Energy and Environmental Benefits of Extruded Polystyrene Foam and Fiberglass Insulation Products in U.S. Residential and Commercial Buildings

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ABSTRACT

The use of extruded polystyrene foam and fiberglass insulation products in U.S. residential and commercial buildings has been analyzed to determine whether they have a net energy and environmental benefit. The fundamental questions are whether the energy consumed and emissions produced to manufacture these products are less than, equal to or exceed those benefits when installed in buildings. Several hundred locations across the U.S. were selected to determine the annual energy and emission savings that are realized when extruded polystyrene foam and fiberglass insulation products are used in the envelopes of residential and commercial buildings. The energy savings were segregated by fuel type and the emissions are traced back to the site source. The energy and emissions to manufacture the foam and fiberglass are evaluated the same way for consistency. The first year energy savings exceed the energy used to manufacture the insulation products. The emission savings also provide a net positive benefit. The absolute magnitudes of the emission benefits are directly proportional to the expected useful life of the buildings.

INTRODUCTION

The manufacturing of insulation products is an energy intensive process that results in the generation of direct environmental emissions as well as indirect environmental emissions at electrical power plants. However, the use of those insulation products in residential and commercial buildings provides significant energy and environmental savings over an extended time period. The fundamental questions to answer are whether the energy consumed and emissions produced to manufacture the insulation products are less than, equal to or exceed those benefits when installed in buildings.

BACKGROUND

The benefits of insulation in residential and commercial buildings include lower energy consumptions, improved thermal comfort, reductions in the first costs of the heating and cooling equipment and reductions in CO2 emissions from the burning of fossil fuels across the United States. However, the manufacturing of insulation products generates emissions that contribute to global warming. The issue of global warming has focused attention on the use, regulation and eventual elimination of selected materials that contribute to the greenhouse gases. Also, energy and emission reductions have received increased focus by the building community as the concept of environmentally responsible and sustainable construction or “green” has gained popularity.

Foamed thermal insulations, such as extruded polystyrene (XPS), have come under scrutiny relative to climate change. The blowing agents, which are used to produce the foam and contribute to its high insulating efficiency, have both global warming and ozone depleting environmental impact. A phased transition of ozone depleting materials is being directed by the Montreal Protocol [1] and the U.S. Clean Air Act [2]. The Kyoto Protocol [3] includes HFC's in the "basket of gases" proposed for controlled emissions to mitigate global warming. HFC-134a is the next step in the blowing agent phase transition for XPS thermal insulation under the Montreal Protocol to eliminate the use of ozone depleting substances. The life cycle climate performance included in this paper for fiberglass and XPS will show the important role insulations, including those containing HFC's, play in energy efficient construction to the ultimate benefit of the environment.

OBJECTIVE

The objective is to determine the net energy and environmental impacts of the manufacturing and use of foam and fiberglass insulation products in U.S. residential and commercial buildings.

TECHNICAL APPROACH

There are various technical approaches one could use to perform the analysis ranging from site specific to national averages. The site specific approach would analyze specific buildings in specific locations and the results would be site sensitive. To be absolutely correct one would then have to link each building site with an insulation manufacturing plant and the local utilities to calculate the emissions. This would be an extremely complex and time consuming process.

The other end of the spectrum is the national average approach which would model a typical or average residential and commercial building to determine their energy savings and then use aggregated data for emissions from all of the insulation manufacturing plants and electric utilities. One of the challenges with a national average approach is the difficulty in defining a single residential and commercial building, construction features and HVAC systems that are truly representative. The fundamental problem is that energy codes require different levels of insulation by climate zones so there is a broad range of energy consumptions and emissions.

The approach adopted for this study was to analyze site specific residential and commercial buildings in multiple locations to determine their energy savings because the savings are climate and HVAC system sensitive but then use national average data for the insulation manufacturing energy and emissions as well as for electrical power plants. This approach is reasonable because insulation products can be shipped across broad geographical distances due to specific demands and the flow of electricity across the U.S. grid makes it extremely difficult to specify with certainty the generation source of the electrical energy consumed at a specific site.

TECHNCIAL ANALYSIS

There are many steps in the technical analysis to determine the energy and environmental impact of insulation products in residential and commercial buildings across the U.S. The major steps are: (1) determine the energy consumed and emissions generated during the insulation manufacturing process, (2) identify the energy conservation features and HVAC systems for residential and commercial buildings across the U. S., (3) determine the energy savings in multiple locations for residential and commercial buildings, (4) identify the emission coefficients for the various energy sources aligned with the manufacturing process and the HVAC systems in the buildings and (5) estimate the environmental emission savings due to the insulation energy savings. Each of these steps will be presented in detail.

Insulation Manufacturing Energy Use and Emissions

Manufacturing of insulation products occurs at various geographical locations, encompasses a variety of processes, consumes multiple fuels, uses various chemicals, and generates multiple emissions at each site. In addition there are indirect emissions associated with the production of the electrical energy used in the manufacturing process. Assimilating and reporting of these are a routine process for insulation manufacturers. To simplify the analyses for this paper the data have been aggregated for six fiberglass manufacturing plants: Delmar, NY; Eloy, AZ; Fairburn, GA; Kansas City, KS; Newark, OH; and Santa Clara, CA as well as three foam insulation plants: Tallmadge, OH; Rockford, IL; and Valleyfield, QC. The measured energies consumed, insulation materials made and the direct emissions generated are presented in Table 1. Also, included in Table 1 are the projected manufacturing emissions for HFC-134a as a future blowing agent replacement assuming a concentration of 6.5% [4].

Table 1 Insulation Manufacturing Energy Consumptions, Insulation Productions and Direct Emissions

Energy Consumption	**Fiberglass (Measured)**	**HCFC-142b (Measured)**	**HFC-134a (Projected)**
Electricity - kWh	1,205,803,921	39,045,241	
Natural Gas - DT	6,201,695	0	
Steam – GJ	3,597	0	
Insulation Productions	2,084,048,000 lb	585,391 MBF	
Direct Emissions			
CO2	794.3 lb/ton	0	0
Blowing Agent	0	0.0172 lb/lb_{foam}	0.0103lb/lb_{foam}

Residential and Commercial Building Energy Conservation Features

In order to simplify the analysis all newly constructed buildings were assumed to comply with the current national energy codes. Low-rise residential buildings were assumed to meet the 2003 International Energy Conservation Code prescriptive envelope criteria with the fenestration area set at 15% of the gross exterior wall area [5]. Commercial buildings were assumed to meet the prescriptive envelope criteria in ASHRAE Standard 90.1-2001 [6].

The basic assumptions for the low-rise residential building are presented in Table 2. The definition of a residence follows the building codes – one or two single family dwelling units, three stories or less in height.

Table 2 Low-rise Residential Building Characteristics		
Item	**One Story**	**Two Story**
Gross Floor Area– ft^2	2484	2484
Ceiling Area – ft^2	2484	1242
Gross Wall Area – ft^2	1691.62	2396.46
Fenestration Area – ft^2	253.74	359.47
Door Area – ft^2	60	60
Net Wall Area – ft^2	1377.87	1976.99
Perimeter – ft	211.45	140.97

The 2003 IECC prescriptive insulation levels for low-rise residences are presented in Appendix A. The seventeen climate zones are related to increasing values of heating degree days to base 65^{o}F (HDD65). For example, Zone 1 is Miami, FL (HDD65=200), zone 7 is Atlanta, GA (HDD65=2991) and zone 14 is Chicago, IL (HDD65=6536). The envelope sections and insulation products used in this analysis are: ceilings (fiberglass), exterior walls (fiberglass in the cavity and foam sheathing), basement walls (exterior foam), slabs (foam), and crawl spaces (exterior foam). The basements are assumed to be conditioned for human occupancy. Floors over unconditioned spaces were not included in the analysis since the foundations walls were assumed to be insulated with foam.

The low-rise residential heating and cooling equipment efficiencies used an AFUE of 80% for all gas and oil furnaces and boilers, a SEER of 10 for central cooling with either air conditioners or heat pumps and a HSPF of 6.8 for heating with heat pumps. All electric heating systems used 100% efficiency levels. The insulation requirements for the air distribution systems follow the IECC while the heating and cooling duct distribution efficiencies were obtained from ASHRAE Standard 90.2 [7]. Each duct efficiency was a function of the duct insulation level, the location of the duct (attic, crawl space or basement) and whether heating or cooling was being modeled.

Commercial buildings were assumed to meet the prescriptive envelope criteria in ASHRAE Standard 90.1-2001, see Appendix B. The prescriptive criteria are presented as insulation R-values for 26 climate zones and thirteen classes of construction. Each climate zone is defined as a range of HDD65 and CDD50. Zone 1 represents the most severe cooling conditions (outside the U.S.) while zone 2 is Miami, FL, zone 13 is St. Louis, MO and zone 26 (Barrow, AK) represents the most severe heating conditions. The criteria contained in boxes are for continuous foam insulation, e.g. above roof deck, wall sheathing, mass walls and slab edges. Thirteen classes of construction were modeled and the insulation materials that were used are presented in Table 3. For each of these construction classes a one square foot of each section was modeled and then the results were scaled according to the total square footage of construction activity for each of the 318 locations analyzed.

Table 3 ASHRAE Standard 90.1-2001 Opaque Construction Classes and Insulation	
Roofs Insulation Above Deck - Foam Metal Buildings - F/G Attic and Other - F/G	**Floors** Mass - Foam Steel Joist - F/G Wood Framed and Other - F/G
Walls, Above Grade Mass - Foam Metal Building - F/G Steel Framed - F/G + Foam Wood Framed and Other - F/G + Foam	**Slab-On-Grade** Unheated - Foam Heated – Foam **Wall, Below Grade** Below Grade Wall - Foam

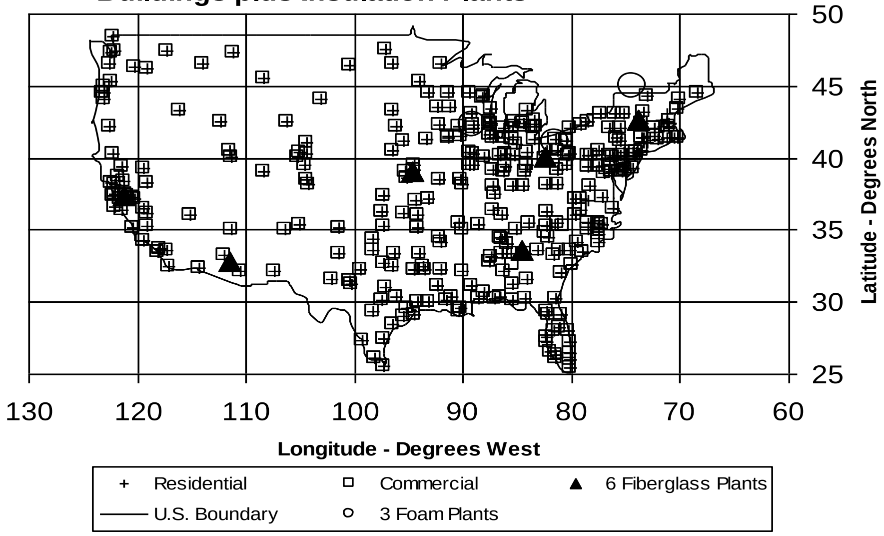
There are multiple energy sources and various HVAC equipment types that can be used in commercial buildings. A detailed analysis of these choices was completed using the number of buildings and the total floor area as weighting factors from both the U.S. Census Bureau [8] and DOE [9]. Heating energy sources were limited to electricity, natural gas and propane and fuel oil. These three categories accounted for 93-97% of the total energy sources. Neglected in the analysis were district heating and cooling systems and wood. The final weighting factors used were: 10.4 % electric, 74.1% natural gas and propane and 15.6% fuel oil. Cooling energy was all electricity.

The HVAC equipment types and efficiencies match those used to develop the criteria for ASHRAE Standard 90.1-2001. The average efficiency used for the heating equipment was 81%. This was reasonable considering national average values for all existing commercial buildings are 9.2% heat pumps (COP=3.1), 60.3% furnaces, individual space heaters and packaged heating units (AFUE=80%) and 20.6% boilers (Efficiency = 80%). The average SEER used for the cooling equipment was 10.3. Again, this was reasonable considering national average values for all existing commercial buildings are 67.4% residential type central units (SEER=9.5), 10.9% heat pumps (SEER=8.8) and 14.7% central chillers (COP=4.45).

Residential and Commercial Building Energy Analysis

The determination of energy savings due to the installation of foam and fiberglass insulation in residential and commercial buildings is a complex analysis. The low-rise residential energy saving calculations utilized the ASHRAE Standard 90.2-2001 methodology. A data base of 328 Metropolitan Statistical Areas (MSA) was used as weighting factors to aggregate the individual city results to a national level, see Figure 2 [10]. These 328 MSAs represent 1,005,206 single family housing starts which were considered adequate to characterize the national housing starts across the U.S. Specific housing characteristics for the type of HVAC system and fuel sources, number of stories and foundation types were defined by state averages [11].

Figure 1 Location of Residential and Commercial Buildings plus Insulation Plants



The energy savings analysis for commercial buildings utilized the methodology presented in ASHRAE Standard 90.1-2001. A data base from F.W. Dodge for 318 locations with 23 building types was used as the weighting factors to aggregate the individual city results to a national level, see Table 4 [12]. These 318 locations represent 1,580,807,000 square feet of U.S. commercial building construction activity in 2001 and are also shown in Figure 1. In each location these constructions were aggregated into the ASHRAE Standard 90.1 classes: nonresidential - commercial buildings (1-21), high-rise residential - four or more stories (22) and warehouses - semi-heated to 50^{o}F and not air-conditioned (23).

Table 4 F. W. Dodge Commercial Building Types

No.	Description	No.	Description
1	Arenas	13	Office
2	Auto Service	14	Parking Garage
3	Capitols	15	Police/Fire Station
4	Detention Facilities	16	Post Office
5	Dormitories	17	Religious Buildings
6	Exhibition Halls	18	Retail
7	Food/Beverage Service	19	Schools/Universities
8	Gyms/Field Houses	20	Theaters
9	Hospitals/Health Care	21	Transportation Service Terminals
10	Hotel/Motel	22	Apartments (High-rise Residential)
11	Libraries	23	Warehouses (Semi-heated)
12	Museums		

Emission Factors and Greenhouse Gas Coefficients

Use of acceptable coefficients is essential to any analysis that calculates emissions. The coefficients used in the study are presented in Table 5. These coefficients were extracted from multiple sources [13, 14, 15, 16 and 17]. Coefficients for the electric power plants are composites for the entire U.S. based on a mixture of fuel sources [18].

Table 5 Emission Coefficients				
Greenhouse Gas	**Fuel**	**Coefficient**	**Units**	**Application**
CO_2	Natural Gas	120,000	lb/million ft^3	All
	#2 Oil	22,300	lb/1000 gal	All
	Mixture	1.34	lb/kWh	Elec. Power Plants
N_2O	Natural Gas	2.2	lb/million ft^3	Small Boiler
	Natural Gas	2.2 (E)	lb/million ft^3	Residential Furnace
	#2 Oil	0.11 (B)	lb/1000 gal	Small Boiler
	#2 Oil	0.05	lb/1000 gal	Residential Furnace
	Mixture	0.0192	lb/million Wh	Elec. Power Plants
CH_4	Natural Gas	2.3	lb/million ft^3	Commercial Boiler
	Natural Gas	2.3 (B)	lb/million ft^3	Residential Furnace
	#2 Oil	0.216	lb/1000 gal	Commercial Boiler
	#2 Oil	1.78	lb/1000 gal	Residential Furnace
	Mixture	0.0111	lb/million Wh	Elec. Power Plants

Note: Letters in parenthesis reflect confidence in the values:(A) = highest, (E) = lowest.

The global warming potentials for the greenhouse gases were set for a time horizon of 100 years using the coefficients presented in Table 6 [13, 14, 15, 16 and 17]. These coefficients are the basis for estimates of emissions presented in the Inventory of U.S. Greenhouse Gas Emissions and Sinks [15], which are consistent with the Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report (SAR) and updates of 1995 and 1996. The GWPs typically have an uncertainty of roughly $\pm$35%.

Table 6 Global Warming Potential Values	
Source	**GWP100**
CO_2	1
CH_4	21
N_2O	310
HFC-134a	1300
HCFC-142b	2000

RESULTS

The key results are the net energy and environmental impacts. In order to reach these final results the intermediate results of the major steps need to be presented. Those steps are the weighted average pounds of insulation used, the weighted average energy savings and the weighted average emissions generated and saved.

Insulation

The weighted average pounds of fiberglass and foam used in the residential and commercial buildings are presented in Table 7. The low-rise residential pounds are for the ceilings, above-grade walls, basement walls, crawl space walls and slab edges for one and two story dwelling units. The commercial pounds presented in Table 7 represent the insulation for one square foot of each of the thirteen construction classes previously presented in Table 3. The foam is divided into two different densities. The 1.6 lb/ft^3 foam is used in roofs while the 1.8 lb/ft^3 foam is used in walls.

Table 7 Insulation Material Used

Building Type	Fiberglass (lb)	Foam (lb)	Foam-roofs (lb @ 1.6 lb/ft^3)	Foam-walls (lb @ 1.8 lb/ft^3)
Low-rise Res.	1474.95	343.94		343.97
Commercial				
Nonresidential	2.43	1.06	0.40	0.66
High-rise Res.	2.66	1.33	0.40	0.93
Warehouse	1.43	0.34	0.11	0.23
Sum	6.52	2.73	0.91	1.82

Annual Energy Savings

The weighted average annual energy savings achieved by insulating the residential and commercial buildings are presented in Table 8. The results are broken out for heating and cooling for the fiberglass and foam insulation materials in order to properly determine the emissions that can be saved because the buildings have been insulated.

Table 8 Annual Energy Savings due to Insulation

Commercial-Fiberglass	**Heating - therms**	**Cooling - kWh**	**Equivalent Total - kWh**	**Total - kWh/lb**
Nonresidential	10.03	26.2	320	131.7
High-rise Res.	5.04	46.52	194	73.0
Warehouse	0.95	0	28	19.5
SUM	16.02	72.72	542	83.1
Commercial – Foam	**Heating - therms**	**Cooling - kWh**	**Equivalent Total - kWh**	**kWh/lb**
Nonresidential	2.39	14.8	85	80.0
High-rise Res.	3.31	24.98	122	91.8
Warehouse	0.4	0	12	34.5
SUM	6.1	39.78	219	80.1
Low-rise Residential – Fiberglass	**Energy**	**Energy Content BTU/gal**	**Equivalent Total - kWh**	**kWh/lb**
Gas – therms	1,237.61		36,262	

Electricity – kWh	11,842.18		11,842	
Oil –gal	79.67	140,000	3,268	
SUM			51,372	34.8
Low-rise Residential – Foam	**Energy**	**Energy Content BTU/gal**	**Equivalent Total - kWh**	**kWh/lb**
Gas – therms	317.68		9,308	
Electricity – kWh	3,170.34		3,170	
Oil –gal	24.20	140,000	993	
SUM			13,471	39.5

In order to determine the net impact of these energy savings they need to be compared directly to the energy required to manufacture the insulation. Those results are summarized in Table 9. To simplify the comparisons all of the energy savings and manufacturing energy are presented in the same units of kWh/lb. Also presented are the ratios of the annual energy savings divided by the manufacturing energy. This allows one to immediately comprehend the net energy benefits.

Table 9 Comparison of Annual Energy Savings vs. Manufacturing Energy

Annual Energy Savings	**Fiberglass**		**Foam**	
Commercial Buildings	**kWh/lb**	**Annual Energy Savings/ Mfg. Energy**	**kWh/lb**	**Annual Energy Savings/ Mfg. Energy**
Nonresidential	131.7	91	80.0	168
High-rise Residential	73.0	50	91.8	193
Warehouses	19.5	13	34.5	72
Weighted Average	83.1	57	80.1	168
Low-rise Residential	34.8	24	39.2	82
Manufacturing Energy	1.451		0.476	

Clearly, both fiberglass and foam insulations have extremely positive net energy benefits for all residential and commercial buildings. The annual energy saved far exceeds the energy required for manufacturing in all cases. It is important to recognize that these insulation energy savings benefits vary for each city due to the application (ceiling, wall, or foundation), the stringency of the energy codes, the HVAC systems and the construction weighting factors.

Emissions

The emissions generated in the manufacturing process of fiberglass and foam insulation are presented in Table 10. The direct emissions generated in the manufacturing of fiberglass are primarily comprised of the carbon dioxide emissions due to the combustion of natural gas and/or fuel oil, as well as liberated in the glass melting process. By and large, the GHG emissions are determined using emission factors from widely accepted literature [13]. Since GHG emissions are not required to be measured or reported in the U.S., very little effort has occurred to further quantify them.

However, estimates of CH4 and N20 from the manufacturing process are included in the analysis. Furthermore, the indirect emissions generated at electrical power plants include additional greenhouse gases and those are included in the results.

Table 10 Insulation Manufacturing Emissions						
GHG	**Direct Mfg. Emissions**	**Emission Coefficient (Table 5)**	**Indirect Electricity Emissions**	**GWP 100**	**Indirect CO2 Emissions**	**Total GWP CO2 Equivalent**
Fiberglass	**lb/ton**				**lb/ton**	**lb/ton**
CO2	794.3	1.34	1,551	1	1,551	2,345
CH4	0.3	0.0111	0.0128	21	0.3	7
N2O	3.675	0.0192	0.0221	310	7.0	1,146
SUM					1,558	3,498
Foam	**lb/lb**				**lb/lb**	**Lb/MBF**
CO2	0	1.34	0.638	1	0.638	92.2
CH4	0	0.0111	5.288E-06	21	0.000	0.016
N2O	0	0.0192	9.147E-06	310	0.003	0.410
HCFC-142b Mfg. Process	0.0172			2000	34.4	4,816
SUM					35.0	4,909

The annual emissions avoided due to insulation are presented in Table 11.

Table 11 Annual Emissions Avoided Due to Insulation														
Application - Material	**Electric Emissions Coefficients**	**Electric Cooling kWh**	**Electric Heating kWh**	**Electric Total kWh**	**Electric lb GHG**	**Gas Emissions Coefficients**	**Gas ft3**	**Gas lb GHG**	**Oil Emissions Coefficients**	**Oil gal**	**Oil lb GHG**	**Total lb GHG per lb ins.**	**EIA 1605 GWP100**	**Total GWP Equivalent**
COMMERCIAL - FIBERGLAS														
Carbon Dioxide - CO2	1.34	72.72	12.76	85.48	114.54	120,000	1164	139.66	22,300	1.79	39.81	294.01	1	90,186
Methane - CH4	0.0111			85.48	9.49E-07	2.3	1164	2.68E-03	0.216	1.79	3.86E-04	0.0031	21	20
Nitrous Oxide - N20	0.0192			85.48	1.64E-06	2.2	1164	2.56E-03	0.11	1.79	1.96E-04	0.0028	310	262
SUM														90,468
COMMERCIAL - FOAM														**CO2 lb/MBF**
Carbon Dioxide - CO2	1.34	39.78	18.59	58.37	78.21	120,000	443	53.18	22,300	0.680	15.16	146.55	1	7,758
Methane - CH4	0.0111			58.37	6.48E-07	2.3	443	1.02E-03	0.216	0.680	0.000147	0.0012	21	1
Nitrous Oxide - N20	0.0192			58.37	1.12E-06	2.2	443	9.75E-04	0.11	0.680	0.000075	0.0011	310	17
SUM														7,777
LOW-RISE RESIDENTIAL - FIBERGLASS														**CO2 lb/ton**
Carbon Dioxide - CO2	1.34			11,672.7	15,641	120,000	121,020	14,522	22,300	75.84	1691.23	31,855	1	43,194
Methane - CH4	0.0111			11,672.7	1.30E-04	2.3	121,020	2.78E-01	0.216	75.84	0.01638	0.2949	21	8
Nitrous Oxide - N20	0.0192			11,672.7	2.24E-04	2.2	121,020	2.66E-01	0.11	75.84	0.00834	0.2748	310	116
SUM														43,318
LOW-RISE RESIDENTIAL - FOAM														**CO2 lb/MBF**
Carbon Dioxide - CO2	1.34			3,170.3	4248.26	120,000	31,145	3,737.41	22,300	24.2	539.66	8,525	1	3,718
Methane - CH4	0.0111			3,170.3	3.52E-05	2.3	31,145	7.16E-02	0.216	24.2	0.005227	0.0769	21	1
Nitrous Oxide - N20	0.0192			3,170.3	6.09E-05	2.2	31,145	6.85E-02	0.11	24.2	0.00266	0.0712	310	10
SUM														3,728

Following the approach used to compare the net energy impacts, the net emission impacts are summarized in Table 12. Also presented are the ratios of the annual emission savings divided by the manufacturing emissions. This allows one to immediately comprehend the net emission benefits. Projections for HFC-134a have been calculated and are also presented. The HFC-134a calculations used a 6.5% concentration of the blowing agent and a GWP100 of 1300.

Table 12 Comparison of Insulation Emission Savings vs Manufacturing Emissions						
	Fiberglass		**Foam HCFC-142b**		**Foam HFC-134a (Projected)**	
Annual Emission Savings	**Total GWP100 CO2 – lb/ton**	**Annual Emission Savings/ Mfg. Emissions**	**Total GWP100 CO2 – lb/MBF**	**Annual Emission Savings/ Mfg. Emissions**	**Total GWP100 CO2 - lb/MBF**	**Annual Emission Savings/ Mfg. Emissions**
Commercial	90,468	26	7,777	1.6	7,777	3.8
Low-rise Res.	43,318	12	3,728	0.8	3,728	1.8
Mfg. Emissions	3,498		4,909		2,029	
Total Outgasing			31,315		12,205	

Clearly, the fiberglass insulation has an extremely positive net emissions benefit for both commercial and low-rise residential buildings. The first year emissions saved by fiberglass insulation far exceed the emissions required for manufacturing it in all cases. In simple terms the annual emission savings exceed the manufacturing emissions by factors of 12 to 26 which mean net emission benefits can be achieved within 14 to 29 days.

The emission story for the foam is more complex because the foam continues to outgas over time. Eventually, the blowing agent will completely outgas so the total emissions were evaluated. All of the emission results can best be summarized by determining the time required to achieve a net positive benefit, see Table 13.

Table 13 Time to Achieve Net Positive Emission Benefits						
	Fiberglass		**HCFC-142b**		**HFC-134a (Est.)**	
	Comm.	**Res.**	**Comm.**	**Res.**	**Comm.**	**Res.**
	Years	**Years**	**Years**	**Years**	**Years**	**Years**
Manufacturing	0.04	0.08	0.6	1.3	0.3	0.5
Complete Outgassing			4.0	8.4	1.6	3.3

The emission savings from commercial buildings exceeds the total HCFC-142b emissions within four years while low-rise residential emission savings exceeds the total HCFC-142b emissions in 8.4 years. Similar analyses for HFC-134a show that commercial buildings have a net emission savings within 1.6 years and low-rise residences have a net emission savings in 3.3 years.

CONCLUSIONS

A comprehensive analysis has been completed to determine the net energy and emissions impact of fiberglass and foam insulation products in U.S. residential and commercial buildings. The analysis was based on representative residential and commercial buildings in over 300 locations using prescriptive envelope criteria from the current national energy codes. The results for each location were appropriately weighted using current construction activity measures to obtain national average values.

The manufacturing energy consumed and emissions generated were based on measured data from six fiberglass plants and three foam plants. Emission coefficients for the greenhouse gases were obtained from current reports published by federal government agencies. Both direct and indirect emissions were included in order to make the analysis complete.

The net impacts in terms of energy were that both fiberglass and foam insulation have positive net benefits. The first year energy savings for fiberglass exceeds the energy required to manufacture the insulation by factors ranging from 13 to 91 depending upon the building type. The first year energy savings for foam exceeds the energy required to manufacture the insulation by factors ranging from 72 to 193 depending upon the building type.

The net impacts in terms of emissions were that both fiberglass and foam insulations have positive net benefits. The emissions from fiberglass manufacturing are offset by the reduction in emissions due to residential energy savings in less than 0.08 years. The emissions from manufacturing foam with HCFC-142b are offset by the reduction in emissions due to residential energy savings in less than 1.3 years. When HFC-134a is used the manufacturing emissions are offset within 0.5 years. The limiting case for the foam emissions was to assume that all of the blowing agent will eventually out gas. This worst case analysis showed that the reductions in emissions due to residential energy savings offset the total blowing agents in 8.4 years for HCFC-142b and 3.3 years for HFC-134a. All of the times required for commercial applications to achieve positive net emission benefits are even less than those required for residential applications. This means that all residential and commercial buildings when evaluated over their normal life span will have net positive reductions in emissions for all insulation materials.

RECOMMENDATIONS

The use of fiberglass and foam insulation products in residential and commercial buildings has an enormous net energy benefit within the first year and should continue to play a predominate role in achieving energy conservation. Fiberglass and foam insulation products also have net positive benefits relative to greenhouse gas emissions and play an important role in advancing the “green” building philosophy.

ACKNOWLEDGEMENTS

The author acknowledges the following colleagues for their invaluable contributions in the development of the technical data and analyses of this paper: Robin Edmiston-Bennett, Barb Fabian, Frank M. Kristie, Don R. Miller, Pat Rynd, Leonard Suharli, Joseph B. Vocke, Francesco M. Vigo and Stanley J. Wolfersberger.

ACRONYMS, SYMBOLS AND UNIT MEASURES

AFUE	- Annual Fuel Utilization Efficiency (dimensionless, capacity/input)
ASHRAE	- American Society of Heating, Refrigerating and Air-Conditioning Engineers
BF	- Board Foot (1 inch thick by 1 ft^2)
Btu	- British Thermal Unit

CDD50	- Cooling Degree Days to base 50°F
CH4	- Methane
CO2	- Carbon Dioxide
COP	- Coefficient of Performance (dimensionless, capacity/electric input)
DOE	- U.S. Department of Energy
DT	- Dekatherm (10 therms)
EPA	- U.S. Environmental Protection Agency
F/G	- Fiberglass
GHG	- Greenhouse Gas
GJ	- Gigajoules (10^9 joules)
GWP	- Global Warming Potential
HFC	- Hydrofluorocarbon
HFC-134a	- Hydrofluorocarbon 134a (1,1,1,2-tetrafluoroethane)
HCFC-142b	- Hydrochlorofluorocarbon (chlorodifluoroethane)
HDD65	- Heating Degree Days to base 65°F
HSPF	- Heating Season Performance Factor (Btu/watt-hour)
HUD	- Housing and Urban Development
HVAC	- Heating, Ventilating and Air-Conditioning
ICC	- International Code Council
IECC	- International Energy Conservation Code
MBF	- Thousands of Board Feet
MSA	- Metropolitan Statistical Area
N2O	- Nitrous Oxide
R-value	- Thermal Resistance $(\text{Btu/hr-ft}^2\text{-}^o\text{F})^{-1}$
SEER	- Seasonal Energy Efficiency Ratio (Btu/watt-hour)
THERMS	- 100,000 Btu
TON	- 2000 pounds
XPS	- Extruded Polystyrene

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APPENDIX A

2003 International Energy Conservation Code Prescriptive Envelope Criteria

Table A-1 IECC Prescriptive Envelope Criteria
Window Area 15 Percent of Gross Exterior Wall Area

Zone	HDD65	Ceiling	Ext. Wall[1]	Floor	Basement Wall[2]	Slab Perimeter [2]	Crawl Wall[2]
		R	R	R	R	R-feet	R
1	0-499	13	11	11	0	0-0	0
2	500-999	19	11	11	0	0-0	4 (5)
3	1000-1499	19	11	11	0	0-0	5
4	1500-1999	26	13	11	5	0-0	5
5	2000-2499	30	13	11	5	0-0	6 (7.5)
6	2500-2999	30	13	19	6 (7.5)	4-2 (5)	7 (7.5)
7	3000-3499	30	13	19	7 (7.5)	4-2 (5)	8 (10)
8	3500-3999	30	13	19	8 (10)	5-2	10
9	4000-4499	38	13	19	8 (10)	5-2	11 (12.5)
10	4500-4999	38	16 (13+3)	19	9 (10)	6-2 (7.5)	17 (17.5)
11	5000-5499	38	18 (13+5)	19	9 (10)	6-2 (7.5)	17 (17.5)
12	5500-5999	38	18(13+5)	21	10	9-2 (10)	19 (20)
13	6000-6499	38	18(13+5)	21	10	9-4 (10)	20
14	6500-6999	49	21	21	11 (12.5)	11-4 (12.5)	20
15	7000-8499	49	21	21	11 (12.5)	13-4 (15)	20
16	8500-8999	49	21	21	18 (20)	14-4 (15)	20
17	9000-12999	49	21	21	19 (20)	18-4 (20)	20

Notes: 1 – R-values in parenthesis are fiberglass cavity insulation plus foam products.

2 – R-values in parenthesis are the foam products analyzed to meet the prescriptive criteria.

APPENDIX B

ASHRAE Standard 90.1-2001 Prescriptive Envelope Criteria (Opaque Elements)

Table B-1 ASHRAE Standard 90.1 - 2001 Nonresidential Prescriptive Envelope Requirements for Opaque Sections (Insulation R-values)

		Climate Bins																									
Section	**Item**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**
Roof	Above Deck	15	15	15	10	15	15	10	15	15	15	15	10	15	15	15	15	15	15	15	15	15	15	15	20	20	25
	Metal Building	19	19	19	19	19	19	16	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	26	32	32	35
	Attic & Other	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	38	30	30	38	30	38	38	38	38	38	60
Walls, AG	Mass	0	0	0	0	0	0	0	0	0	5.7	5.7	5.7	5.7	5.7	5.7	7.6	7.6	7.6	9.5	9.5	11.4	11.4	11.4	13.3	15.2	15.2
	Metal Building	13	13	13	11	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	26	26	26	26	26	26
	Steel Framed	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
	Sheathing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.8	3.8	0	3.8	3.8	7.5	7.5	7.5	7.5	7.5	10
	Wood Framed	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
	Sheathing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.8	7.5	7.5	7.5
Walls, BG	Below Grade	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.5	7.5	7.5	7.5	7.5	7.5
Floors	Mass	0	0	0	0	4.2	4.2	4.2	4.2	4.2	6.3	6.3	4.2	6.3	6.3	6.3	8.3	8.3	6.3	8.3	8.3	10.4	8.3	10.4	12.5	12.5	14.6
	Steel Joist	0	0	0	0	19	19	19	19	19	19	19	19	19	19	19	19	19	19	30	19	30	30	30	30	38	38
	Wood Framed	0	0	0	0	19	19	13	19	19	19	19	19	19	19	19	30	30	19	30	30	30	30	30	30	30	30
Slabs	Unheated	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	15	15
	Depth - inches	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	24	24	24
	Heated	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	10	10	10	10	10	10	10	10	10	10	10
	Depth - inches	12	12	12	12	12	12	12	12	12	12	12	12	24	24	24	36	36	36	36	36	36	36	48	48	48	48

Note: Insulation R-values in boxes are for continuous foam insulation.

Table B-2 ASHRAE Standard 90.1 - 2001 Residential Prescriptive Envelope Requirements for Opaque Sections (Insulation R-values)																											
		Climate Bins																									
Section	**Item**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**
Roof	Above Deck	20	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	20	15	20	20	20	25
	Metal Building	26	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	26	19	26	32	32	32
	Attic & Other	38	38	38	30	38	30	30	38	30	38	30	30	38	30	30	38	38	30	38	38	38	38	38	38	38	60
Walls, AG	Mass	5.7	5.7	5.7	0	5.7	5.7	5.7	7.6	5.7	7.6	7.6	7.6	9.5	9.5	7.6	11.4	11.4	11.4	11.4	11.4	15.2	13.3	15.2	15.2	15.2	15.2
	Metal Building	13	13	13	11	13	13	13	13	13	13	13	13	13	13	13	26	26	13	26	26	26	26	26	26	29	26
	Steel Framed	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
	Sheathing	3.8	0	0	0	0	0	0	3.8	0	3.8	3.8	0	7.5	3.8	3.8	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	10	18	21.6
	Wood Framed	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
	Sheathing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.8	0	0	3.8	3.8	7.5	7.5	7.5	7.5	7.5	10
Walls, BG	Below Grade	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.5	7.5	7.5	7.5	7.5	7.5	12.5	15
Floors	Mass	0	0	0	0	6.3	6.3	4.2	6.3	6.3	8.3	8.3	6.3	8.3	8.3	8.3	10.4	10.4	8.3	12.5	10.4	12.5	12.5	12.5	14.6	16.7	16.7
	Steel Joist	0	0	0	0	19	19	19	19	19	19	19	19	30	19	19	30	30	30	30	30	30	30	30	38	38	38
	Wood Framed	0	0	0	0	19	19	13	19	19	30	30	19	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Slabs	Unheated	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	15	15	15	20
	Depth - inches	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	24	24	24	24	24
	Heated	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	Depth - inches	12	12	12	12	12	12	12	12	12	12	24	12	36	36	36	36	36	36	48	48	48	48	48	48	48	48
	Note: Insulation R-values in boxes are for continuous foam insulation.																										

Table B-3 ASHRAE Standard 90.1 - 2001 Warehouse Prescriptive Envelope Requirements for Opaque Sections (Insulation R-values)																											
		Climate Bins																									
Section	**Item**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**
Roof	Above Deck	0	0	0	0	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	5	5	5	5	5	5	5	7.6	10	10	10
	Metal Building	0	0	0	0	6	6	6	6	6	10	10	10	10	10	10	10	10	10	10	10	10	10	13	16	16	19
	Attic & Other	0	0	0	0	13	13	13	13	13	13	13	13	13	13	13	19	19	19	19	19	19	19	19	30	30	30
Walls, AG	Mass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.7	5.7	7.6	9.5
	Metal Building	0	0	0	0	6	6	6	6	6	6	6	0	10	10	10	11	11	11	13	13	13	13	13	13	13	13
	Steel Framed	0	0	0	0	0	0	0	0	0	0	0	0	13	13	13	13	13	13	13	13	13	13	13	13	13	13
	Sheathing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.8
	Wood Framed	0	0	0	0	0	0	0	0	0	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
	Sheathing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Walls, BG	Below Grade	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Floors	Mass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.2	4.2	4.2	4.2	6.3	6.3
	Steel Joist	0	0	0	0	0	0	0	0	0	13	13	13	13	13	13	13	13	13	13	13	19	19	19	19	19	19
	Wood Framed	0	0	0	0	0	0	0	0	0	0	0	0	13	13	13	13	13	13	13	13	13	13	19	19	19	19
Slabs	Unheated	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Depth - inches	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Heated	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	10
	Depth - inches	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	24	24	36
	Note: Insulation R-values in boxes are for continuous foam insulation.																										