A Comparison of CO2-equivalent Emissions From the Use of Various Extruded Polystyrene Foam Insulations:

XPS foam sheathing applied to exterior walls of single family residential housing in four cities in the United States.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY / ABSTRACT

This study compares the overall carbon dioxide (CO_2) emissions created by the energy consumption of a typical US single family house, insulated partly or totally with sheathing made of various extruded polystyrene foam insulation products (XPS), with the overall CO_2 emissions created by the production, transport and use of the XPS insulation products themselves.

Some of the blowing agents used for the extruded polystyrene foams are substances specifically reviewed by the United Nations IPCC/TEAP Special Report on Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons.

There was a need to quantify the global warming contribution from the fluorinated blowing agents in the foams and compare it to the huge energy savings (i.e. CO_2 emission savings) that the same fluorinated gases allow when used as blowing agents in XPS foam because of their specifically low intrinsic thermal conductivity values.

When considering the impact (calculated as CO_2 equivalent emissions) of both the energy consumed and the direct and indirect emissions from the use of XPS foam insulation, the results show that, over a 50-year life time of a single family residential house for four climatic areas of the United States, a CO_2-blown XPS foam is only slightly favorable compared to an XPS foam blown with an HCFC, and is equivalent to that of an HFC blown foam.

Given the significant energy savings, and other associated emissions savings, versus the insignificant differences between the overall CO_2 emissions created over the life time of a widely practiced insulation application for XPS in North America such as sheathing insulation, it is recommended that the choice of future replacement alternatives for HCFC blowing agents should remain open to the use of HFC blowing agents.

INTRODUCTION

The objective of this study is to determine the net impact of XPS insulation products, both current commercial products and future product developments, when used over a 50 year time period in sheathing applications in the United States.

Four different representative climatic conditions have been selected. Three different XPS blowing agent formulations have been selected: the current HCFC based formulation and two potential replacements, one based on HFC and one based on CO_2.

The life cycle data from the production, transport and use phase of the insulation products have been considered, including the primary energy consumption and global warming impact as CO_2 equivalent creation.

ASSUMPTIONS AND DATA

Climates represented

Four cities have been selected to represent the diversity of the US climatic conditions: Minneapolis, Indianapolis, Atlanta and Phoenix.

The heat flows, hence energy consumption, calculations require the use of heating and cooling degree days or hours (HDD and CDD or CDH) representative for these cities and these were extracted from ASHRAE 90.2-1993 standard as follows:

Locations	Average Temperature (F)	HDD-65	CDH-74
Minneapolis, MN	45	8010	6806
Indianapolis, IN	52	5616	9212
Atlanta, GA	61	3025	16,803
Phoenix, AZ	71	1444	54,404

Model home description

The same typical house is assumed for the four cities. The floor area of the house is 2,200 square feet. It is two story (25' x 44') and has three bedrooms. There is 15% window area (glazing) above grade and a conditioned basement.

An illustration of a sheathing application with XPS can be found in Figure 1 below:

Figure 1: Installation of sheathing insulation

The following scenarios have been studied:

	Insulation above grade on top of the fiber type cavity insulation	Insulation below grade
"No XPS"	None	None
"XPS above grade"	XPS 1" thick	None
"XPS above & below grade"	XPS 1" thick	XPS 2" thick

The interior temperature was held at 72 F in all cases and for all locations year round. The ceiling and wall R-values were varied to meet minimum local building codes requirements:

Location	Ceiling R-value	Exterior above grade cavity wall insulation R-value
Minneapolis, MN	38	15
Indianapolis, IN	38	13
Atlanta, GA	30	13
Phoenix, AZ	19	11

There was no insulation between the first floor and the basement (conditioned air) in all cases and for all locations but the furnace duct work was insulated with an R-5 cover.

Utilities

<u>Heating Furnace</u>
50k/80 AFUE (Rated output cap./Annual Fuel Utilization Efficiency).
Heating is always done with a furnace using natural gas with the exception of Phoenix where an electric heat pump is used.
Water is also heated with gas but was not included in the energy calculations or in the CO_2 study.

<u>Cooling with air conditioning</u>
A/C: 10.0 SEER (Seasonal Energy Efficiency Ratio).
Cooling is always done using electricity.

Energy calculator / Energy consumption

The program "REM/Design version 11.3" from Architectural Energy Corporation has been used to calculate the energy consumption of the model house with the various levels of insulation and in the four different locations as defined above.

An example, for the city of Minneapolis, describing the various insulation conditions and the corresponding calculated energy consumption values is found in Annex 1.

Gross energy demand and carbon dioxide emissions from energy use

The electricity and natural gas Life Cycle Inventory (LCI) data specific for each city have been used. Energy is supplied through different commercial grids in the United States as follows:

Locations	Energy grid name	Gross energy from electricity use (MJ/MJ)	Gross energy from gas use (MJ/MJ)	CO2 emissions from electricity use (kg/MJ)	CO2 emissions from gas use (kg/MJ)
Minneapolis, MN	MAPP	3.53988	1.06554	0.263343	0.075753
Indianapolis, IN	MAIN	3.57561	1.06554	0.217603	0.075753
Atlanta, GA	SERC	3.45713	1.06554	0.213066	0.075753
Phoenix, AZ	WSCC	3.45713	Not used	0.182135	Not used

The values for gross energy and CO2 emissions related to each specific grid and energy type are from the Boustead Life Cycle Model V5.0. The data are representative of the year 1999.

Production of insulation products

Three types of extruded polystyrene foams (XPS) blown with different substances have been studied: the current North American formulation, which is based on HCFC-142b; and two formulations developed in Europe - one based on HFC-134a and one using carbon dioxide (CO2) as blowing agent.

The life cycle inventory data for the production of the foams has been collected in the Joliet, IL plant for HCFC, and in the Rheinmuenster, Germany and Drusenheim, France plants for the other formulations. The corresponding XPS life-cycle assessment (LCA)[‡] reports for these three plants, as well as the calculations for this particular study, have been peer reviewed by an external LCA expert, Dr. I. Boustead, Boustead Consulting Ltd., who confirmed that the work was carried in compliance with the ISO 1404X series of standards and satisfied the stated goals of the respective reports and study.

[‡] Note that these LCA Reports are, so called, 'cradle to gate' life-cycle assessments (sometimes referred to as eco-profile assessments), which are studies using life-cycle assessment principles and techniques according to ISO1404X where the system boundary encloses all processes from the extraction of raw materials from the ground up to the production of one unit of a product. They do not include the product use and end of product life phases.

XPS foam is delivered as 4'x 8' sheets of 1" and 2" thickness. The density of all three foam products has been assumed to be identical at 1.62 lb/ft³ (26 kg/m³).

The size of the studied model house requires 60 sheets above grade (35 boards per story, less 15% for windows) and, when applicable, 35 more sheets below grade (no windows).

Transport of insulation products

The transport has been calculated using the distance from the nearest XPS insulation plant for each city in the study. The truck load of XPS foam is assumed to be 36864 board ft (bf).
(1 bf = 0.00236 m³).

Location	Nearest XPS plant location	Distance, miles
Minneapolis, MN	Joliet	355
Indianapolis, IN	Joliet	160
Atlanta, GA	Dalton	80
Phoenix, AZ	Torrance	400

The values for gross energy and CO2 emissions related to road transport with an articulated 18-25 ton truck are from the Boustead Life Cycle Model V5.0:
CO2 equivalents - 100 years per vehicle-km = 1.52546 kg
Gross energy for transport per vehicle-km = 19.10504 MJ

The use phase of the insulation products

Both HCFC-142b and HFC-134a have comparably low thermal conductivity. Therefore, the XPS products blown with them have a similar thermal performance of R-5 per inch. The CO2-blown XPS has only an R-4.2 thermal performance because the thermal conductivity value of CO2 is not as low as that of the fluorinated gases and the CO2 is also emitted rapidly from the foam and replaced by air.

The emission of HCFC-142b and HFC-134a at the production plant stage has been assumed to be equal to that of the Joliet LCA[†] study for HCFC based products.

The diffusion of both HCFC-142b and HFC-134a from XPS during the use phase is 0.75% +/- 0.25% per year (reference Lee and Mutton, Earth Technology Forum, 2004).

Since the global warming potential (GWP) values, at a time horizon of 100 years, for HCFC-142b and HFC-134a, are respectively 2400 and 1300 CO2 equivalents, there is an

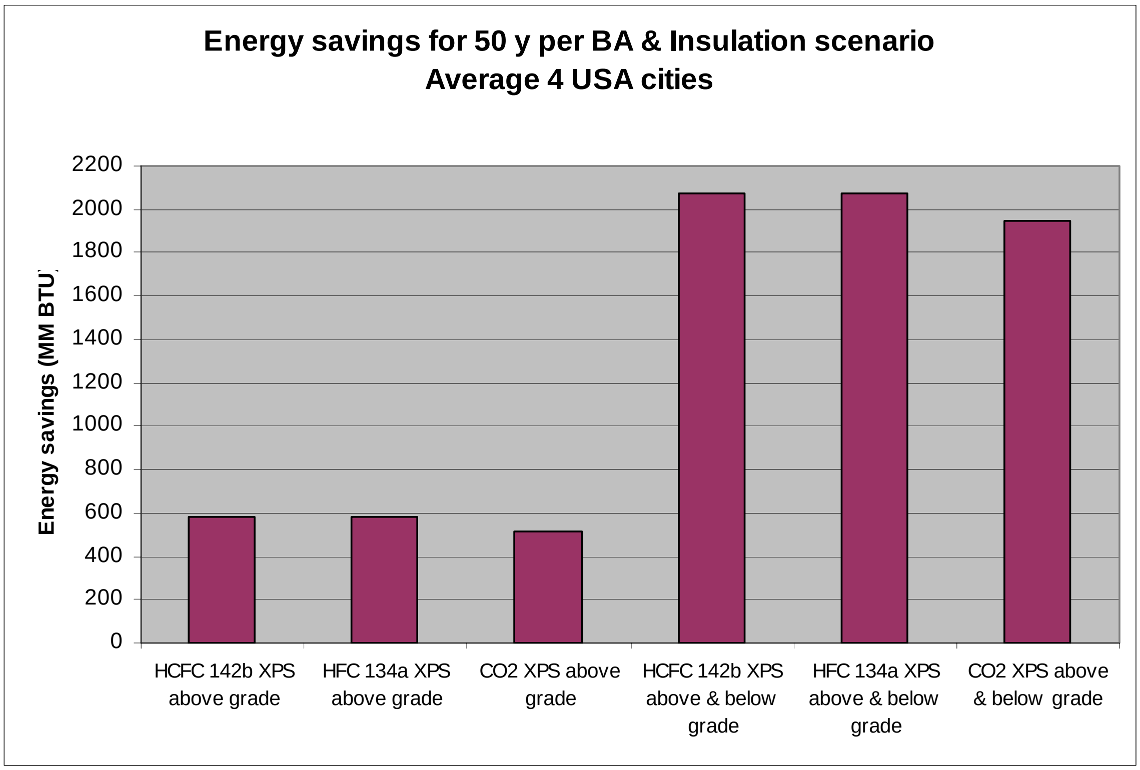
[†] a 'cradle to gate' life-cycle assessment (see previous footnote).

additional equivalent emission of CO2 which needs to be considered when using foams blown with these substances.

RESULTS

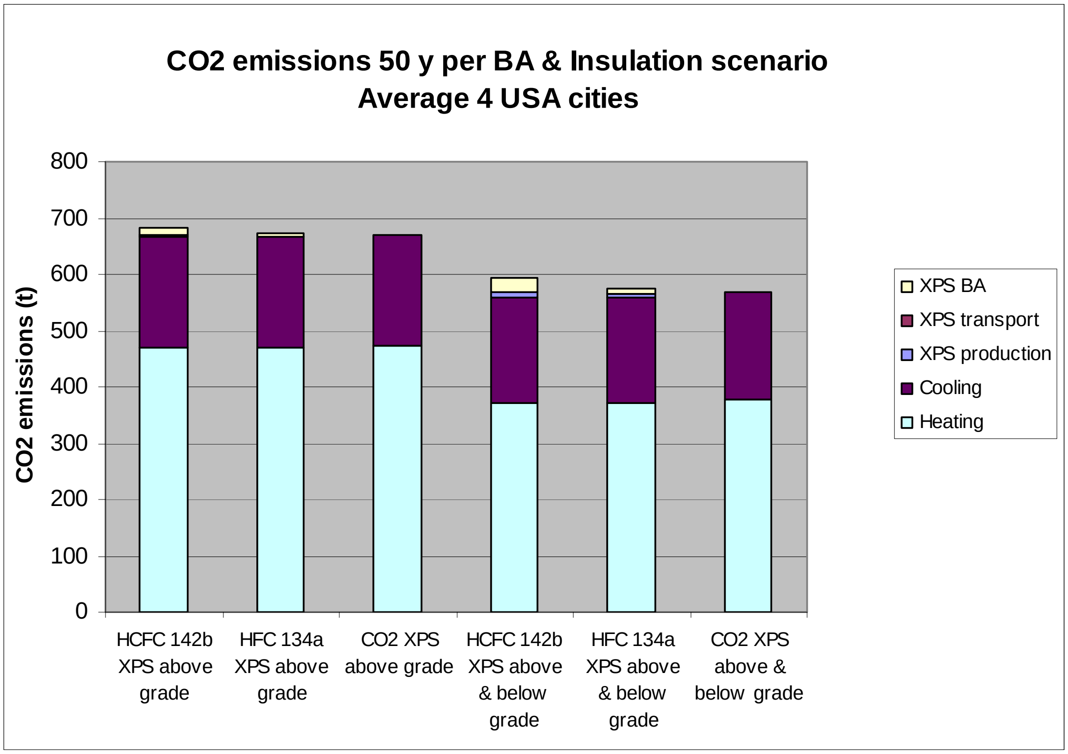
The result for the average values of the four cities studied is shown below. Detailed data per city are found in Appendix 2.

First, the difference in energy savings is compared for both insulation arrangements and for each of the three XPS products:



There is a significant difference in the energy savings generated through the use of the HCFC or HFC blown foams versus the CO2 product, from about 6% to up to 14% depending on the climates and the insulation arrangement.

Because energy in the USA is mostly based on fossil fuels, these energy savings also translate into large savings of air emissions (e.g., CO2, SOx, NOx), which can be precisely determined using life cycle analysis data for electricity and gas use.
Both HCFCs and HFCs contribute to a significant emission of CO2 equivalents due to their global warming potential. The overall CO2 emissions due to, on one side, the heating and cooling of the house and, on the other side, to the insulation products, have been compared for both insulation arrangements and for each of the three XPS products:



As shown on the above graph the CO2 emissions additionally generated by the insulation foam products are small compared to those created by the heating and cooling of the house over a 50 year period.

Considering the average of the four studied US climates, we can conclude that the three blowing agent formulations have an equivalent impact on climate change for the scenarios studied within the expected accuracy of the LCA data.

CONCLUSION AND RECOMMENDATION

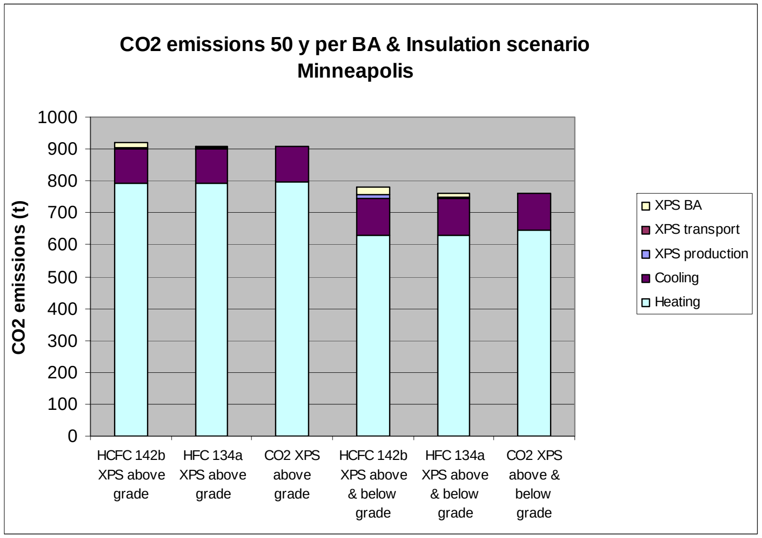
Given the significant energy savings and other associated emissions savings versus the insignificant differences between the overall CO2 emissions created over the life time of a widely practiced insulation application for XPS in North America such as sheathing insulation, it is recommended that the choice of future replacement alternatives for HCFC blowing agents should remain open to the use of HFC blowing agents. HFC blowing agents provide the combination of high technical performance and application performance currently demanded by the North American consumer.

APPENDIX 1: Summary of energy consumption and savings in Minneapolis

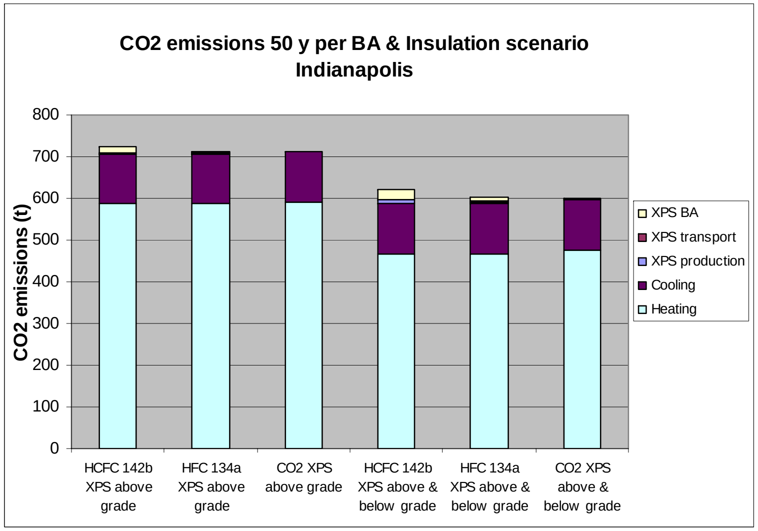
Model Home* Location & HDD, CDD Plus Utilities	XPS Insulation or Not	Estimated No. of 4X8 XPS Sheets	Annual Energy Consumption (MM BTU/yr)		Change in Energy Consumption - Savings Over No XPS (MM BTU/yr)	
For XPS blown with HCFC and HFC:						
Minneapolis, MN 8010, 6806	None Above or Below Grade	0	H= C= T=	211.3 7.9 219.2	T=MM BTU/yr	0
E=$0.085/Kwh; G=$0.90 Furnace: 50K/80AFUE A/C: 3 Ton/ 10.0 SEER	1" Above Grade (2 story) None Below Grade ***R 5***	60	H= C= T=	198.3 7.9 206.2	T=MM BTU/yr	13
Gas Hot Water Heater, 0.65EF	1" Above Grade (2 story) 2" Below Grade ***R 5 & R 10***	60 35 95	H= C= T=	157.9 8.3 166.2	T=MM BTU/yr	53
For XPS blown with CO2:						
E=$0.085/Kwh; G=$0.90 Furnace: 50K/80AFUE A/C: 3 Ton/ 10.0 SEER	1" Above Grade (2 story) None Below Grade ***R 4.2***	60	H= C= T=	199.8 7.9 207.7	T=MM BTU/yr	11.5
Gas Hot Water Heater, 0.65EF	1" Above Grade (2 story) 2" Below Grade ***R 4.2 & R 8.4***	60 35 95	H= C= T=	161.3 8.3 169.6	T=MM BTU/yr	49.6

*2200 ft2, 2 story with 15% Window Glazing, and conditioned basement.

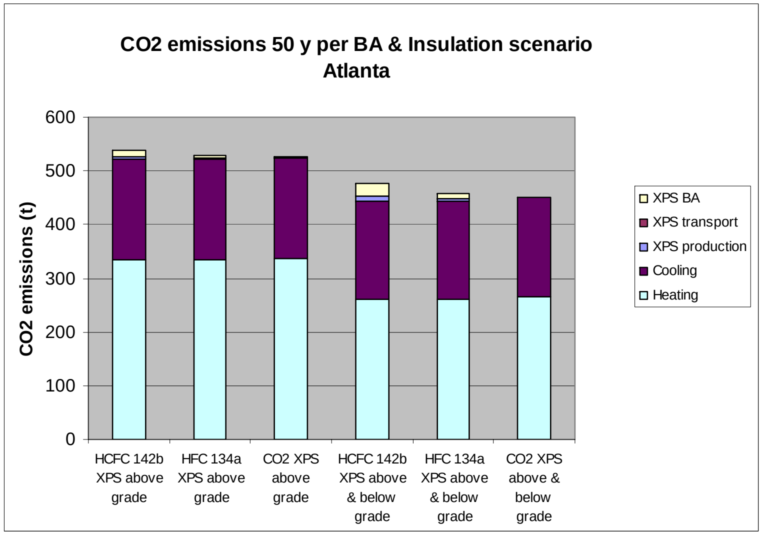
APPENDIX 2



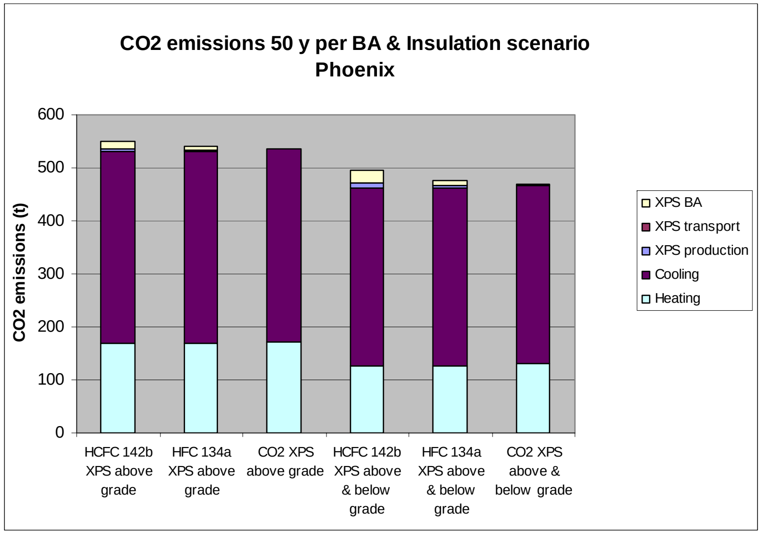
CO2 emissions 50 y per BA & Insulation scenario
Minneapolis
CO2 emissions (t)
1000
900
800
700
600
500
400
300
200
100
0
HCFC 142b XPS above grade
HFC 134a XPS above grade
CO2 XPS above grade
HCFC 142b XPS above & below grade
HFC 134a XPS above & below grade
CO2 XPS above & below grade
XPS BA
XPS transport
XPS production
Cooling
Heating



CO2 emissions 50 y per BA & Insulation scenario
Indianapolis
CO2 emissions (t)
800
700
600
500
400
300
200
100
0
HCFC 142b XPS above grade
HFC 134a XPS above grade
CO2 XPS above grade
HCFC 142b XPS above & below grade
HFC 134a XPS above & below grade
CO2 XPS above & below grade
XPS BA
XPS transport
XPS production
Cooling
Heating



CO2 emissions 50 y per BA & Insulation scenario
Atlanta
CO2 emissions (t)
600
500
400
300
200
100
0
HCFC 142b XPS above grade
HFC 134a XPS above grade
CO2 XPS above grade
HCFC 142b XPS above & below grade
HFC 134a XPS above & below grade
CO2 XPS above & below grade
XPS BA
XPS transport
XPS production
Cooling
Heating



CO2 emissions 50 y per BA & Insulation scenario
Phoenix
CO2 emissions (t)
600
500
400
300
200
100
0
HCFC 142b XPS above grade
HFC 134a XPS above grade
CO2 XPS above grade
HCFC 142b XPS above & below grade
HFC 134a XPS above & below grade
CO2 XPS above & below grade
XPS BA
XPS transport
XPS production
Cooling
Heating