings, with results given in Chapter 6.0 of this report. As noted in Section 8.4, these six buildings cover 1.474 billion square feet of the total 2.240 billion square feet of floor area (66%) projected for new construction and are believed to be a reasonable cross section for the purpose here to represent the energy performance of all fifteen (15) benchmark models. The boundary limits listed in Section 8.4 established for the market analysis provide the limits to assess the impact of constructing commercial buildings so that the continuous insulation of all exterior walls and low-slope roofs comply with the upgraded energy efficiency standards. The data collected from the six (6) buildings modeled and weighted by the methodology described in Section 8.2 drives the assessment presented in this Chapter.

The simulations were conducted in a progressive order so that the effect of each individual variable could be observed: 1.) The first step was to run the model in its original ASHRAE 90.1 compliant design. 2.) The model was next modified to improve the efficiency of the building (improvements in lighting, HVAC and air infiltration) and this simulation was established as the baseline case. As discussed earlier in this report, this was done to reflect the likelihood newly constructed buildings in the near future would have other enhanced efficiency measures installed in addition to higher levels of insulation. This was appropriate to reflect the true energy performance of the building, however, it clearly increased the energy performance of the baseline for which the higher levels of insulation were compared. 3.) The third stage was to change the roof insulation only to the minimum level of insulation of the preliminary version of ASHRAE 90.1-2010. 4.) Next, this model input file was adjusted to reflect the minimum insulation level of ASHRAE 90.1-2010P. Lastly, both the roof and the walls were adjusted to reflect the values of ASHRAE 189.1P.

Note: It is highly probable that the rate of unintentional air infiltration would be significantly improved through the continuous application of PUR/PIR products. Data providing evidence of the magnitude of this benefit is not available, so no adjustments were made in the model input file to reflect this affect.

### 9.1 Annual Energy Savings and GWP Prevented

In this section, we explore the potential energy and emissions impact of future advanced model energy codes following their implementation and effective enforcement. First, an explanation will be provided as to the methodology of expanding the results from the simulation of these six (6) buildings in sixteen (16) separate locations. The energy savings data were organized by building type in climate zones and the weighting was applied. Since all models were simulation with a low-lope roof design, the roof data was multiplied by a factor of 0.68 to reflect the portion of new construction which is IEAD application. All wall data were included in the analysis.

The annual source energy savings and GWP prevented data are presented in Table 18 below. The thickness of insulation added to the roof is greater than that of the wall and the results clearly show it with higher energy savings and GWP prevented on a per square foot basis. Use Phase savings of 21.0 and 12.3 trillion Btu were achieved for ASHRAE 90.1-2010P and ASHRAE 189.1P, respectively. GWP preventions of 1.489 and 0.867 million metric tons CO<sub>2</sub>-eq. were achieved for ASHRAE 90.1-2010P and ASHRAE 189.1P, respectively.

A comparison of these results to those of the recent study released by the authors where baseline building is R-12 provides an interesting point of reference for both studies [2]. Released in April 2009, this similar comprehensive energy study indicated that the existing building stock with low-slope roofs only required roof replacement at the rate of 2.75 billion square feet of floor area each year. Furthermore, it is at this rate that additional insulation can be installed.

**Table 18: Annual Use Phase Source Energy Savings and GWP Prevented**

Annual Use Phase Impact Reductions		Floor Area	Source Energy Savings		GWP Prevented	
		Billion ft <sup>2</sup>	kBtu/ft <sup>2</sup>	Trillion Btu	kg CO <sub>2</sub> -eq/ft <sup>2</sup>	Million Metric Tons CO <sub>2</sub> -eq
<b>90.1-2010P VS 90.1-2004</b>	<i>Low-Slope Roofs 90.1-2010P</i>	1.52*	6.92	10.5	0.488	0.743
	<i>Exterior Walls 90.1-2010P</i>	2.24	4.68	10.5	0.331	0.746
	<i>Above Grade Bldg. Envelope 90.1-2010P</i>	2.24	9.39	21.0	0.665	1.489
<b>189.1P VS 90.1-2004</b>	<i>Above Grade Bldg. Envelope 90.1-2010P</i>	2.24	5.49	12.3	0.387	0.867
<b>Re-roof Study 90.1-2010P VS R-12 [2]</b>		2.75**	10.76	29.6	0.771	2.12

\*68% of annual new construction floor area has low-slope roof

\*\*Study estimated that 2.75 billion ft<sup>2</sup> of floor area of existing buildings with low-slope roofs required re-roofing and insulation could be installed.

Lifetime (60 Year) Use Phase Impact Reductions		Floor Area	Use Phase Energy Savings	Incremental Embodied Energy	Net Total Energy Saved	Use Phase Savings vs. Incremental Embodied
		Billion ft <sup>2</sup>	Trillion Btu			Ratio
90.1-2010P VS 90.1-2004	<i>Low-Slope Roofs 90.1-2010P</i>	1.52*	633	22	611	29
	<i>Exterior Walls 90.1-2010P</i>	2.24	629	11	618	57
	<i>Above Grade Bldg. Envelope 90.1-2010P</i>	2.24	1,262	33	1,229	38
189.1P VS 90.1-2004	<i>Above Grade Bldg. Envelope 90.1-2010P</i>	2.24	738	25	713	30

\*68% of annual new construction floor area has low-slope roof  
Note: Incremental Embodied Energy as % Energy Saved = 2.6% for 90.1-2010P and 3.4% for 189.1P vs. 90.1-2004, respectively.

Lifetime (60 Year) Use Phase Impact Reductions		Floor Area	Use Phase GWP Prevented	Incremental GWP Generated	Net GWP Prevented	Use Phase GWP Prevented vs. Incremental GWP Generated
		Billion ft <sup>2</sup>	Million metric tons CO <sub>2</sub> -eq.			Ratio
90.1-2010P VS 90.1-2004	<i>Low-Slope Roofs 90.1-2010P</i>	1.52*	44.6	1.4	43.2	32
	<i>Exterior Walls 90.1-2010P</i>	2.24	44.7	0.8	43.9	56
	<i>Above Grade Bldg. Envelope 90.1-2010P</i>	2.24	89.3	2.2	87.1	41
189.1P VS 90.1-2004	<i>Above Grade Bldg. Envelope 90.1-2010P</i>	2.24	52.0	1.7	50.3	31

\*68% of annual new construction floor area has low-slope roof  
Note: Incremental GWP as % GWP Prevented = 2.5% for 90.1-2010 and 3.3% for 189.1P vs. 90.1-2004, respectively.

## 9.2 Net Life Cycle Energy Savings and GWP Prevented

Table 19 and Table 20 show the energy and environmental impact of ASHRAE 90.1-2010P and 189.1P for a sixty (60) year insulation lifetime. The results illustrate the magnitude of the benefits provided by durable products such as PUR/PIR insulation, and quantitatively demonstrate that incremental embodied energy (or GWP generated) is relatively negligible compared to use phase energy saved and GWP emissions prevented. These results also highlight the value of a life cycle approach to assessing the energy or GWP impact of products, as this balanced perspective shows that the whole life cycle must be considered and pinpoints the life cycle phases that make substantial energy and environmental contributions. The dominant life cycle phase for PUR/PIR insulation is clearly the use phase.

Installed insulation on the exterior walls and low-slope roofs at the levels required under the prescriptive minimums of ASHRAE 90.1-2010P or 189.1P for each year of new construction accumulates 738 to 1,262 trillion Btus of use phase energy savings, and 52.0 to 89.3 million metric tons of use phase GWP prevented during the lifetime of the buildings. In contrast, the one time energy or GWP associated with other life cycle phases (raw material extraction, manufacturing, transportation, installation, end-of-life disposal) amounts to approximately 2.5% to 3.5% of energy saved or GWP emissions prevented.

The total estimated energy savings (or GWP prevented) given in Tables 19 and 20 are based on prorating the energy savings (or GWP prevented) for the six buildings based on floor space up to the total projected energy savings (or GWP prevented) based on new construction floor space. Roof energy savings (or GWP prevented) included only that realized from installing insulation on low-slope roofs, i.e. 1.52 billion ft<sup>2</sup> of floor space versus the total of 2.24 billion ft<sup>2</sup> of floor space used for wall estimates.

Total incremental embodied energy and associated GWP were based on using the Strip Mall and calculating the embodied energy and associated GWP emissions using the weighted average of additional insulation installed across all eight US climate zones. Thus, the factors for embodied energy (kBtu/BF) and associated GWP (kg CO<sub>2</sub>-eq./BF) for a specified insulation R-value (or thickness) in Chapter 4 were used to determine the embodied energy and associated GWP for the base ASHRAE 90.1-2004, 90.1-2010P and 189.1P insulation cases in each climate zone. These were summed up to determine the total embodied energy and associated GWP for each of the three standards, and the total floor area was then used to obtain the weight average normalized embodied energy (kBtu/ft<sup>2</sup>) and associated GWP (kg CO<sub>2</sub>-eq./ft<sup>2</sup>) for each of the standards. The incremental normalized embodied energy and associated GWP were obtained by subtracting the ASHRAE 90.1-2010P and 189.1P values from the base 90.1-2004 value, respectively. These factors were then applied to the total floor space associated with roofing and wall insulation noted in Table 19 and Table 20.

Although the incremental embodied energy and associated GWP for installed insulation may vary somewhat for different building configurations, climate zones etc, factors obtained using the Strip Mall provide a reasonable first-pass estimate of the net total energy saved (or GWP prevented) during the building life span. As shown in Table 19, total energy saved during building use is 30 to 38 times more than the total embodied energy for additional insulation required by ASHRAE 189.1P and 90.1-2010P versus the ASHRAE 90.1-2004 base standard, respectively. Thus, from a total life cycle perspective, insulation pays energy dividends many times over compared to the one time energy used to make and install it.

As shown in Table 20, total GWP emissions avoided during building use is 31 to 41 times more than GWP emissions generated from all other life cycle phases for additional insulation required by ASHRAE 189.1P and 90.1-2010P versus the ASHRAE 90.1-2004 base standard, respectively. Similarly, from a total life cycle perspective, insulation provides environmental benefits through substantial prevention of GWP emissions in the use phase compared to the relatively negligible one time GWP emissions associated with all other life cycle phases.

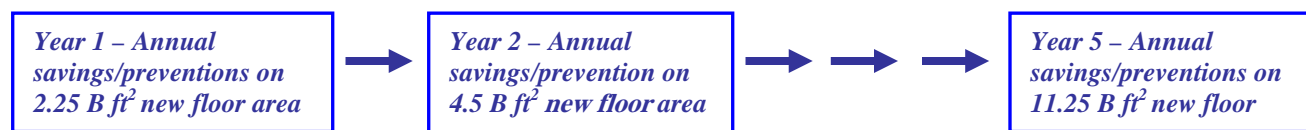
It is interesting to observe from Table 19 and Table 20, for the ASHRAE 90.1-2010P versus the ASHRAE 90.1-2004 base standard, that the ratio of energy saved (or GWP prevented) versus embodied energy (or associated GWP generated) for wall insulation is about two times greater than this ratio for roof insulation. This results mainly from the relatively thinner wall insulation compared to roof insulation, which means a lower estimated embodied energy (or associated GWP generated) for the wall insulation. The identical type of insulation material (foam with GRF facer) was used to calculate the embodied energy (or associated GWP) for both the roofs and walls. These ratios could change if, for example, an aluminum craft paper facer is used for wall insulation that carries a higher embodied energy (or associated GWP). Since data for such refined estimates are not yet available to the authors and are beyond the scope of this report, the values provided above are used to provide a preliminary estimate.

### 9.3 Cumulative Impact Assessment

To represent the cumulative benefits, six parameters were established and are explained below. First, the cumulative impacts on an annual basis are evaluated in terms of the following three boundary points:

- **Annual energy savings and emissions prevention after five (5) years.**
- **Annual energy savings and emissions prevention after ten (10) years.**
- **Annual energy savings and emissions prevention after twenty (20) years.**

Following the successful nation-wide adoption and effective enforcement of updated energy codes, the use of PUR/PIR insulation products can potentially play an important role in achieving deep reductions in energy and environmental impacts of constructing and operating new buildings. Here, the annual rate of realizing these reductions through the accumulation of 2.25 billion square feet of floor area each year to the stock of commercial buildings with increased levels of insulation is demonstrated. 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.



Next, are a set of parameters that use the same time spans as above, but that demonstrate the potential additive impact of the new standards. In other words, instead of calculating the annual rates, these boundary points will demonstrate total accumulation of savings and preventions through the given time spans:

- **Accumulation of energy savings and emissions prevention through five (5) years.**
- **Accumulation of energy savings and emissions prevention through ten (10) years.**
- **Accumulation of energy savings and emissions prevention through twenty (20) years.**

As is evident by the data presented regarding the cumulative savings calculations, the opportunity for energy consumption reductions through added levels of PUR/PIR insulation in the construction of commercial buildings is compelling.



Tables 21 through 23 provide the cumulative annual results for ASHRAE 90.1-2010P and ASHRAE 189.1P. Adding 2.24 billion square feet of floor area of new construction each year for 11.2, 22.2 and 44.8 billion square feet for 5, 10 and 20 years, respectively. The annual and cumulative source energy savings and GWP preventions calculated and compiled in these tables provide an important perspective of the impact of compliance with the proposed energy efficiency standards included in the scope of this project.

**Table 21: Cumulative Annual Use Phase Source Energy Savings and GWP Prevented, ASHRAE 90.1-2010P**

<b>90.1-2010P VS 90.1-2004</b>	<b>Floor Area Included billion ft<sup>2</sup></b>		<b>Annual Energy Savings Trillion Btu</b>	
	<b>First Year</b>	<b>Year 5, 10 or 20</b>	<b>First Year</b>	<b>Year 5, 10 or 20</b>
<b>After 5 years</b>		11.2		105
<b>After 10 years</b>	2.24	22.4	21.0	210
<b>After 20 years</b>		44.8		420

<b>90.1-2010P VS 90.1-2004</b>	<b>Floor Area Included billion ft<sup>2</sup></b>		<b>Annual GWP Prevention Million Metric Tons CO<sub>2</sub>-eq</b>	
	<b>First Year</b>	<b>Year 5, 10 or 20</b>	<b>First Year</b>	<b>Year 5, 10 or 20</b>
<b>After 5 years</b>		11.2		7.45
<b>After 10 years</b>	2.24	22.4	1.49	14.9
<b>After 20 years</b>		44.8		29.8

**Table 22: Cumulative Annual Use Phase Source Energy Savings and GWP Prevented, ASHRAE 189.1P**

<b>189.1P VS 90.1-2004</b>	<b>Floor Area Included billion ft<sup>2</sup></b>		<b>Annual Energy Savings Trillion Btu</b>	
	<b>First Year</b>	<b>Year 5, 10 or 20</b>	<b>First Year</b>	<b>Year 5, 10 or 20</b>
<b>After 5 years</b>		11.2		61.5
<b>After 10 years</b>	2.24	22.4	12.3	123
<b>After 20 years</b>		44.8		246

<b>189.1P VS 90.1-2004</b>	<b>Floor Area Included billion ft<sup>2</sup></b>		<b>Annual GWP Prevention Million Metric Tons CO<sub>2</sub>-eq</b>	
	<b>First Year</b>	<b>Year 5, 10 or 20</b>	<b>First Year</b>	<b>Year 5, 10 or 20</b>
<b>After 5 years</b>		11.2		4.34
<b>After 10 years</b>	2.24	22.4	0.867	8.67
<b>After 20 years</b>		44.8		17.3

### 9.3.1 SOURCE ENERGY SAVINGS IMPACT ASSESSMENT

Aligned with national targets, ASHRAE has set goals for improvements in energy efficiency through the upgrading of the proposed standards of ASHRAE 90.1-2010 and ASHRAE 189.1 with ASHRAE 90.1-2004 used as the baseline. Of course, these goals can be achieved through enhancements in the standards that apply to measures in addition to continuous insulation requirements. The specific goals are site energy savings of 11kBtu/ft<sup>2</sup>yr (based on floor area) for 90.1-2010 and 22kBtu/ft<sup>2</sup>yr for 189.1. Using the same annual new construction forecast average of 2.24 billion square feet, these annual site energy savings equal 24.6 trillion Btu and 49.2 trillion Btu, respectively. Based on the average U.S. proportion of electricity versus natural gas consumption in buildings concluded by CBECS-2003 data [12], by applying factors of 2.0 and 2.5, these savings are converted into source energy savings in the range of 49.2 - 61.5 trillion Btu for 90.1-2010 and 98.4 - 123 trillion Btu for 189.1. Therefore, results obtained by this study conclude the following in regard to energy savings:

- The U.S. weighted average impact for annual source energy savings under the continuous insulation requirements of the current proposed version of ASHRAE 90.1-2010 is **21 trillion Btu**. Therefore, **between 34 and 43 percent** of the total energy efficiency improvement goal set by ASHRAE for 90.1-2010 can be achieved by these specific requirements.
- The U.S. weighted average impact for annual source energy savings under the continuous insulation requirements of the current proposed version of ASHRAE 189.1 is **12.3 trillion Btu**. Therefore, **between 10 and 13 percent** of the total energy efficiency improvement goal set by ASHRAE for 189.1 can be achieved by these specific requirements.

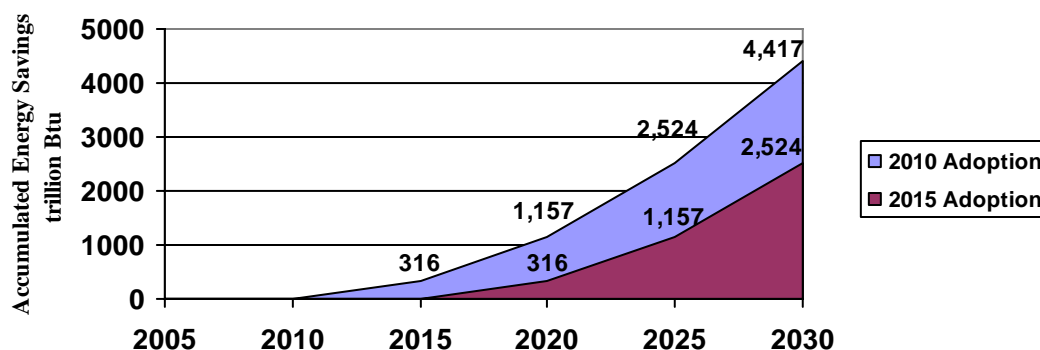
**Table 23: Accumulation of Total Use Phase Source Energy Savings and GWP Prevented, ASHRAE 90.1-2010P**

<b>90.1-2010P VS 90.1-2004</b>	<b>Floor Area Included billion ft<sup>2</sup></b>		<b>Annual Energy Savings Trillion Btu</b>	
	<b>First Year</b>	<b>Year 5, 10 or 20</b>	<b>First Year</b>	<b>Year 5, 10 or 20</b>
<b>Through 5 years</b>		11.2		316
<b>Through 10 years</b>	2.24	22.4	21.0	1,157
<b>Through 20 years</b>		44.8		4,417
<b>90.1-2010P VS 90.1-2004</b>	<b>Floor Area Included billion ft<sup>2</sup></b>		<b>Annual GWP Prevention Million Metric Tons CO<sub>2</sub>-eq</b>	
	<b>First Year</b>	<b>Year 5, 10 or 20</b>	<b>First Year</b>	<b>Year 5, 10 or 20</b>
<b>Through 5 years</b>		11.2		22.3
<b>Through 10 years</b>	2.24	22.4	1.49	81.9
<b>Through 20 years</b>		44.8		313

**Table 24: Accumulation of Total Use Phase Source Energy Savings and GWP Prevented, ASHRAE 189.1P**

<b>189.1P VS 90.1-2004</b>	<b>Floor Area Included billion ft<sup>2</sup></b>		<b>Annual Energy Savings Trillion Btu</b>	
	<b>First Year</b>	<b>Year 5, 10 or 20</b>	<b>First Year</b>	<b>Year 5, 10 or 20</b>
<b>Through 5 years</b>		11.2		184
<b>Through 10 years</b>	2.24	22.4	12.3	676
<b>Through 20 years</b>		44.8		2,581
<b>189.1P VS 90.1-2004</b>	<b>Floor Area Included billion ft<sup>2</sup></b>		<b>Annual GWP Prevention Million Metric Tons CO<sub>2</sub>-eq</b>	
	<b>First Year</b>	<b>Year 5, 10 or 20</b>	<b>First Year</b>	<b>Year 5, 10 or 20</b>
<b>Through 5 years</b>		11.2		13.0
<b>Through 10 years</b>	2.24	22.4	0.867	47.7
<b>Through 20 years</b>		44.8		182

### Source Energy Savings, ASHRAE 90.1-2010



**Figure 22: Impact on Savings due to Energy Adoption Timing**

Furthermore, it is useful to consider the impact of not implementing and enforcing energy codes that adopt these standard minimum requirements and also to consider the implication of delaying their adoption from a source energy consumption perspective. For example, the typical U.S. coal-fired power plant generates 13.7 trillion Btu of electricity annually which equates to 43 trillion Btu of source energy. Therefore, the annual source energy savings realized from the increased stringency for continuous insulation in ASHRAE 90.1-2010 is equal to the energy consumed to generate the electricity of 2.5 coal-fired power plants in five (5) years, nearly five (5) plants in ten (10) years and nearly ten (10) plants in twenty (20) years.

To fully appreciate the magnitude of importance of the prompt adoption of these energy standards, it is useful to consider the accumulated benefits given the continual and long term durability of PUR/PIR insulation products. Figure 22 illustrates this point. If implemented in the near future so that the benefits can be realized beginning in 2011, the U.S. can save the consumption of energy of greater than 4,400 trillion Btu. If instead, five years pass before implementation nearly 1,900 trillion Btu of source energy savings will be lost.

Finally, it is pertinent to note that the source energy savings results from the re-roof study conducted by the same authors [2]. This study utilized the same rigorous and comprehensive tools and procedures to conclude that 1.5 billion square feet annually of low-slope existing commercial buildings that require roof replacement would highly benefit from adding insulation to the 90.1-2010P levels. The conclusions from this analysis included an annual source energy savings rate of 266 and 532 trillion Btu after ten (10) and twenty (20) years, respectively.

#### 9.3.2 GWP PREVENTION IMPACT ASSESSMENT

The discussion in this section is closely linked to Chapter 3, “Global Greenhouse Gas (GHG) Abatement”, where the McKinsey Initiative and their conclusions regarding abatement opportunities are described. Recall that a key aspect of this initiative is that the “cluster” of options connected to building and appliance energy efficiency was identified as being the most critical. The findings from the research here are very relevant to the abatement options identified through the McKinsey project.

McKinsey identified 60 to 72 million metric tons CO<sub>2</sub>eq of abatement potential by 2030 for the building shells that are equally split between residential and commercial buildings. The report stated that the reference base for comparison in the case of commercial buildings is one which is built to a higher standard than residential. This suggests that the baseline building used was already at least fairly energy efficient and was similar to the baseline building used in this study. Comparing this potential to the annual GWP prevention results listed in Table 21 indicates that if ASHRAE 90.1-2010 is adopted promptly, this abatement can be realized fully through the continuous insulation requirements alone (Table 26).

<b>Annual Emissions Prevention by 2030</b>	<b>Million Metric tons CO<sub>2</sub>-eq</b>
<b>McKinsey</b>	<b>30 to 36</b>
<b>This study – 90.1-2010P</b>	<b>30</b>
<b>This study – 189.1P</b>	<b>17</b>
<b>Re-roof study</b>	<b>38</b>

## 10.0 CONCLUSIONS

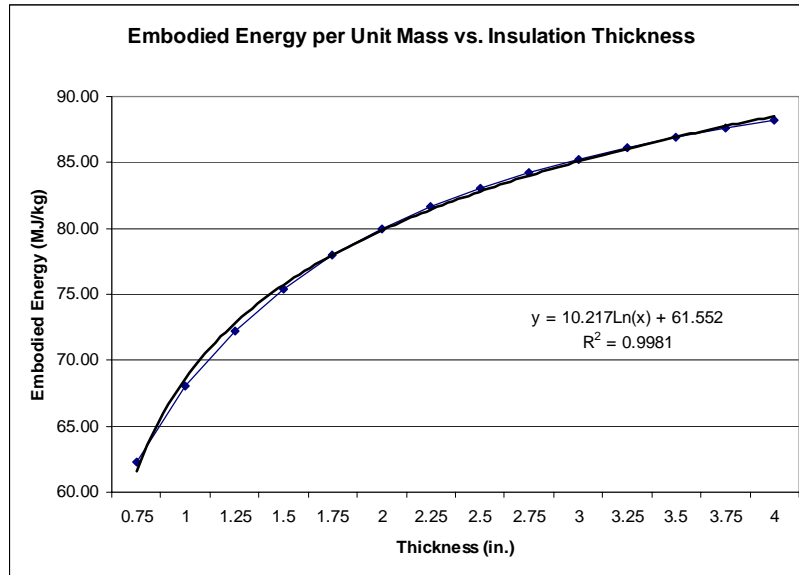
In concert with aggressive U.S. and global targets for energy efficiency and environmental impact, policy is currently driving the prompt transformation of energy standards and codes for new and retrofit construction. It is the intent of this study to demonstrate that spray polyurethane, boardstock and metal faced polyisocyanurate insulation products can support this transformation, as credible evidence of energy savings and emissions prevention is provided. From the research conducted and the results presented in this report, the intent has been satisfied and the following conclusions have been established:

- Long term projections for new construction along with goals of deep reductions in energy consumption and emissions of greenhouse gases, reinforce the essential need to enhance, promptly adopt and enforce energy standards and codes for commercial buildings. These projections show that the U.S. commercial building stock will grow from today's 73 billion square feet to 108 billion square feet of floor area by 2030. In addition to the 35 billion square feet of added floor area over the next twenty (20) plus years, 21 billion square feet will replace demolished existing buildings.
- The enhanced continuous insulation (ci) requirements of the proposed standard codes, ASHRAE 90.1-2010P and ASHRAE 189.1P contribute substantially to the near term and universal energy efficiency improvement target of thirty (30) percent. In fact, by implementing promptly and through effective enforcement, source energy savings of the magnitude of 246 (189.1P) to 420 (90.1-2010P) trillion Btu annually can be achieved by 2030. These estimates do not consider additional enhancements in ci requirements beyond the implementation of these two standards.
- The enhanced requirements of the proposed standards also contribute to the long term targets of deep reductions of greenhouse gas emissions. Through prompt implementation and effective enforcement, annual emissions reductions can be realized at the magnitude of 17 to 30 million metric tons of CO<sub>2</sub>-eq by 2030.
- Time is of the essence, as the opportunity lost by delaying the enactment of stricter energy standards and codes is very significant. A delay in implementing the ci requirements in ASHRAE 90.1-2010P until 2015 can result in not realizing as much as 1,900 trillion Btu and 134 million metric tons of CO<sub>2</sub>-eq by 2030.
- The adoption of these standards has an extraordinary influence on the size of the market potential for PUR/PIR insulation products. Based on the ci requirements of ASHRAE 90.1-2010, the market potential for new construction (i.e. re-roof/retrofit market not included) increases by 87 percent to 4.7 billion board feet. The growth in the wall market potential is even more dramatic; with the current market under ASHRAE 90.1-2004 of barely 200 million board feet, the market potential under 90.1-2010 could increase by 270 percent to approximately one billion board feet. In all, the market size for PUR/PIR and other rigid foam products in low-slope roof and all exterior walls for new construction of commercial buildings could increase by roughly 3 billion board feet to 5.7 board feet.
- From a net life cycle energy or GWP perspective, the total embodied energy in the insulation (i.e. energy for raw material extraction, manufacturing, installation, disposal etc) is typically recovered within one to two years by the energy savings during its use. The payback period for greenhouse gas emissions prevented is similar, as the one time emissions associated with manufacture, installation, disposal etc are recovered with a one to two year period by the greenhouse gas emissions prevented during use. As shown also by the ratios of use phase energy saved to embodied energy (29 for roofs, 57 for exterior walls) and similar ratios for GWP prevented during use versus GWP associated with other life cycle phases (32 for roofs, 56 for exterior walls), the energy and GWP impacts from manufacturing phases are relatively negligible compared to the use phase benefits.
- The results of this study are consistent with the annual GWP abatement potential published by McKinsey and Company in 2007 and the number one opportunity recommended by the National Resources Defense Council for reducing greenhouse gases through improved building efficiency. The McKinsey analysis noted that 30 to 36 million metric tons per year of CO<sub>2</sub>-eq. could be reduced by 2030 due to commercial building shell improvements. The authors' study quantified that 30 million metric tons per year of CO<sub>2</sub>-eq. could be prevented annually by 2030 through implementing the proposed ASHRAE 90.1-2010P standard. Thus, the commercial building GWP abatement potential reported by McKinsey can be implemented by improved insulation requirements alone.
- Vast energy and greenhouse gas reductions can be achieved by using existing technology that is proven in practice, readily available, simple to apply and durable: foam insulation. With the adoption and implementation of the proposed ASHRAE standards, energy reduction and greenhouse gas emissions prevention can be realized for the benefit of U.S. energy security, the environment and the polyurethane industry.

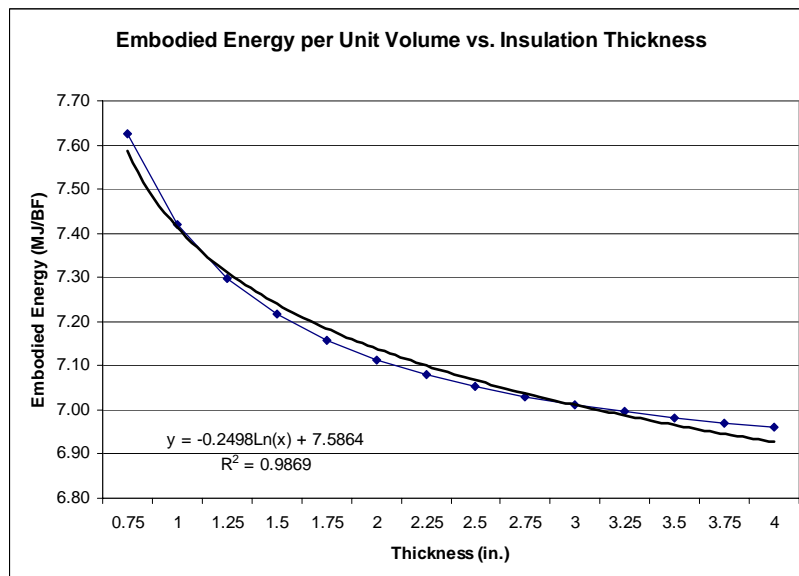
## APPENDIX A: ADDITIONAL INFORMATION ON EMBODIED ENERGY & GWP FACTORS

### Single Layer Insulation: Trends in Embodied Energy and GWP as a Function of R-Value

For single layer foam insulation with facer on each side, embodied energy or GWP per unit mass increases as a function of insulation R-value, where R is a function of insulation thickness for a given foam density and facer. However, the trend is opposite when embodied energy or GWP is normalized on a board foot or BF (ft<sup>2</sup>.in.) or volume basis. These trends, based on values calculated using data from a preliminary 2008 study [1], are shown in Figures A1 and A2 below for embodied energy.

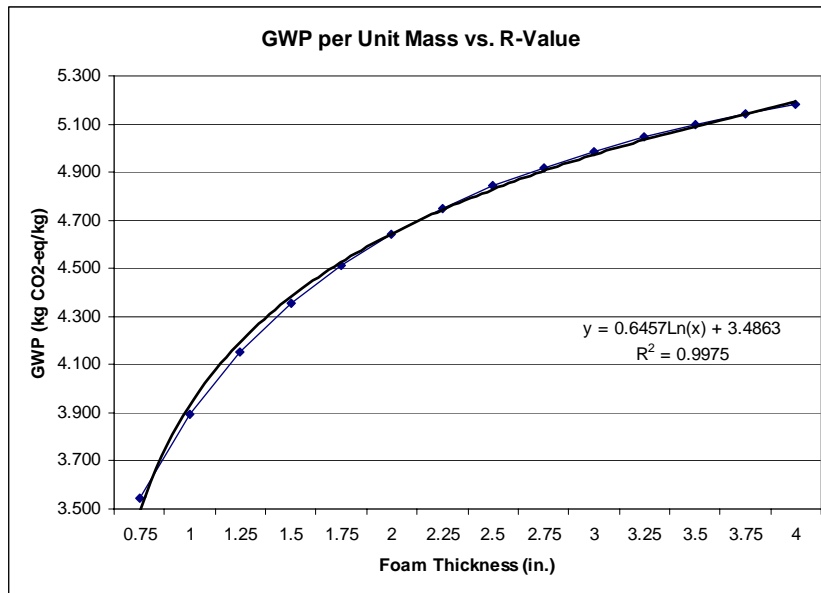


**Figure A1: Embodied Energy (MJ/kg) Single Layer Insulation**

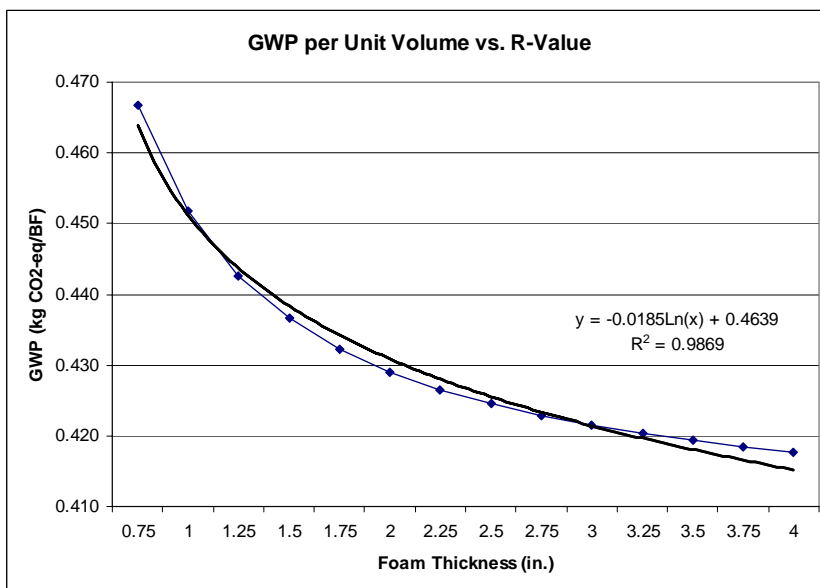


**Figure A2: Embodied Energy (MJ/BF) Single Layer Insulation**

Likewise, a similar trend is shown for GWP in Figures A3 and A4 below:



**Figure A3: GWP (kg CO<sub>2</sub>eq./kg) Single Layer Insulation**



**Figure A4: GWP (kg CO<sub>2</sub>eq./BF) Single Layer Insulation**

**Table A1: Properties of Insulation Components per Unit Mass and Volume**

<b>Insulation Component</b>	<b>Approx. Density (lb/ft<sup>3</sup>)</b>	<b>Embodied Energy per Unit Mass (MJ/kg)</b>	<b>Embodied Energy per Unit Volume (MJ/ft<sup>3</sup>)</b>
<b>Foam</b>	<b>2</b>	<b>85</b>	<b>77</b>
<b>Facer</b>	<b>12</b>	<b>25</b>	<b>136</b>

The explanation below is given for embodied energy, but it applies also to the trends demonstrated for GWP. Table A1 provides key values that are referenced in the following discussion that explains these trends:

As shown in Figure A1, the *embodied energy per unit mass* increases with insulation R-value or thickness. The function is non-linear as expected, since only the foam varies in mass, whereas the facer mass remains constant. The trend in Figure A1 shows a high correlation with  $R^2$  almost equal to 1. This curve results because the foam is composed primarily of chemicals with a relatively higher energy intensity (85 MJ/kg) versus the facer material, which is based on recycled materials with minimal energy burden and thus has a relatively lower energy intensity (25 MJ/kg). So when the thickness is increased, a higher portion of the total polyiso insulation is foam with a higher energy intensity (85 MJ/kg) compared to the facer's lower energy intensity (25 MJ/kg), and thus the overall embodied energy increases with insulation thickness.

As shown in Figure A2, the *embodied energy per unit volume* (expressed in BF) decreases with insulation R-value or thickness. The function is non-linear as expected, since only the foam varies in volume whereas the facer volume remains constant. The plot in Figure [list] shows a high correlation with  $R^2$  almost equal to 1. This trend is opposite compared to the mass basis trend noted above. The facer is a thin layer composed mostly of paper with some fiberglass threads and the facer is denser (12 lb/ft<sup>3</sup>) than the foam (2 lb/ft<sup>3</sup>), so the energy intensity of the facer is much greater on volume basis (136 MJ/ft<sup>3</sup>) compared to the foam (77 MJ/ft<sup>3</sup>). Thus, decreasing thickness of the foam results in higher overall energy intensity as the facer contribution (136 MJ/ft<sup>3</sup>) to the overall embodied energy fraction becomes greater relative to the foam's contribution (77 MJ/ft<sup>3</sup>). As the foam becomes thicker, the overall embodied energy decreases, as the foam's lower energy intensity contributes relatively more to the overall insulation's embodied energy.

### **Double Layer Insulation: Trends in Embodied Energy and GWP as a Function of R-Value**

In cases where double layering is used, the trend is quite straight forward. A linear relationship holds and the normalized embodied energy (or GWP) is equal to the single layers factored by their fractional contribution. *On an absolute basis*, this is because the additional layers are composed of both foam and facer, so adding for example another layer of insulation with equivalent thickness simply doubles the embodied energy or GWP. *On a normalized basis*, for example, the embodied energy for 4.90 inch thick insulation made from two 2.45 inch layers =  $[(0.5 \times 83.1) + (0.5 \times 83.1)] = 83.1$  MJ/kg. Thus, the normalized value for the double layer of two equivalent thicknesses is the same as for the single layer, as expected when normalized by the additional mass.

**APPENDIX B: R-VALUE AND PUR/PIR THICKNESS AND BOARD FEET TABLES**

The tables in this appendix provide further information regarding the minimum R-value/U-values and resulting PUR/PIR thicknesses and board footage involved in complying with the prescriptive building envelope requirements of the various ASHRAE standards included in this study.

*Table B1: Comparison of versions of ASHRAE Standard Requirements in PUR/PIR Minimum ci Thickness, inches*

Climate Zone	1	2	3	4	5	6	7	8
<b>Roofs IEAD – All Models</b>								
90.1-2004	2.45	2.45	2.45	2.45	2.45	2.45	2.45	3.25
90.1-2010P	3.30	4.08	4.08	4.90	4.90	4.90	5.72	5.72
189.1P	3.30	4.08	4.08	4.08	4.08	4.90	5.72	5.72
<b>Mass Wall Construction – Retail &amp; Small Office</b>								
90.1-2004	NR	NR	0.69	0.69	0.94	1.25	1.50	1.75
90.1-2010P	NR	0.75	1.00	1.25	1.50	2.75	3.00	3.00
189.1P	0.75	1.00	1.25	1.50	1.75	2.00	3.00	3.00
<b>Steel Frame Wall Construction – Strip Mall, Medium Office, Primary &amp; Secondary Schools</b>								
90.1-2004	NR	NR	NR	NR	0.59	0.59	1.25	1.25
90.1-2010P	1.25	1.25	1.25	1.25	2.50	3.00	3.00	3.00
189.1P	0.75	0.75	0.75	1.50	1.50	1.50	1.50	1.50

*Table B2: Strip Mall PUR/PIR continuous insulation, ci, requirements*

Strip Mall			Climate Zone							
	Floor Area	Bldg. Envelope Area	1	2	3	4	5	6	7	8
	Ft <sup>2</sup>	Ft <sup>2</sup>	Board Ft	Board Ft	Board Ft	Board Ft	Board Ft	Board Ft	Board Ft	Board Ft
90.1-2004	22,497	Roof = 22,497	55,117	55,117	55,117	55,117	55,117	55,117	55,117	73,114
		Wall = 10,907	-	-	-	-	6,476	6,476	13,634	13,634
90.1-2010P	22,497	Roof = 22,497	74,239	91,786	91,786	110,233	110,233	110,233	128,680	128,680
		Roof Delta	19,122	36,669	36,669	55,117	55,117	55,117	73,564	55,556
		Wall = 10,907	13,634	13,634	13,634	13,634	27,267	32,721	32,721	32,721
		Wall Delta	13,634	13,634	13,634	13,634	20,791	26,245	19,087	19,087
189.1P	22,497	Roof = 22,497	74,239	91,786	91,786	91,786	91,786	110,233	128,680	128,680
		Roof Delta	19,122	36,669	36,669	36,669	36,669	55,117	73,564	55,556
		Wall = 10,907	8,180	8,180	8,180	16,360	16,360	16,360	16,360	16,360
		Wall Delta	8,180	8,180	8,180	16,360	9,884	9,884	2,727	2,727

**Table B3: Retail PUR/PIR continuous insulation, ci, requirements**

Retail			Climate Zone							
	Floor Area	Bldg. Envelope Area	1	2	3	4	5	6	7	8
	Ft <sup>2</sup>	Ft <sup>2</sup>	Board Ft	Board Ft	Board Ft	Board Ft	Board Ft	Board Ft	Board Ft	Board Ft
90.1-2004	24,692	Roof = 24,692	60,496	60,496	60,496	60,496	60,496	60,496	60,496	80,250
		Wall = 11,766	-	-	8,089	8,089	11,006	14,708	17,649	20,591
90.1-2010P	24,692	Roof = 24,692	81,485	100,745	100,745	120,993	120,993	120,993	141,240	141,240
		Roof Delta	20,989	40,249	40,249	60,496	60,496	60,496	80,744	60,990
		Wall = 11,766	-	8,825	11,766	14,708	17,649	32,357	35,298	35,298
		Wall Delta	-	8,825	3,677	6,618	6,643	17,649	17,649	14,708
189.1P	24,692	Roof = 24,692	81,485	100,745	100,745	100,745	100,745	120,993	141,240	141,240
		Roof Delta	20,989	40,249	40,249	40,249	40,249	60,496	80,744	60,990
		Wall = 11,766	8,825	11,766	14,649	17,649	20,591	23,532	35,298	35,298
		Wall Delta	8,825	11,766	6,618	9,560	9,585	8,825	17,649	14,708

**Table B4: Small Office PUR/PIR continuous insulation, ci, requirements**

Small Office			Climate Zone							
	Floor Area	Bldg. Envelope Area	1	2	3	4	5	6	7	8
	Ft <sup>2</sup>	Ft <sup>2</sup>	Board Ft	Board Ft	Board Ft	Board Ft	Board Ft	Board Ft	Board Ft	Board Ft
90.1-2004	5,500	Roof = 5,500	13,476	13,476	13,476	13,476	13,476	13,476	13,476	17,876
		Wall = 2,390	-	-	1,643	1,643	2,235	2,987	3,584	4,182
90.1-2010P	5,500	Roof = 5,500	18,151	22,441	22,441	26,952	26,952	26,952	31,586	31,586
		Roof Delta	4,675	8,966	8,966	13,476	13,476	13,476	17,986	13,586
		Wall = 2,390	-	1,792	2,390	3,584	3,584	6,571	7,169	7,169
		Wall Delta	-	1,792	747	1,344	1,349	3,584	3,584	2,987
189.1P	5,500	Roof = 5,500	18,151	22,441	22,441	22,441	22,441	26,952	31,586	31,586
		Roof Delta	4,675	8,966	8,966	8,966	8,966	13,476	17,986	13,586
		Wall = 2,390	1,792	2,390	2,987	3,584	4,182	4,779	7,169	7,169
		Wall Delta	1,792	2,390	1,344	1,942	1,947	1,792	3,584	2,987

**Table B5: Medium Office PUR/PIR continuous insulation, ci, requirements**

Medium Office			Climate Zone							
	Floor Area	Bldg. Envelope Area	1	2	3	4	5	6	7	8
	Ft <sup>2</sup>	Ft <sup>2</sup>	Board Ft	Board Ft	Board Ft	Board Ft	Board Ft	Board Ft	Board Ft	Board Ft
90.1-2004	53,626	Roof = 17,879	43,803	43,803	43,803	43,803	43,803	43,803	43,803	58,106
		Wall = 14,260	-	-	-	-	8,467	8,467	14,260	14,260
90.1-2010P	53,626	Roof = 17,879	59,000	72,946	72,946	87,606	87,606	87,606	102,267	102,267
		Roof Delta	15,197	29,143	29,143	43,803	43,803	43,803	58,464	44,161
		Wall = 14,260	17,826	17,826	17,826	17,826	35,651	42,781	42,781	42,781
		Wall Delta	17,826	17,826	17,826	17,826	27,184	34,314	24,956	24,956
189.1P	53,626	Roof = 17,879	59,000	72,946	72,946	72,946	72,946	87,606	102,267	102,267
		Roof Delta	15,197	29,143	29,143	29,143	29,143	43,803	58,464	44,161
		Wall = 14,260	10,695	10,695	10,695	21,391	21,391	21,391	21,391	21,391
		Wall Delta	10,695	10,695	10,695	21,391	12,924	12,924	3,565	3,565

**Table B6: Primary School PUR/PIR continuous insulation, ci, requirements**

<i>Primary School</i>			<i>Climate Zone</i>							
	<b>Floor Area</b>	<b>Bldg. Envelope Area</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>
	<b>Ft<sup>2</sup></b>	<b>Ft<sup>2</sup></b>	<b>Board Ft</b>	<b>Board Ft</b>	<b>Board Ft</b>	<b>Board Ft</b>	<b>Board Ft</b>	<b>Board Ft</b>	<b>Board Ft</b>	<b>Board Ft</b>
90.1-2004	73,959	Roof = 79,959	181,199	181,199	181,199	181,199	181,199	181,199	181,199	240,366
		Wall = 17,431	-	-	-	-	10,350	10,350	21,789	21,789
90.1-2010P	73,959	Roof = 79,959	244,064	301,752	301,752	362,398	362,398	362,398	423,044	423,044
		Roof Delta	62,865	120,553	120,553	181,199	181,199	181,199	241,845	182,678
		Wall = 17,431	21,789	21,789	21,789	21,789	43,578	52,294	52,294	52,294
		Wall Delta	21,789	21,789	21,789	21,789	33,228	41,944	30,505	30,505
189.1P	73,959	Roof = 79,959	244,064	301,752	301,752	301,752	301,752	362,398	423,044	423,044
		Roof Delta	62,865	120,553	120,553	120,553	120,553	181,199	241,845	182,678
		Wall = 17,431	13,073	13,073	13,073	26,147	26,147	26,147	26,147	26,147
		Wall Delta	13,073	13,073	13,073	26,147	15,797	15,797	4,358	4,358

**Table B7: Secondary School PUR/PIR continuous insulation, ci, requirements**

<i>Secondary School</i>			<i>Climate Zone</i>							
	<b>Floor Area</b>	<b>Bldg. Envelope Area</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>
	<b>Ft<sup>2</sup></b>	<b>Ft<sup>2</sup></b>	<b>Board Ft</b>	<b>Board Ft</b>	<b>Board Ft</b>	<b>Board Ft</b>	<b>Board Ft</b>	<b>Board Ft</b>	<b>Board Ft</b>	<b>Board Ft</b>
90.1-2004	210,886	Roof = 126,677	310,359	310,359	310,359	310,359	310,359	310,359	310,359	411,701
		Wall = 44,005	-	-	-	-	26,128	26,128	55,006	55,006
90.1-2010P	210,886	Roof = 126,677	418,034	516,843	516,843	620,718	620,718	620,718	724,593	724,593
		Roof Delta	107,676	206,484	206,484	310,359	310,359	310,359	414,234	312,892
		Wall = 44,005	55,006	55,006	55,006	55,006	110,011	132,014	132,014	132,014
		Wall Delta	55,006	55,006	55,006	55,006	83,884	105,886	77,008	77,008
189.1P	210,886	Roof = 126,677	418,034	516,843	516,843	516,843	516,843	620,718	724,593	724,593
		Roof Delta	107,676	206,484	206,484	206,484	206,484	310,359	414,234	312,892
		Wall = 44,005	33,003	33,003	33,003	66,007	66,007	66,007	66,007	66,007
		Wall Delta	33,003	33,003	33,003	66,007	39,879	39,879	11,001	11,001

## 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 is a 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 worked at Exxon's petroleum refining units as a process engineer/long range planner in New Jersey, Louisiana and Texas, with assignments in distillation, energy and environmental operations. He currently works at Bayer MaterialScience in Pittsburgh focusing on Life Cycle Assessments and global Product Stewardship. His work at Bayer included developing and implementing pollution prevention programs, environmental impact analyses, and global EH&S management systems and auditing programs. This included several years in Europe and Asia, and assignments at numerous plants in the U.S.A. George has an MS in Civil Engineering from Carnegie Mellon University and BS degrees in Chemical Engineering and Biology from the University of Pittsburgh.

## REFERENCES

1. Phelan, J and G. Pavlovich. 2008. "Energy & Environmental Benefits of Insulating Commercial Buildings with Polyiso", presented at the Center for the Polyurethanes Industry 2008 Proceedings, October 1-2, 2008.
2. Phelan, J, G. Pavlovich and Ma E. April 2009. "Energy & Environmental Impact Reductions for Existing Buildings with Low-Slope Roofs". Bayer MaterialScience, Pittsburgh, PA.
3. The Alliance to Save Energy. Building Codes Assistance Project. [www.ase.org/section/program/buildingcodes](http://www.ase.org/section/program/buildingcodes).
4. Creyts, J. ET. Al. December 2007. "Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?" U.S. Greenhouse Gas Abatement Mapping Initiative, McKinsey & Company, New York.
5. Duke, R. and Lashof, D. June 2008. "Putting America on the Path to Solving Global Warming". National Resources Defense Council, Washington DC.
6. McKinsey & Company. March 2009. "Pathways to a Low-Carbon Economy". U.S. Greenhouse Gas Abatement Mapping Initiative, McKinsey & Company, New York.
7. International Council of Chemical Associations. July 2008. "Innovations for Greenhouse Gas Reductions". ICCA.
8. Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI), U.S. EPA [www.epa.gov/nrmrl/std/sab/traci](http://www.epa.gov/nrmrl/std/sab/traci)
9. U.S. Department of Energy, Energy Efficiency and Renewable Energy. [www.eere.energy.gov](http://www.eere.energy.gov) Programs: Building Technologies.
10. U.S. Department of Energy, Energy Efficiency and Renewable Energy. [www.eere.energy.gov](http://www.eere.energy.gov) Programs: High Performance Commercial Building/Commercial Building Benchmark.
11. Energy Information Administration. February 2007. "The Annual Energy Outlook with Projections to 2030". DOE-EIA Office of Integrated Analysis and Forecasting.
12. Deru, Michael, Brent Griffith, Kyle Benne, Paul Torcellini; PNNL: Mark Halversion, Dave Winiarski, Bing Liu; LBNL: Joe Huang and Mehry Yazdani; DOE: Drury Crawley, December, 2008. "DOE Commercial Building Benchmark Models for Energy Simulation", NREL.
13. "2003 Commercial Buildings Energy Consumption Survey", Energy Information Administration