# ENERGY AND GREENHOUSE GAS SAVINGS FOR EPS FOAM INSULATION APPLIED TO EXTERIOR WALLS OF SINGLE FAMILY RESIDENTIAL HOUSING IN THE U.S. AND CANADA

**Final Revised Report**

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## INTRODUCTION

The production of EPS foam insulation uses fossil fuel resources for process and transportation energy as well as using fuel resources as material inputs for the production of plastic resin and blowing agent. However, the use of foam insulation on a building significantly increases the R-value of walls and therefore saves energy and reduces greenhouse gas emissions over the useful life of the building.

This analysis examines energy savings and subsequent greenhouse gas emission reductions resulting from the addition of expanded polystyrene (EPS) foam insulation to the exterior walls of residential buildings. Energy use for space conditioning is evaluated for various locations in the United States and Canada.

## GOAL

The goal of this analysis is to quantify the energy and emissions associated with the production of EPS foam insulation used in defined residential building applications and to compare these burdens with the savings in energy and greenhouse gas resulting from the added R-value of the foam during the building's use phase.

## SCOPE AND BOUNDARIES

This study analyzes the effect that EPS foam insulation has on energy use and greenhouse gas emissions for heating and cooling single-family residential buildings in the United States and Canada. In order to evaluate the range of savings across different regions of North America, a representative U.S. home is evaluated for five climate zones in the U.S., and a representative Canadian home is evaluated in each of twelve Canadian provinces.

The scope of the study is limited to an evaluation of energy and greenhouse gas associated with the foam insulation. The life cycle stages evaluated include all steps in the production of EPS foam insulation, from raw material extraction through production of the insulation and shipment to the construction site. The study does not include construction of the building itself or production of fiberglass batt insulation. No data were available on energy use for installation of the foam insulation. The study includes electricity and natural gas consumption for heating and cooling of the building during use, but does not include demolition of the building at the end of its useful life or disposal of construction and demolition waste.

The energy and greenhouse gas savings are determined by comparing the heating and cooling energy requirements for the defined housing application with no added insulation to the heating and cooling energy for the same house with added EPS insulation. Use phase savings are evaluated for two foam insulation scenarios, R-4 EPS insulation and R-6 EPS insulation.

Although there are many ways that energy can be lost out of a building, this report focuses only on conductive heat flow through the insulated walls. It does not include air leakage through walls or ducts, location of ducts throughout the house, convection within wall cavities or any other possible routes for energy loss. Therefore, any advantages that the foam insulation might have as a vapor or air barrier have not been included in the results.

## INSULATION PRODUCTION

EPS insulation boardstock is made from polystyrene resin that has been impregnated with a pentane blowing agent. The beads are pre-expanded by direct exposure to steam and then allowed to age. After aging, the beads are again exposed to pressurized steam, causing them to further expand and fuse into a block shape. The blocks are then cut into boards.

According to the ASHRAE Handbook of Fundamentals, the R-value of EPS foam insulation is 3.85 $ft^2$/Btu/hr/°F/inch. The density of EPS foam is 1.0 pound per cubic foot. The production of EPS resin is modeled using unit process data in the U.S. LCI Database (www.nrel.gov/lci) for upstream steps leading to polystyrene resin production and data from Franklin Associates' private LCI database for blowing agent production and EPS resin production.

Process data for block molding of EPS were gathered from 10 manufacturing facilities in the U.S. and Canada. The data included information on virgin and regrind EPS inputs to the process, distances and transportation modes for transporting input materials to the manufacturing facility, pentane content of the resin, molding process energy requirements, solid wastes, and atmospheric and waterborne emissions. The data were compiled to produce a North American industry average data set.

In order to comply with fire safety regulations, the brominated flame retardant hexabromocyclododecane (HBCD) is commonly used in EPS foam insulation at about 0.7 percent by weight of the resin. Data on the production of HBCD were not available; thus, the entire weight of the foam insulation is modeled as EPS. Because the flame retardant contributes such a small amount to the foam insulation, modeling the entire weight of the insulation as EPS is expected to have minimal influence on the total energy and greenhouse gas results.

Insulation board is trucked to stores and construction sites. Because of the low density of the foam boards, truckloads max out by volume before the load weight limit is reached.

Thus, foam transportation fuel requirements are based on the number of volume-limited truckloads required to ship the quantity of foam insulation boards required for the application. In this study, transportation of foam board is based on 300 miles transport from the manufacturing facility to a construction site with 3,072 cubic feet of insulation per truck. The fuel efficiency of the truck is modeled as 6.5 miles per gallon. The amount of foam produced and transported was scaled up to cover an estimated 10 percent scrap rate during installation, i.e., for small trim scrap pieces that are not reused.

For electricity used in insulation production and for space conditioning the building, country-specific electricity grids are used to model the energy requirements and greenhouse gas emissions for electricity generation, transmission, and distribution. For the U.S. applications, the electricity used in foam insulation production and during building operation is modeled using the national average mix of fuels used to generate electricity for the U.S., compiled using publicly available data from the U.S. EPA's eGRID database.[1] For electricity used in insulation manufacture and building operation in Canada, the Canadian national electricity grid is modeled using data from the International Energy Agency.[2] Precombustion energy and emissions are calculated for each country based on its fuel mix, using Franklin Associates' life cycle inventory models.

## RESIDENTIAL HEAT FLOW METHODOLOGY FOR THE U.S.

The base walls of the U.S. homes are modeled as 2x4 wood frame construction, with studs 16" on center, R-13 of fiberglass insulation and wood siding. Using Oak Ridge National Lab's (ORNL) Whole Wall R-value Calculator, this wall structure has a whole-wall R-value of 10.74. The ORNL calculator was used because it takes into account aspects of the wall such as window and door framing, interior wall partitions and corners.

To isolate the energy flow through the insulated portion of the walls, it was assumed that windows make up 15 percent of the wall area. While energy will flow through the windows, it will flow in parallel with the energy moving through the walls and will not affect the final calculations. The same is true for heat flow through the roof and any basement area.

Using just the base R-value from ORNL and a simple heat flow model, the calculated energy savings will likely understate the total energy savings realized. Fiberglass insulation provides little protection from air convection, so its stated R-value is only true when air cannot flow through or around it; foam insulation can form an air barrier, reducing heat loss by impeding air flow. Additional insulation also keeps the interior of the walls warmer, which increases the mean radiant temperature of the living space. This allows for the occupants to be comfortable at lower air temperatures, reducing the energy used to heat and cool the home. Finally, with lower heating and cooling loads, the heating and air conditioning equipment can be downsized, providing further energy savings.

[1] http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html
[2] Accessed at http://iea.org , May 2008.

For the foam insulation scenarios, the R-value of the foam insulation was added to the R-10.74 base value of the wall to determine the energy flow. The increase in R-value would be slightly larger than just the value of the insulation because of reduced thermal bridging. Thermal bridging happens when heat flows through two materials in parallel (such as insulation and wood framing), and the R-value of one is much lower than the other. Adding foam insulation reduces the amount of heat that will flow through the wood, which is 'bridging' the distance across the insulation. The effect of thermal bridging is expected to be small in comparison to the overall savings in space conditioning.

To determine the heat flow through the walls of the house as both a national average and within specific climate regions, the Heating Degree Day (HDD) and Cooling Degree Day (CDD) data were collected from the National Oceanic and Atmospheric Administration (NOAA) and weighted by the number of new housing starts within the state.

A HDD represents an average daily temperature difference below 65° F, while a CDD represents the average daily temperature difference above 65° F. The states were separated into regions based on the number of HDD and CDD (Table 1). Regional degree days were calculated by weighting each state based on the number of permits for single unit homes in 2006. Since EPS insulation would be installed during the construction of new houses, the weighting was done so that the average weather would reflect areas where new houses were being built.

A simple one-dimensional heat flow model was used to find the energy needed to heat and cool the model house in each region. Any energy loss through air leakage or routes other than straight conduction through the walls was assumed to be zero. A detailed sample calculation can be found in Appendix A.

The building dimensions for the U.S. residential application evaluated in this analysis is from a 2000 insulation life cycle study conducted by Franklin Associates.[3] The total insulated wall area is 1,791 square feet. Scaled up for 10 percent installation scrap, the total amount of EPS foam insulation produced and transported to the construction site is 1,970 square feet. For EPS foam with an R-value of 3.85 $ft^2$/Btu/hr/°F/inch, the thicknesses of R-4 and R-6 foam insulation are 1.04 and 1.56 inches, respectively. The total weight of EPS insulation manufactured is 170.6 pounds for the R-4 insulation scenario and 255.9 for the R-6 scenario.

3 **Plastics Energy and Greenhouse Gas Savings Using Rigid Foam Insulation Applied to Exterior Walls of Single Family Residential Housing in the U.S. and Canada – A Case Study.** Conducted by Franklin Associates for the American Chemistry Council and Environment and Plastics Industry Council of the Canadian Plastics Industry Association. September 2000.

**Table 1**

**ASSIGNMENT OF STATES TO CLIMATE ZONES**

| Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 |
|---|---|---|---|---|
| | Fewer than 2000 CDD and -- | | | 2000 CDD or More and Fewer than 4000 HDD |
| More than 7000 HDD | 5500 to 7000 HDD | 4000 to 5499 HDD | Fewer than 4000 HDD | |
| Maine | Colorado | Connecticut | Arkansas | Alabama |
| Minnesota | Idaho | Deleware | California | Arizona |
| Montana | Illinois | Indiana | Georgia | Florida |
| North Dakota | Iowa | Kansas | North Carolina | Louisiana |
| Vermont | Massachusetts | Kentucky | South Carolina | Mississippi |
| Wyoming | Michigan | Maryland & DC | Tennessee | Nevada |
| | Nebraska | Missouri | Virginia | Oklahoma |
| | New Hampshire | New Jersey | | Texas |
| | South Dakota | New Mexico | | |
| | Utah | New York | | |
| | Wisconsin | Ohio | | |
| | | Oregon | | |
| | | Pennsylvania | | |
| | | Rhode Island | | |
| | | Washington | | |
| | | West Virginia | | |

Table 2 presents a summary of the HDD, CDD and annual reductions in energy flow through walls for the U.S. regions and insulation scenarios in this analysis.

**Table 2**

**REDUCTIONS IN ANNUAL ENERGY FLOW THROUGH WALLS FOR USE OF EPS INSULATION ON A U.S. HOUSE**

| | | | Reduction in Heating Energy Flow (BTU/year) | | Reduction in Cooling Energy Flow (BTU/year) | | Total Reduction in Energy Flow (BTU/year) | |
|---|---|---|---|---|---|---|---|---|
| | HDD | CDD | EPS R-4 | EPS R-6 | EPS R-4 | EPS R-6 | EPS R-4 | EPS R-6 |
| **US weighted average** | **3,418** | **1,732** | **3,712,321** | **4,903,191** | **1,881,452** | **2,485,000** | **5,593,773** | **7,388,191** |
| Zone 1 (coldest) | 7,432 | 555 | 8,071,485 | 10,660,725 | 602,251 | 795,446 | 8,673,736 | 11,456,171 |
| Zone 2 | 6,211 | 692 | 6,745,532 | 8,909,421 | 752,088 | 993,349 | 7,497,620 | 9,902,770 |
| Zone 3 | 4,875 | 812 | 5,295,002 | 6,993,578 | 882,046 | 1,164,997 | 6,177,049 | 8,158,575 |
| Zone 4 | 2,952 | 1,420 | 3,206,189 | 4,234,697 | 1,541,936 | 2,036,571 | 4,748,125 | 6,271,269 |
| Zone 5 (warmest) | 1,534 | 3,050 | 1,666,483 | 2,201,071 | 3,313,036 | 4,375,820 | 4,979,518 | 6,576,891 |

Source: Franklin Associates, Ltd.

## RESIDENTIAL HEAT FLOW METHODOLOGY FOR CANADA

The basic methodology for calculating heat flow in Canadian homes is identical to that of the U.S. The Canadian home in this analysis was modeled as the same size as the U.S. home, with 1,791 square feet of wall area, so the quantities of R-4 and R-6 insulation required to insulate the Canadian home are the same as for the U.S. home. Heating degree data for the largest city in each Canadian province was used to represent each province. Cooling degree days were not considered, because the energy to cool homes in Canada is less than one percent of the energy used to heat them. To keep methodology consistent with that used in the U.S., the number of new houses in each province was used to weight the national degree day average. Data are also reported for twelve individual provinces.

The base walls of the Canadian homes are modeled as 2x6 wood frame construction, with studs 16" on center, R-19 of fiberglass insulation and wood siding. From the Oak Ridge National Lab's Whole Wall R-value Calculator, this wall structure has a whole-wall R-value of 13.65.

Table 3 presents a summary of the HDD and annual reductions in heat flow through walls for the Canadian locations and insulation scenarios in this analysis. For each province, the table also shows the name of the city or location within each province whose climate data are used to represent that province as a whole.

**Table 3**

**REDUCTIONS IN ANNUAL ENERGY FLOW THROUGH WALLS FOR USE OF EPS INSULATION ON A CANADIAN HOUSE**

| | | Reduction in Heating Energy Flow (BTU/year) | |
|---|---|---|---|
| | **HDD** | **EPS R-4** | **EPS R-6** |
| **Canada weighted average** | **7,674** | **3,574,448** | **4,815,955** |
| Alberta (Calgary) | 9,227 | 4,298,081 | 5,790,925 |
| British Columbia (Vancouver) | 5,300 | 2,468,651 | 3,326,083 |
| Manitoba (Winnipeg) | 10,432 | 4,859,092 | 6,546,792 |
| New Brunswick (St. John) | 8,590 | 4,001,351 | 5,391,133 |
| Newfoundland (St. John's) | 8,819 | 4,107,835 | 5,534,602 |
| Northwest Territories (Yellowknife) | 14,893 | 6,937,208 | 9,346,697 |
| Novia Scotia (Halifax Airport) | 7,893 | 3,676,616 | 4,953,609 |
| Ontario(Toronto) | 6,457 | 3,007,947 | 4,052,691 |
| Prince Edward Island (Charlottetown) | 8,520 | 3,968,483 | 5,346,849 |
| Quebec (Montreal airport) | 8,166 | 3,803,642 | 5,124,755 |
| Saskatchwean (Saskatoon Airport) | 10,566 | 4,921,893 | 6,631,405 |
| Yukon Territory (Whitehorse) | 12,292 | 5,725,889 | 7,714,652 |

Source: Franklin Associates, Ltd.

## FUELS USED FOR HOME HEATING AND COOLING

For the U.S., the energy flows for heating shown in Table 2 were converted to equivalent quantities of heating fuels using EIA data from 2001 on the ratio of heating fuels in each region, with some modifications based on 2006 Census data for new construction houses. These modifications were necessary because many older houses use oil furnaces, while few new houses are built with them. There was also a rise in the use of electric heat pumps from 2004-2006, with a corresponding decline in natural gas furnaces. EIA fuel categories such as 'Other' were ignored, and data not listed by the EIA due to high statistical error was assumed to be zero. It was assumed that all cooling was done by electrically powered central air conditioners.

Efficiencies for each of the heating and cooling methods were based on 2006 EPA regulations, with the assumption that kerosene heaters are portable, and release 100 percent of their heat into the room. Given that kerosene heating makes up 2 percent or less of the total space heating, this assumption should not impact the final results. Gas and oil furnaces were assumed to be 83 percent efficient, electric heat pumps have a Heating Season Performance Factor (HSPF) of 7.7, and air conditioners were rated a Seasonal Energy Efficiency Ratio (SEER) of 13. It was assumed, based on U.S. Census data, that only 3 percent of electric heating was from electrical resistance, with the rest from heat pumps.

Canadian homes use a different mix of fuels for heating than those in the U.S. Wood stoves make up a significant percentage (14 percent) of heating in Canada. According to a Canadian wood stove expert, 70 percent is a reasonable efficiency for modern wood stoves. All other heating efficiencies were assumed to be the same as in the U.S. Fuel use for new houses only was not available, so the mix for all houses in 2005 was used for all provinces.

The mix of fuels used for home heating in each U.S. region and Canada is shown in Table 4.

**Table 4**

**FUEL MIX FOR HOME HEATING IN THE U.S. AND CANADA**

| | Electricity | Nat. Gas | Fuel Oil | Kerosene | LPG | Wood | Total |
|---|---|---|---|---|---|---|---|
| **US average** | **35%** | **58%** | **2%** | **1%** | **5%** | | **100%** |
| Zone 1 | 14% | 60% | 16% | 1% | 9% | | 100% |
| Zone 2 | 14% | 80% | 2% | | 5% | | 100% |
| Zone 3 | 29% | 59% | 7% | | 5% | | 100% |
| Zone 4 | 34% | 59% | | 2% | 5% | | 100% |
| Zone 5 | 54% | 42% | | | 4% | | 100% |
| **Canada*** | **20%** | **57%** | **9%** | | | **14%** | **100%** |

*Fuel mix by province was not available.

Source: Franklin Associates, Ltd.

## RESULTS FOR U.S. SCENARIOS

### U.S. Energy Results

The total energy requirements for producing R-4 and R-6 EPS foam insulation for the defined residential building application are shown at the top of Table 5. The EPS insulation production energy requirements include all material extraction, processing, and fabrication steps, as well as energy used to transport materials from place to place during the journey from raw material to block molded foam. The production energy requirements also include the energy value of fuel resources used as material inputs to produce the insulation, that is, the crude oil and natural gas extracted from the earth and used as material feedstocks to produce the resin and blowing agent. This energy is referred to as “energy of material resource,” or EMR. Combustion of fossil fuels for process and transportation energy produces greenhouse gases, while EMR does not result in greenhouse gas emissions unless the material is eventually burned. The energy shown separately for foam transportation is for transportation of the foam board to the installation site, assuming a distance of 300 miles.

The lower section of Table 5 shows the energy savings per year for adding R-4 EPS and R-6 EPS to the base wall with an R-value of 10.74. The table also shows the payback time, expressed as years for the energy savings to offset the energy for production of the foam.

The energy savings shown in Table 5 are greater than the reductions in the heat flow through the home walls shown in Table 2. This is because the savings in Table 5 include not only the heat flow through the walls of the home but also the energy required to produce and deliver the fuels and electricity that are used to heat and cool the home.

The energy payback time for R-4 insulation is less than 2 years for all U.S. climate zones. The payback time is shortest in colder zones. More material and more energy is required to produce and transport R-6 insulation, as shown in the foam production energy results at the top of Table 5, so the payback period is slightly longer for R-6 foam. However, the greater R value results in greater savings each year for home heating and cooling. Although it takes slightly longer to achieve energy payback for R-6 foam, over the life of the building the R-6 foam results in substantially greater energy savings.

**U.S. Greenhouse Gas Results**

Table 6 uses the same format as Table 5 to display U.S. results for greenhouse gases from EPS insulation production and transport, as well as the annual savings due to reduced energy usage for building heating and cooling. The total global warming potential (GWP) for each scenario is expressed in carbon dioxide equivalents, and includes contributions from emissions of fossil carbon dioxide, methane, and nitrous oxide.

Emissions of each greenhouse gas are multiplied by its potency relative to carbon dioxide, using 100-year GWP factors from the Fourth Assessment Report of the International Panel on Climate Change (IPCC), published in November, 2007. Using carbon dioxide as the reference substance (GWP = 1), the 100 year GWP factors for methane and nitrous oxide are 25 and 298, respectively.

Although some greenhouse gases are emitted from the sequence of processes in the production of EPS insulation, by far the dominant source of greenhouse gases for EPS foam production is fossil fuel combustion for process and transportation energy. In Table 5, a significant portion of the total energy requirements is the energy content of the fuel resources used as material inputs to foam, which does not have associated combustion emissions. As a result, payback times are faster for greenhouse gases than for energy.

As with energy results, Table 6 shows that there is variation in the results across climate regions. Homes in colder regions show greater annual savings and faster payback time than those in warmer regions, because the increased R-value with insulation saves more heating energy and avoids the related fossil fuel combustion emissions.

Production of R-6 foam results in more greenhouse gas emissions than the same square footage of R-4 foam, so the GWP payback time for R-6 foam is slightly longer than for R-4 foam, but the use of R-6 foam results in greater savings in greenhouse gases for each year of the building's operation.

**Table 5**

**ENERGY SAVINGS FOR EPS INSULATION USE ON THE EXTERIOR WALLS OF A U.S. HOME**

| | R4 EPS | | R6 EPS | |
|---|---|---|---|---|
| **Energy for Adding EPS Sheathing** | **Energy (MMBtu)** | | **Energy (MMBtu)** | |
| EPS Production (1) | 8.90 | | 13.35 | |
| EPS Transport | 0.13 | | 0.20 | |
| **Total Energy** | **9.04** | | **13.55** | |
| | | | | |
| **U.S. Average** | **Energy Savings (2)** | **Payback Years** | **Energy Savings (2)** | **Payback Years** |
| Annual savings compared to base wall | 6.58 | 1.37 | 8.68 | 1.56 |
| Savings over 50 years | 329 | | 434 | |
| **Zone 1 (coldest)** | | | | |
| Annual savings compared to base wall | 11.37 | 0.79 | 15.02 | 0.90 |
| Savings over 50 years | 568 | | 751 | |
| **Zone 2** | | | | |
| Annual savings compared to base wall | 9.58 | 0.94 | 12.66 | 1.07 |
| Savings over 50 years | 479 | | 633 | |
| **Zone 3** | | | | |
| Annual savings compared to base wall | 7.84 | 1.15 | 10.36 | 1.31 |
| Savings over 50 years | 392 | | 518 | |
| **Zone 4** | | | | |
| Annual savings compared to base wall | 5.58 | 1.62 | 7.37 | 1.84 |
| Savings over 50 years | 279 | | 368 | |
| **Zone 5 (warmest)** | | | | |
| Annual savings compared to base wall | 5.00 | 1.81 | 6.60 | 2.05 |
| Savings over 50 years | 250 | | 330 | |

(1) Based on a U.S. home with 1,791 square feet of insulated exterior wall.
(2) Includes energy flow through walls plus energy to produce and deliver the fuels and electricity used for home heating and cooling.

Source: Franklin Associates, Ltd.

**Table 6**

**REDUCTIONS IN GLOBAL WARMING POTENTIAL FOR EPS INSULATION USE ON THE EXTERIOR WALLS OF A U.S. HOME**

| | R4 EPS | | R6 EPS | |
|---|---|---|---|---|
| **GWP for Adding EPS Sheathing** | **GWP (lb CO2 equiv)** | | **GWP (lb CO2 equiv)** | |
| EPS Production (1) | 795 | | 1,193 | |
| EPS Transport | 24 | | 36 | |
| **Total GWP** | **819** | | **1,229** | |
| **U.S. Average** | **GWP Savings** | **Payback Years** | **GWP Savings** | **Payback Years** |
| Annual savings compared to base wall | 982 | 0.83 | 1,297 | 0.95 |
| Savings over 50 years | 49,095 | | 64,843 | |
| **Zone 1 (coldest)** | | | | |
| Annual savings compared to base wall | 1,669 | 0.49 | 2,205 | 0.56 |
| Savings over 50 years | 83,473 | | 110,250 | |
| **Zone 2** | | | | |
| Annual savings compared to base wall | 1,354 | 0.61 | 1,788 | 0.69 |
| Savings over 50 years | 67,682 | | 89,394 | |
| **Zone 3** | | | | |
| Annual savings compared to base wall | 1,155 | 0.71 | 1,525 | 0.81 |
| Savings over 50 years | 57,739 | | 76,260 | |
| **Zone 4** | | | | |
| Annual savings compared to base wall | 831 | 0.99 | 1,097 | 1.12 |
| Savings over 50 years | 41,527 | | 54,848 | |
| **Zone 5** | | | | |
| Annual savings compared to base wall | 777 | 1.05 | 1,027 | 1.20 |
| Savings over 50 years | 38,867 | | 51,335 | |

(1) Based on a U.S. home with 1,791 square feet of insulated exterior wall.

Source: Franklin Associates, Ltd.

## RESULTS FOR CANADIAN SCENARIOS

### Canadian Energy Results

Table 7 shows the production energy requirements for foam insulation in Canada, along with the annual energy savings and energy payback period. The Canadian electricity grid uses more hydropower and less fossil fuel combustion than the U.S. grid, resulting in lower total energy and greenhouse gas emissions per kWh of Canadian electricity. As a result of the lower energy and emissions for Canadian electricity, there is less energy and greenhouse gas emissions for producing the foam to insulate a Canadian home compared to producing the foam to insulate the same size U.S. home.

The colder average temperatures in Canada and associated higher heating requirements result in greater energy savings per year for use of foam insulation. The energy payback periods for Canadian scenarios are less than one year for R-4 foam and R-6 foam in all provinces. Table 7 shows greater energy savings than Table 3 because the savings in Table 3 include only the heat flow through the walls of the home, while Table 7 also includes the energy required to produce and deliver the fuels and electricity that are used to heat the home.

### Canadian Greenhouse Gas Results

Table 8 shows the global warming potential (expressed in pounds of carbon dioxide equivalents) for production of the foam, as well as the emissions avoided due to energy savings from the use of EPS insulation. Canada's substantial use of hydroelectric power and lower use of coal means that the electricity grid produces less greenhouse gas emissions per kWh than the U.S. average electricity grid. The greenhouse gas payback time for all Canadian locations is less than two years for both R-4 and R-6 foam.

## LIMITATIONS

The results presented in this report represent single-family homes with the defined square footage and base wall construction described in the heat flow methodology sections. There are many sizes and designs of residential buildings, with differences in footprints, percentage of wall area occupied by windows, etc. Different home designs use various types of wall assemblies with different material compositions and R-values.

Construction practices are highly variable, including the use of a wide range of thicknesses of insulation and of standard wall construction. Construction quality greatly affects the functioning of insulation products. For example, leaky doors and windows can increase heating and cooling energy use despite well-insulated walls. Weather conditions and temperatures have a significant impact on heating and cooling requirements, but are highly variable from day to day and year to year. Homeowners may choose to use thermostat settings that are considerably higher or lower than the 65°F used as the basis for calculating the HDD and CDD. The use of 65°F likely leads to an underestimate of energy for heating and an overestimate of energy for cooling.

**Table 7**

**ENERGY SAVINGS FOR EPS INSULATION USE ON THE EXTERIOR WALLS OF A CANADIAN HOME**

| | R4 EPS | | R6 EPS | |
|---|---|---|---|---|
| **Energy for Adding EPS Sheathing** | **Energy (MMBtu)** | | **Energy (MMBtu)** | |
| EPS Production (1) | 8.48 | | 12.72 | |
| EPS Transport | 0.14 | | 0.20 | |
| **Total Energy** | **8.62** | | **12.92** | |
| | | | | |
| **Canada Average** | **Energy Savings (2)** | **Payback Years** | **Energy Savings (2)** | **Payback Years** |
| Annual savings compared to base wall | 19.15 | 0.45 | 25.81 | 0.50 |
| Savings over 50 years | 958 | | 1,290 | |
| **Alberta** | | | | |
| Annual savings compared to base wall | 23.03 | 0.37 | 31.03 | 0.42 |
| Savings over 50 years | 1,152 | | 1,552 | |
| **British Columbia** | | | | |
| Annual savings compared to base wall | 13.23 | 0.65 | 17.82 | 0.73 |
| Savings over 50 years | 661 | | 891 | |
| **Manitoba** | | | | |
| Annual savings compared to base wall | 26.04 | 0.33 | 35.08 | 0.37 |
| Savings over 50 years | 1,302 | | 1,754 | |
| **New Brunswick** | | | | |
| Annual savings compared to base wall | 21.44 | 0.40 | 28.89 | 0.45 |
| Savings over 50 years | 1,072 | | 1,444 | |
| **Newfoundland** | | | | |
| Annual savings compared to base wall | 22.01 | 0.39 | 29.66 | 0.44 |
| Savings over 50 years | 1,101 | | 1,483 | |
| **Northwest Territories** | | | | |
| Annual savings compared to base wall | 37.17 | 0.23 | 50.08 | 0.26 |
| Savings over 50 years | 1,859 | | 2,504 | |
| **Novia Scotia** | | | | |
| Annual savings compared to base wall | 19.70 | 0.44 | 26.54 | 0.49 |
| Savings over 50 years | 985 | | 1,327 | |
| **Ontario** | | | | |
| Annual savings compared to base wall | 16.12 | 0.53 | 21.72 | 0.60 |
| Savings over 50 years | 806 | | 1,086 | |
| **Prince Edward Island** | | | | |
| Annual savings compared to base wall | 21.26 | 0.41 | 28.65 | 0.45 |
| Savings over 50 years | 1,063 | | 1,433 | |
| **Quebec** | | | | |
| Annual savings compared to base wall | 20.38 | 0.42 | 27.46 | 0.47 |
| Savings over 50 years | 1,019 | | 1,373 | |
| **Saskatchwean** | | | | |
| Annual savings compared to base wall | 26.37 | 0.33 | 35.53 | 0.36 |
| Savings over 50 years | 1,319 | | 1,777 | |
| **Yukon Territory** | | | | |
| Annual savings compared to base wall | 30.68 | 0.28 | 41.34 | 0.31 |
| Savings over 50 years | 1,534 | | 2,067 | |

(1) Based on a Canadian home with 1,791 square feet of insulated exterior wall.

(2) Includes energy flow through walls plus energy to produce and deliver the fuels and electricity used for home heating.

Source: Franklin Associates, Ltd.

**Table 8**

**REDUCTIONS IN GLOBAL WARMING POTENTIAL FOR EPS INSULATION USE ON THE EXTERIOR WALLS OF A CANADIAN HOME**

| | R4 EPS | | R6 EPS | |
|---|---|---|---|---|
| **GWP for Adding EPS Sheathing** | **GWP (lb CO2 equiv)** | | **GWP (lb CO2 equiv)** | |
| EPS Production (1) | 683 | | 1,024 | |
| EPS Transport | 24 | | 36 | |
| **Total GWP** | **707** | | **1,060** | |
| **Canada Average** | **GWP Savings** | **Payback Years** | **GWP Savings** | **Payback Years** |
| Annual savings compared to base wall | 742 | 0.95 | 1,000 | 1.06 |
| Savings over 50 years | 37,124 | | 50,018 | |
| **Alberta** | | | | |
| Annual savings compared to base wall | 893 | 0.79 | 1,203 | 0.88 |
| Savings over 50 years | 44,640 | | 60,144 | |
| **British Columbia** | | | | |
| Annual savings compared to base wall | 513 | 1.38 | 691 | 1.53 |
| Savings over 50 years | 25,639 | | 34,545 | |
| **Manitoba** | | | | |
| Annual savings compared to base wall | 1,009 | 0.70 | 1,360 | 0.78 |
| Savings over 50 years | 50,466 | | 67,995 | |
| **New Brunswick** | | | | |
| Annual savings compared to base wall | 831 | 0.85 | 1,120 | 0.95 |
| Savings over 50 years | 41,558 | | 55,992 | |
| **Newfoundland** | | | | |
| Annual savings compared to base wall | 853 | 0.83 | 1,150 | 0.92 |
| Savings over 50 years | 42,664 | | 57,482 | |
| **Northwest Territories** | | | | |
| Annual savings compared to base wall | 1,441 | 0.49 | 1,941 | 0.55 |
| Savings over 50 years | 72,050 | | 97,075 | |
| **Novia Scotia** | | | | |
| Annual savings compared to base wall | 764 | 0.93 | 1,029 | 1.03 |
| Savings over 50 years | 38,185 | | 51,448 | |
| **Ontario** | | | | |
| Annual savings compared to base wall | 625 | 1.13 | 842 | 1.26 |
| Savings over 50 years | 31,240 | | 42,091 | |
| **Prince Edward Island** | | | | |
| Annual savings compared to base wall | 824 | 0.86 | 1,111 | 0.95 |
| Savings over 50 years | 41,217 | | 55,532 | |
| **Quebec** | | | | |
| Annual savings compared to base wall | 790 | 0.89 | 1,065 | 1.00 |
| Savings over 50 years | 39,505 | | 53,226 | |
| **Saskatchwean** | | | | |
| Annual savings compared to base wall | 1,022 | 0.69 | 1,377 | 0.77 |
| Savings over 50 years | 51,119 | | 68,874 | |
| **Yukon Territory** | | | | |
| Annual savings compared to base wall | 1,189 | 0.59 | 1,602 | 0.66 |
| Savings over 50 years | 59,469 | | 80,124 | |

(1) Based on a Canadian home with 1,791 square feet of insulated exterior wall.

Source: Franklin Associates, Ltd.

The heat transfer model used here is a simple one that depends only on the R-value of the walls and the number of degree days in a given region. The effective R-value of an insulated wall area can vary due to air leakage or poor installation; adding foam insulation will likely increase the R-value of the wall by more than the value of the foam. Because of these effects, the model has probably overstated the insulating value of a wall without foam insulation and understated the insulating value of a wall with foam insulation. Thus, the results presented in this analysis can be considered a conservative estimate of the energy and greenhouse gas savings for use of EPS foam insulation. The energy savings over the lifetime of the foam will be proportional to the heating and cooling degree days, but the amount of energy saved over the lifetime of the foam is much greater than the production energy. Any general conclusions drawn from the study will still hold valid.

## CONCLUSIONS

In summary, it would be an overgeneralization to assume that the savings for all North American residences will be similar to the savings calculated for the specific homes modeled in this analysis. However, the results of this analysis clearly indicate that the energy and greenhouse gas savings resulting from use of EPS foam insulation is more than sufficient to offset the energy and greenhouse gases from production of the foam in a short period of time. The payback times that it takes for energy and greenhouse gas savings from foam use to offset foam production impacts are very short, two years or less.

Another important issue addressed in this analysis is the relative benefits of R-4 and R-6 EPS insulation. Because R-6 insulation uses more EPS resin than R-4 insulation, it requires more material and more energy to produce and transport R-6 insulation, so there is a greater energy and greenhouse gas investment in producing R-6 foam. However, the greater R value results in greater savings for building heating and cooling for each year of building operation. Thus, although it takes somewhat longer to achieve energy and greenhouse gas payback for R-6 foam, over the life of the building the R-6 foam results in greater overall savings on an annual basis.

## DATA SOURCES AND ASSUMPTIONS FOR CONSTRUCTION AND HEAT TRANSFER MODELING

- 2006 Heating Degree Days and Cooling Degree Days were obtained from the National Oceanic and Atmospheric Administration (NOAA), accessed at http://www.ncdc.noaa.gov/oa/documentlibrary/hcs/hdd.200507-200706.pdf and http://www.ncdc.noaa.gov/oa/documentlibrary/hcs/cdd.200601-200709.pdf. The data were weighted by state and then region. The region weighting used 2006 new home authorization for 1-unit homes, referenced at http://www.census.gov/const/C40/Table2/tb2u2006.txt.

- The number of U.S. households using each type of heating fuel in each climate zone was based on the Energy Information Administration (EIA) 2001 Residential Energy Consumption Survey: Household Energy Consumption and Expenditures Tables. Heating fuel use was based on Table CE2-1c: Space-Heating Energy Consumption in U.S. Households by Climate Zone, 2001, and cooling energy was based on Table CE3-1c: Electric Air-Conditioning Energy Consumption in U.S. Households by Climate Zone, 2001.

- The EIA assigned households to climate zones based on 50 year averages (1961-1990) of temperatures from a nearby weather station. Because of this, households may be counted as part of different climate regions in the two methods, but any error should be negligible.

- The EIA heating fuel data is for households of all ages. Similar data for households by year of construction shows that new houses (build from 1990-2001) use a mix of fuels similar to the national average used in the study, although with more electricity (36% vs 30%) and less fuel oil (1% vs 8%). Census data for 2006 new housing construction (U.S. Census Bureau, Characteristics of New Housing Index, "Type of Heating System Used in New One-Family Houses Completed" 2006) was used to determine boundaries for each fuel type, and revise the numbers as seen fit. These data may overestimate the amount of natural gas used in heating new households, due to a drop in gas warm-air furnaces (approx. 7%), and a rise in electric heat pumps (6-7%) from 2004 to 2006.

- When determining percentage of households using each fuel type, 'Other' and 'No Space Heating' were not included.

- Some EIA data were listed as 'omitted' due to a high relative statistical error or low number of households. In both cases, it was assumed that the number of households using that type of fuel in the climate region was zero.

- The base R-value for a standard house was taken from the Oak Ridge National Lab's Whole Wall R-value Calculator (accessed at http://www.ornl.gov/sci/roofs+walls/AWT/InteractiveCalculators/rvalueinfo.htm) For U.S. houses, the assumptions were wood frame construction with 2x4 studs 16" on center, R-13 of fiberglass insulation and wood siding. This gave a base value of R-10.74. For Canadian houses, the assumptions were wood frame construction with 2x6 studs 16" on center, R-19 of fiberglass insulation and wood siding, giving a base value of R-13.65. The R-value for homes with EPS foam insulation was modeled by adding the R-values for the EPS foam insulation options (R-4 and R-6) to the base R-value of the wall.

- The efficiencies of heating and cooling equipment were taken, when possible, from minimum EPA standards enacted in 2006.

- Canadian Degree Day data was obtained from Environment Canada for the largest city in each province and then weighted for the entire country by the number of household starts in each province using the report "Dwelling Starts, Completions, Under Construction and newly Completed and Unabsorbed Dwellings – 2006" from the Canadian Mortgage and Housing Corporation.

- Canadian residential energy use was taken from Natural Resources Canada. Natural Resources Canada, "Residential Sector – Energy Use Analysis" 2007. Data for 2005 was used to determine the ratio of heating fuels used. The data showed that cooling energy was negligible in comparison to heating energy.

- Wood stove efficiency was assumed to be 70%, based on email correspondence with John Gulland, an independent consultant within the wood heater industry. All other heating efficiencies were assumed to be the same as in the U.S.

- Many sources of energy loss were neglected, such as ducts, ceiling/attics, crawl spaces, basements and general air leakage. According to the DOE, 10-30% of energy can be lost thorough leaky ducts, and 30% or more of heating and cooling costs can be from air leakage in general.

# APPENDIX A

## SAMPLE HEAT FLOW CALCULATIONS

**Explanation of Energy Calculations**

Energy savings = Energy use with base wall – Energy use with added foam insulation

**Annual Energy Use For Each Zone:**

Energy savings from heating + Energy savings from cooling

The energy calculations depend upon the heating degree-days (HDD) and cooling degree-days (CDD). Each is obtained by finding the difference between the average temperature and 65ºF. A day that averages 70ºF will add 5 CDD, and a day that averages 60ºF will add 5 HDD. By summing the HDD and CDD over the course of a year, the energy requirements for heating a cooling a house can be approximated.

The standard heat flow equation is $Q = A(\Delta T)/R$. If the total heat flow were desired for one hour, the HDD for that one day would be used for the $\Delta T$. The equation as it stands using standard units is for the heat flow per hour. If the heat flow is desired for one day, a factor of 24 needs to be multiplied times the value calculated for the heat flow for 24 hours. Thus, the equation becomes $Q = 24A(HDD)/R$, where HDD is the "heating degree day" for that day.

If the heat is desired for an entire year, the daily heat flow needs to be scaled up for the 365 days. In other words, the daily heat flow must be calculated for each day, and the results must be summed. Because the area and R are the same for each day, these can be factored out of the summation, leaving the summation of the daily HDD values, which is just the annual HDD value.

**The Annual Energy Flow From Heating Is:**

**WALL AREA* HDD*24 ÷ R**

- Wall area is 1,791 $ft^2$
- The U.S. national weighted average of HDD was 3,418 in 2006.
- R is thermal resistivity; for the U.S. base wall the value was 10.74.

Using these values, the energy flow through the walls of the U.S. home without added EPS foam insulation is

$$\frac{1{,}791\,ft^2 \times 3{,}418 \times 24}{10.74} = 13.7 \times 10^6\ Btu\ .$$

This value does not include the efficiency of the heating equipment or precombustion energy.