PLASTICS' ENERGY AND GREENHOUSE GAS SAVINGS USING HOUSEWRAP APPLIED TO THE EXTERIOR OF SINGLE FAMILY RESIDENTIAL HOUSING IN THE U.S. AND CANADA A CASE STUDY

Final Report

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EXECUTIVE SUMMARY

This study is an analysis of the energy savings and related reduction in greenhouse gas emissions resulting from the use of an exterior barrier to airflow applied to single family houses in the U.S. These products are commonly called housewraps, and are quite effective at reducing air infiltration. The U.S. Department of Energy (DOE) has determined that about one-half of all energy used in heating and cooling homes results from the air infiltrating from the outside of a house to the inside. Thus, the blocking of that infiltration can produce significant reductions of energy use and associated greenhouse gas (GHG) emissions. However, this must be balanced against the energy and GHG emissions associated with the manufacture and installation of the housewrap products. This study is a "life cycle" inventory applied to put all of these issues into perspective.

The results presented here are from a "cradle-to-grave" analysis of fuels used for heating and cooling houses. The analysis begins with the extraction of raw materials (fuels) from the earth, includes processing and delivery of those fuels, and ends with the release of combustion products into the environment. The life cycle results for the materials in the production of housewraps are a "cradle-to-manufacture" analysis. They do not include the process of applying wrap to houses nor the subsequent end-of-life disposition that will occur at some future date.

The U.S. DOE Lawrence Berkeley National Laboratory has recently completed a comprehensive study of air infiltration into houses. This work was the source of the energy database used in this study. They estimate that, at this time, the average house in the U.S. incurs 1.1 complete air changes per hour (ACH), and that about one-half of all energy used in heating and cooling houses is used to heat or cool infiltrated air.

Air infiltration comes from many sources of air leakage, including opening of doors and windows, fireplaces and the many seams and openings in exterior walls. There is a lack of publicly available data on how much of the air leakage is blocked by housewrap. The evidence is that it is highly variable and dependent on many factors, but likely falls in the range of 10% to 50% reduction of the infiltrated air. Given that most houses today were built before use of housewrap was common, we have estimated the effect of adding housewrap. The calculations for this study assume that the reduction in heating and cooling for houses as a result of application of housewrap falls somewhere in the range of a 10% to 50% reduction in the amount of energy required to heat and cool infiltrated air.

U.S. Results

As shown in Table ES-1, the reduction in energy consumption of a typical house in the U.S. as a result of applying housewrap is estimated to be 12 to 60 million Btu per year. Over a period of 30 years, these values become 360 to 1,800 million Btu.

These savings need to be contrasted with the energy to manufacture the housewrap products. For several decades, plastic film vapor barriers have been applied to the interior walls of houses to serve as a moisture barrier and to enhance the effectiveness of insulation. Although not always applied for that purpose, these films have significantly reduced air infiltration even though the integrity of these films is often breached by passage of wires, fasteners and careless tearing. Recently, polyolefin fiber films have become available. These products, installed on the exterior of walls, are much more effective at reducing infiltration. They also have the advantage of reducing air leakage as well as providing for better control of moisture migration through walls. Recent specifications for polyolefin woven fabrics are used as the basis of these calculations, although 30 years ago most of the infiltration reduction would have been provided by the vapor barriers. No data were found on the effectiveness of reducing infiltration by films primarily designed as vapor barriers, but an assumption that they reduce infiltration by at least 10% (the lower limit of our range) seems a conservative assumption.

Table ES-1

REDUCTIONS IN ENERGY USE AND GREENHOUSE GAS EMISSIONS RESULTING FROM THE APPLICATION OF PLASTIC HOUSEWRAP TO A TYPICAL HOUSE LOCATED IN THE U.S.

	ENERGY (1) (million Btu)	GHG EMISSIONS (1) (pounds of CO_2 equivalents)
ENERGY AND GHG SAVINGS		
Annual	12-60	1,600-8,100
30 years	360-1,800	49,000-244,000
Plastics Life Cycle (2)	1.2-1.8	70-98
Pay Back (days)	7-54	3-22

(1) Based on 10-50% reduction in air infiltration compared to absence of any plastic wrap.

(2) Cradle-to-manufacture energy and GHG for producing plastic housewrap. Range reflects values for two different types of plastics used. Feedstock energy is included.

As shown in Table ES-1, the energy to manufacture housewrap for a single house is only 1.2 to 1.8 million Btu depending on the type of polyolefin used. Compared to the energy savings resulting from the application of housewrap, the average "pay back" period ranges from only 7 to 54 days.

Table ES-1 also shows the greenhouse gas (GHG) emissions associated with the energy consumption. The reduction in GHG emissions resulting from the application of housewrap is 1,600 pounds to 8,100 pounds annually, or 49,000 to 244,000 pounds over a period of 30 years. The payback period on GHG emissions resulting from the use of housewrap ranges from 3 to 22 days.

It is not known how many houses in the U.S. currently have either a plastic film in place as a moisture and air penetration barrier, or have the newer plastic fiber housewraps. However, if we assume that all houses built since 1980 have a plastic air infiltration barrier in place that would reduce the infiltration in the range of 10% to 50%, the estimated energy savings since 1980 is 1.8 to 8.9 Quad (one Quad = 10^{15} Btu) and the total reduction in GHG emissions is 120 to 600 million tons. If instead, we assume that all houses built since 1990 (to correspond to the baseline year specified by the Kyoto agreements) have some plastic air infiltration barrier in place, the estimated energy savings since 1990 is 0.3 to 1.7 Quad (one Quad = 10^{15} Btu) and the total reduction in GHG emissions is 23 to 113 million tons.

It is clear that the use of plastics in this application results in significant national savings in energy and reductions in GHG emissions. To put these numbers in perspective, the total reductions in energy since 1980 has resulted in a savings of 14.2 billion to 70 billion dollars. Reductions in GHG emissions since 1980 is equivalent to the amount of CO_2 from the combustion of 12 to 60 billion gallons of gasoline in automobiles. If instead we look at the time period of 1990 to 1997, the savings in reduced energy costs would be 2.6 to 13 billion dollars, and the savings in GHG is equivalent to the combustion of 2.3 to 11 billion gallons of gasoline in automobiles.

Canadian Results

As shown in Table ES-2, the reduction in energy consumption of a typical house in Canada as a result of applying housewrap is estimated to be 8.0 to 40 million Btu per year. Over a period of 30 years, these values become 240 to 1,200 million Btu. The energy to manufacture housewrap for a single house is only 1.1 to 1.6 million Btu in Canada depending on the type of polyolefin used. Compared to the energy savings resulting from the application of housewrap, the average "pay back" period ranges from only 10 to 75 days.

Table ES-2 also shows the greenhouse gas (GHG) emissions associated with the energy consumption. The reduction in GHG emissions resulting from the application of housewrap is 790 pounds to 4,000 pounds annually, or 23,700 to 119,000 pounds over a period of 30 years. The payback period on GHG emissions resulting from the use of housewrap ranges from 8 to 54 days.

It is not known how many houses in Canada currently have either a plastic film in place as a moisture and air penetration barrier, or have the newer plastic fiber housewraps. However, if we assume that all houses built from 1981 to 1995 have some plastic air infiltration barrier in place, the estimated energy savings since 1981 is 0.24 to 1.2 Quad (one Quad = 10^{15} Btu), and the total reduction in GHG emissions is 12 to 60 million tons. If we use a 1991 to 1995 time period, the estimated energy savings is 0.04 Quad to 0.18 Quad, and the total reduction in GHG emissions ranges from 2 to 9 million tons.

It is clear that the use of plastics in this application results in significant national savings in energy and reductions in GHG emissions. To put these numbers in perspective, the total reductions in energy from 1981 to 1995 has resulted in a savings of 1.6 billion to 8.0 billion Canadian dollars. Reductions in GHG emissions from 1981 to 1995 is equivalent to the amount of CO_2 from the combustion of 1.2 to 6.0 billion gallons of gasoline in automobiles. Also, the savings between 1991 and 1995 accounts to 0.2 to 1.1 billion Canadian dollars in reduced energy costs, and a reduction in GHG equivalent to the combustion of 200 million to 900 million gallons of gasoline.

Table ES-2

REDUCTIONS IN ENERGY USE AND GREENHOUSE GAS EMISSIONS RESULTING FROM THE APPLICATION OF PLASTIC HOUSEWRAP TO A TYPICAL HOUSE LOCATED IN CANADA

	ENERGY (1) (million Btu)	**GHG EMISSIONS (1) (pounds of CO_2 equivalents)**
ENERGY AND GHG SAVINGS		
Annual	**8.0-40**	**790-4,000**
30 years	**240-1,200**	**23,700-119,000**
Plastics Life Cycle (2)	**1.1-1.6**	**84-118**
Pay Back (days)	**10-75**	**8-54**

1) **Based on 10-50% reduction in air infiltration compared to absence of any plastic wrap.**
2) **Cradle-to-manufacture energy and GHG emissions for producing plastic housewrap. Range reflects values for two different types of plastics used. Feedstock energy is included.**

INTRODUCTION

This report describes a case study that explores the actual and potential savings in greenhouse gas emissions and energy use as a result of using housewraps manufactured from polyolefin fibers. The calculations focus on a hypothetical house with average or typical characteristics of residential single family houses in the U.S. or Canada for a recent year. For the base case, the house is assumed to have insulation in place, but without a housewrap or even a plastic film vapor barrier. At this point in time, a house without a vapor barrier would not meet building codes, but this is a relatively recent addition to building codes. The target case examines the energy and greenhouse gas implications of adding a plastic infiltration barrier, especially a modern housewrap to reduce air infiltration through the seams and openings of exterior walls.

The primary mechanisms of heat transfer in and out of houses are conduction, convection, radiation and infiltration. Insulation is effective at stopping convection in walls and convective heat transfers through ceilings. At the same time, insulation reduces heat conduction substantially and radiation to some extent. However, radiation usually accounts for only a small fraction of heat transfer in homes (Kreith, 1997).

According to the U.S. Department of Energy (DOE), about half of all energy used in heating and cooling single family dwellings at this point in time is for heating or cooling outside air which enters from infiltration. Air infiltrates through any opening in the exterior surface, including open doors and open windows, fireplaces, exhaust fans and the many seams and openings in exterior construction products. Infiltration also is greatly affected by wind velocity. When winds are strong, air infiltrates much more rapidly. Air infiltration can never be reduced to zero, because doors must be opened to go in and out of a house.

The measure of air infiltration is the number of complete changes of air per hour, or ACH. An extensive study of the ACH for single family dwellings in the U.S. was recently performed by staff at Lawrence Berkeley National Laboratory for DOE. A report can be downloaded from their website, or found as: Sherman, M. H., N. E. Matson, "Residential Ventilation and Energy Characteristics," ASHRAE Trans. 103 (1), 1997, [LBNL-39036]. This study is very comprehensive and detailed and is used as a significant source of information in this report.

DOE has developed a national database to determine the ACH for residential dwellings. They have used extensive housing data reporting details such as size, construction details, materials, types and styles of houses and ages of houses for the 3,413 counties of the entire U.S. This includes Census data, as well as survey data for 4,800 single-family dwellings. They identified 32 different dwelling configurations, for which they assigned air tightness values. They have combined this with weather and climatological data (such as temperature and wind by day) derived from 240 weather sites, and developed an infiltration degree day measure to be combined with the other information and used to estimate energy expended as a result of infiltration.

The ACH can be quite variable, depending on local and daily factors. Poorly constructed housing, especially older housing, can have ACH as high as 4 to 5. In areas where there is little wind, the ACH can approach zero. The DOE data indicate that the national average ACH is 1.1. The time period could most accurately be called “recent” as the various data sources were for a variety of time periods since 1990. The range of variation in ACH is very large, roughly the size of the mean itself.

The optimum ACH is not zero. The reason is that reducing ventilation to zero produces concerns of air quality. ASHRAE has developed Standard 62-1989 on Ventilation for Acceptable Indoor Air Quality which addresses this issue. This standard recommends generally a minimum of 0.35 ACH. Thus, the maximum desirable potential reduction in infiltration is, on average, from 1.1 to 0.35 ACH, a 68% reduction.

Reduction in infiltration can be achieved by many means. Among those are improved tightness in construction, caulking, use of tighter windows and doors, eliminating or improving infiltration from fireplaces and use of barrier materials.

It is difficult to determine what role the current use of housewraps is playing in the infiltration. An unknown fraction of current homes have plastic films in place, so their contribution to the current rate of 1.1 ACH cannot be determined. In any event, housewrap will stop infiltration only from the openings and seams in the exterior walls, leaving all other air flow routes generally unaffected.

In a personal communication with M. Sherman (DOE), he stated that in California some experiments on new homes had shown that addition of housewrap reduced infiltration by 12%. He further stated that these homes already had infiltration rates well below average, and his opinion was that addition of housewrap to a 1.1 ACH house would produce greater than 12% reduction in infiltration. It is likely that the addition of housewrap could produce as little as a 10% reduction in infiltration, but as great as about 50%. Because of the high variability in ACH, we have used this range in our calculations in order to show the range of possibilities.

DESCRIPTION OF PRODUCTS

Plastic films such as vapor barrier films have been used for many years on walls for this purpose. In fact, they are an essential adjunct for moisture control in insulation to protect outer painted surfaces. Their use became common in the U.S. in the 1970’s as new building codes began to require insulation. However, these films also reduce infiltration. One insulation company suggests that installation of a plastic film can enhance the effectiveness of insulation by as much as 60% by reducing infiltration of air.

While plastic films are effective at reducing infiltration, simple plastic films have a major disadvantage if applied to the exterior because they are impervious to moisture flow. Large differences in absolute humidity between inside and outside air can occur because of many factors both inside and outside of the home. When this occurs, the moisture will migrate either into or, more commonly, out of the house. If a barrier is present, it can cause condensation and a host of associated problems.

Today, we have available housewraps applied to the exterior walls that are constructed of plastic fibers. The porosity of these barriers can be carefully controlled, so that air is essentially blocked while water molecules can migrate through at a controlled rate, thus eliminating this problem of conventional plastic films. They also have the added advantage that they are applied on the exterior walls of the house, which decreases the frequency to which the barrier incurs breaching by other construction requirements.

In this report, we have assumed that housewrap is made of either high density polyethylene fibers or polypropylene fibers. Based upon U.S. Census data, we have assumed that a typical house in the U.S. has a floor area of 2,150 square feet, and that for the country as a whole, half of the houses are two story and half are one story. This leads to a wall area of 1,790 square feet. For Canada, the corresponding calculations are a floor area of 1,334 square feet with a wall area of 1,169 square feet. These values are based upon a 1993 Survey of Household Energy and the 1994 Survey of Houses Built in Canada.

Using data available from manufacturers, we have established the following values in Table 1 for use in this study.

Table 1

SPECIFICATIONS OF PLASTIC HOUSEWRAP

	Area Density (lb / 1,000 sq ft)	Weight of Housewrap for Typical U.S. House (lb / house)	Weight of Housewrap for Typical Canadian House (lb / house)
High Density Polyethylene	12.5	22	15
Polypropylene	18.4	33	22

We have first calculated energy savings and GHG emissions for a single house based upon the assumption that the newer plastic fiber exterior wall housewraps are in place. Separately, we have estimated the cumulative energy savings since 1980, assuming that since that time either a conventional film or a plastic fiber housewrap is in place.

U.S. METHODOLOGY

This report presents the energy and greenhouse gas implications of the use of plastic building wrap. The two major components of the analysis are the energy conservation attributable to adding housewrap to a typical house, and the energy required to manufacture and deliver the plastic product. The energy values will be used as the basis of calculating greenhouse gas emissions, as most of the greenhouse gases emitted have their origin in the fuel cycles (the procurement, processing and burning of fuels).

The results presented here are from a "cradle-to-grave" analysis of fuels used for heating and cooling houses. The analysis begins with the extraction of raw materials (fuels) from the earth, includes processing and delivery of those fuels, and ends with the release of combustion products into the environment. The life cycle results for the materials in the production of housewraps are a "cradle-to-manufacture" analysis. They do not include the process of applying wrap to houses nor the subsequent end-of-life disposition that will occur at some future date. However, our estimates of those final steps leads to the conclusion that their contribution to energy or GHG emissions is quite small. The energy results include the energy content of the petrochemical feedstocks used to manufacture plastic. However, this portion of the total energy is excluded from GHG calculations.

The findings of the DOE study cited earlier serves as the basic data source for energy required to heat or cool infiltrated air in a typical house. DOE states that the annual energy consumption to heat and cool infiltrated air in the 75 million houses in the U.S. for one year is 4.5 EJ (exaJoules, 10^{18} Joules), of which 3.4 EJ is for heating, 0.8 EJ is for cooling, and 0.3 EJ is for parasitics (air handling such as furnace fans, etc.). Based upon this, Table 2 was prepared for a typical house, assuming 1.1 ACH. The totals given by DOE are divided by 75 million houses and converted to Btu. The direct fuels are primarily natural gas burned in a household furnace. The electricity is the direct consumption at the house. According to Census data, 75% of home heating is supplied by direct fired furnaces, and 25% is from electricity.

Table 2

ENERGY REQUIRED TO HEAT AND COOL INFILTRATED AIR FOR ONE YEAR IN A TYPICAL HOUSE LOCATED IN THE U.S.

	DOE Total (million Btu)	Direct Fuels (million Btu)	Electricity (thousand kWh)
Heating	**43.0**	**32.2**	**3.15**
Cooling	**10.1**	**0**	**2.96**
Parasitics	**3.8**	**0**	**1.11**
Total	**56.9**	**32.2**	**7.22**

U.S. RESULTS

Calculations for a Typical House

Table 3 summarizes the energy savings and reductions in GHG emissions that may result from the use of housewrap resulting in a 10% to 50% reduction in energy used to heat or cool infiltrated air. These calculations are for a single house, assuming 1.1 air changes per hour (ACH). The annual savings range from 12 to 60 million Btu per year. The average cost of home heating and air conditioning (developed in the Assumptions) is $7.89 per million Btu. This leads to a savings to U.S. consumers of $2,800 to $14,300 over a 30 year period.

Table 3

ENERGY SAVINGS AND GREENHOUSE GASES REDUCED BY USING EITHER HIGH DENSITY POLYETHYLENE OR POLYPROPYLENE HOUSEWRAP FOR A TYPICAL HOUSE LOCATED IN THE U.S.

	Polyethylene	Polypropylene	Polyethylene	Polypropylene
	@10% ACH Reduction		@50% ACH Reduction	
Energy Savings (Million Btu)				
Annual	12.0	12.0	60.2	60.2
30 years	361	361	1,810	1,810
Plastics Life Cycle Energy (Million Btu)	1.21	1.77	1.21	1.77
Energy Payback (days)	37	54	7	11
Greenhouse Gases (CO2 equivalents in pounds)				
Generated From Plastics	70	98	70	98
Avoided From Annual Energy Savings				
Annual	1,630	1,630	8,140	8,140
30 years	48,900	48,900	244,200	244,200
Greenhouse Gas Payback (days)	16	22	3	4

Note: The energy values in this table include "upstream" energy such as for production, refining, and transportation that are not included in the DOE values in Table 2.

As shown in Table 1, the amount of plastic fiber housewrap required to cover the exterior walls of a house ranges from 22 to 33 pounds, with the HDPE wraps available today requiring less weight than the PP wraps. The energy to manufacture the wraps is shown in Table 3 to be only 1.2 million Btu for HDPE and 1.8 million Btu for PP. When comparing this to the annual energy savings, it is clear that the energy savings are quite large. The time for "payback" for the energy to manufacture the product is recovered in 7 days to 54 days (1.8 months). This can be compared to a conservative estimate of 30 years for the typical life of a house.

The lower portion of Table 3 summarizes the corresponding reduction in greenhouse gas (GHG) emissions resulting from the use of housewraps. The annual reductions of 1,600 pounds to 8,100 pounds each year are contrasted to the 70 to 98 pounds emitted as a result of the manufacturing of the housewraps. This results in a GHG payback of only a few days, ranging from 3 days to 22 days. The GHG emissions of manufacturing are clearly insignificant compared to the 49,000 pounds to 244,000 pounds of GHG emissions reduction that result from the energy savings over a 30-year period. (The GHG payback period is only about one-half of the payback period for energy. The reason for this is that the energy for plastic manufacture includes the feedstock energy of the plastic which is reported as energy consumption, but does not result in GHG. Thus, the GHG per Btu for the plastics manufacture is about one-half of that for a Btu of energy consumed in the home. However, the GHG incurred in extracting and processing the fuels that become feedstocks is included.)

To put these numbers into perspective, the combustion of one gallon of gasoline results in 20 pounds of CO_2 released into the atmosphere. Thus, the annual savings of 1,600 to 8,100 pounds of GHG is the equivalent of the GHG that would be released by the combustion of 80 to 400 gallons of gasoline. For a 30 year period, the savings are 2,400 to 12,200 gallons of gasoline.

Calculations for All Houses in the U.S.

The use of housewraps has been common since the late 1970s. The energy crisis in the early 70s spawned a large number of energy conservation techniques that quickly became widely applied. Census data indicates that, in the period 1980 to 1997, 18.3 million single-family houses were built. Assuming that all houses built during that time have plastic infiltration barriers in place, we can estimate the total effect of using housewrap by multiplying the number of houses built in each year by the years that this housewrap was in place during the period 1980 to 1997. (We have assumed that the energy per house used for heating and cooling was constant over that period. This may be a slight overstatement because the use of air conditioners in cooler climates was less in 1980 than it is today, and the average size of houses has been increasing.) Table 4 shows that the total energy savings ranges from 1.77×10^{15} Btu (1.77 Quad) to 8.89 Quad, and GHG avoidance ranges from 120 million tons to 601 million tons over the 18 year period. The range 1990 to 1997 was also considered for housewrap used on houses constructed, as 1990 is the baseline year specified in the Kyoto agreements. Table 4 displays the total energy savings ranges from 3.34×10^{14} Btu (0.33 Quad) to 1.68×10^{15} Btu (1.68 Quad), and GHG avoidance ranges from 23 million tons to 113 million tons over the 8 year period.

To put these numbers into perspective, the savings in GHG over this period of time from 1980 to 1997 is equivalent to the combustion of 12 to 60 billion gallons of gasoline in automobiles. The savings to consumers in reduced energy costs would be 13 billion to 68 billion dollars between 1980 and 1997. If instead we look at the time period of 1990 to 1997, the savings in reduced energy costs would be 2.6 to 13 billion dollars, and the savings in GHG is equivalent to the combustion of 2.3 to 11 billion gallons of gasoline in automobiles.

These calculations assume that all houses are protected by a plastic infiltration barrier. While this is generally true, some houses are still being built with no housewrap, or with a non-plastic vapor barrier. However, we assume that the exceptions make up only a small fraction of houses built since 1980.

Table 4

ENERGY SAVINGS AND REDUCTIONS IN GREENHOUSE GAS EMISSIONS FROM USING A HOUSEWRAP ON ALL NEW HOUSES IN THE U.S.

	10% ACH Reduction	50% ACH Reduction
Energy Savings (Btu)		
from 1980 to 1997	1.77E+15	8.89E+15
from 1990 to 1997	3.34E+14	1.68E+15
Greenhouse Gases Avoided from Energy Savings (CO_2 equivalents in million tons)		
from 1980 to 1997	120	601
from 1990 to 1997	23	113

Note: This results in this table are based on all new houses built each year inclusive of each year the house remains standing through 1997. (e.g. 1.03 million houses were built in 1992, each having 6 years of energy savings in this table.)

Source: Franklin Associates

CANADIAN METHODOLOGY

No air infiltration data was found for Canada which is comparable to the recent DOE work in the U.S. For example, the average rate of infiltration is not known. In order to produce estimates for Canada, we used the U.S. data and modified it based upon characteristics of Canadian housing and climate.

The key data used was the volume of air in U.S. and Canadian houses, and the differences in heating degree days (HDD). The cooling degree days (CDD) for Canada are less than 1% of the HDD, so they were not included in the calculations. (In these calculations, ºF were used.)

The following values were used.

- Volume of typical house in the U.S. = 17,200 cu ft
- Volume of typical house in Canada = 10,700 cu ft
- Average HDD U.S. = 4,381
- Average HDD Canada = 7,841

Assuming that current infiltration rates in Canada are the same as in the U.S. (1.1 ACH), the energy needed to heat the infiltrated air in Canada can be found by using the following equation:

energy to heat infiltrated air per year in the U.S. (including parasitics)* (vol. of Canadian houses/vol of U.S. houses) * (avg HDD for Canada/avg HDD for U.S.)

The energy needed to heat the infiltrated air in an average Canadian home in one year:

46.1 million Btu/yr * (7,841/4381) * (10,700/17,200) = 51.2 million Btu/yr

The 51.2 million Btu includes 38.4 million Btu of direct fuel (mostly natural gas) and 4,700 kWh of electricity, of which 3,700 kWh is for electrical heating and 1,000 kWh is for the parasitics (furnace fans, etc.). These values were derived from Table 2.

The energy and emissions required to manufacture the plastic fiber housewraps for Canadian applications were similar to those for the U.S., except Canadian electricity grids were used to determine the fuels and other energy sources used to generate electricity. The APC plastics data used in this study is for North American production, which includes Canadian plastics production and electricity. These data are used for both U.S. and Canadian calculations.

CANADIAN RESULTS

Calculations for a Typical House in Canada

Table 5 summarizes the energy savings and reductions in greenhouse gas emissions (GHG) resulting from the use of housewraps in Canada. Table 5 is for a single typical house, assuming a range of from 10% to 50% reduction in infiltrated air as a result of applying a plastic fiber housewrap. The table shows a range of 8.0 to 40 million Btu saved per year, with 240 to 1,200 million Btu for a period of 30 years.

To put this in perspective, the financial savings in a typical house can be calculated. The savings in fuel each year is 3,800 to 19,000 cu ft of natural gas, and the savings of electricity is 470 to 2,400 kWh. Using values (in Canadian dollars) of C$0.0814 per kWh and C$5.83 per 1,000 cu ft of gas, the savings over 30 years is C$1,810 to C$5,860.

The energy to manufacture the housewraps is only 1.1 to 1.6 million Btu, leading to energy payback times of only 10 to 75 days.

Table 5

ENERGY SAVINGS AND GREENHOUSE GASES REDUCED FROM USING EITHER HIGH DENSITY POLYETHYLENE OR POLYPROPYLENE HOUSE WRAP FOR A TYPICAL HOUSE LOCATED IN CANADA

	Polyethylene	Polypropylene	Polyethylene	Polypropylene
	@10% ACH Reduction		@50% ACH Reduction	
Energy Savings (Million Btu)				
Annual	7.99	7.99	40.0	40.0
30 years	240	240	1,200	1,200
Plastics Life Cycle Energy (Million Btu)	1.12	1.63	1.12	1.63
Energy Payback (days)	51	75	10	15
Greenhouse Gases (CO2 equivalents in pounds)				
Generated From Plastics	83.7	118	83.7	118
Avoided From Annual Energy Savings				
Annual	791	791	3,953	3,953
30 years	23,700	23,700	118,600	118,600
Greenhouse Gas Payback (days)	39	54	8	11

Source: Franklin Associates

The bottom portion of the table shows the GHG emissions resulting from the use of plastic fiber housewraps is 790 to 4,000 pounds of CO_2 year, or 30 year totals of 24,000 to 119,000 pounds. To put these values into perspective, an automobile produces 20 pounds of CO_2 per gallon of gasoline, so the GHG savings from using housewraps range from the equivalent of burning 1,200 to 6,000 gallons for thirty years.

The payback times for GHG savings are 8 to 54 days. These are lower than the energy payback periods because of the inclusion of feedstock energy in the plastics manufacture values.

Estimates for All Houses in Canada

The use of housewraps has been common in Canada since the 1970s. During the period 1981 through 1995, 4.2 million homes have been built. If we assume that all houses built since 1981 have a plastic barrier to infiltration, we can make a rough estimate of the total effect of the use of housewraps. The results are shown in Table 6. In this table, we have assumed the same conditions and practices that exist today. Table 6 shows that the total energy savings ranges from 0.24×10^{15} Btu (0.24 Quad) to 1.22 Quad, and GHG avoidance ranges from 12 million tons to 60 million tons over the 15 year period. The range 1991 to 1995 was also considered for housewrap used on houses constructed as 1990 is the baseline year specified in the Kyoto agreements. Table 6 displays the total energy savings ranges from 3.58×10^{13} Btu (0.036 Quad) to 1.79×10^{14} Btu (0.18 Quad), and GHG avoidance ranges from 2 million tons to 9 million tons over the 5 year period.

Table 6

ENERGY SAVINGS AND REDUCTIONS IN GREENHOUSE GAS EMISSIONS USING A HOUSEWRAP ON ALL NEW HOUSES IN CANADA

	10% ACH Reduction	50% ACH Reduction
Energy Savings (Btu)		
from 1981 to 1995	2.44E+14	1.22E+15
from 1991 to 1995	3.58E+13	1.79E+14
Greenhouse Gases Avoided from Energy Savings (CO_2 equivalents in million tons)		
from 1981 to 1995	12	60
from 1991 to 1995	2	9

Note: This results in this table are based on all new houses built each year inclusive of each year the house remains standing through 1995.

Source: Franklin Associates

To put this in perspective, this amounts to a savings between 1981 and 1995 of 1.6 to 7.8 billion Canadian dollars in reduced energy costs, and a reduction in GHG equivalent to the combustion of 1.2 billion to 6.0 billion gallons of gasoline. Also, this amounts to a savings between 1991 and 1995 of 0.2 to 1.1 billion Canadian dollars in reduced energy costs, and a reduction in GHG equivalent to the combustion of 200 million to 900 million gallons of gasoline.

SENSITIVITY ANALYSIS

There are large uncertainties in both the degree to which housewrap or other plastic films reduce air infiltration and the extent to which houses now in existence have barriers in place. The calculations have included large ranges already, so no additional sensitivity analysis has been performed. Under any reasonable scenario, the payback in energy and GHG reductions are quite impressive, even though a precise number is difficult to determine.

ASSUMPTIONS

The principal assumptions made by Franklin Associates follow.

- APC data were used for the manufacture of high-density polyethylene and polypropylene resins for both the U.S. and Canadian results.

- The basic energy database used in this study is taken from the DOE studies conducted at Lawrence Berkeley National Laboratory, for which the full reference can be found in the List of Sources section. The values are summarized in Table 2. The electricity values are derived from DOE electricity energy totals (in Btu) by using the LBL conversion factor of 3,413 Btu/kWh (personal communication with LBL).

- The housewraps in this report are assumed to be made from non-woven HDPE or PP fibers. The area density 12.5 lb/1,000 sq ft used for HDPE is for Tyvek® HomeWrap™ produced by DuPont Tyvek® (obtained from the DuPont Tyvek® web site and confirmed by David Scarborough, DuPont). The area density 18.4 lb/1,000 sq ft used for PP is for Pinkwrap Plus® Housewrap produced by Owens-Corning (obtained from data submitted to us by Owens-Corning.) This report uses these area densities to calculate the weight of housewrap on a typical house and makes no claims about either of these specific housewraps.

- The base case in this study assumes that the house has insulation in place but does not any type of plastic film barrier.

- Department of Energy data indicates that the national average ACH is 1.1.

- ASHRAE standard 62-1989 on Ventilation for Acceptable Indoor Air Quality recommends a minimum of 0.35 ACH.

- The reference for the statement that radiation usually accounts for only a small fraction of heat transfer in home is from calculations in Kreith, Frank and Ronald E. West, Eds., CRC Handbook of Energy Efficiency, CRC Press, Inc., 1997.

- According to M. Sherman of DOE, in California, some experiments on new homes have shown that addition of housewrap reduced infiltration by 12%. Based upon email communications with M. Sherman, we have assumed that although housewrap will have a highly variable effect on air infiltration, it will reduce air infiltration by at least 10%, but not more that 50%. We have used this range in our calculations.

- Based on U.S. Census data, a typical U. S. house has a floor area of 2,150 square feet.

- DOE, in their report on "Household Ventilation Characteristics" (page 2) use the value of 75 million for the total "single-family households" in the U.S. We have used that value when calculating single house values using the DOE report totals. Other sources report 90 million houses (Statistical Abstracts of the U.S. 1998, 118th ed., Table 1211), which includes small apartment buildings with less than 10 units, because their construction is similar to single family house construction, and they use the same insulation products. However, we have used the single family value because of our reliance on the DOE work which uses that value. This results in an under estimate of the total effect of plastic infiltration barriers.

- Based on heating system data from the Statistical Abstract of the United States 1998, U.S. Bureau of the Census, 118th edition, roughly 75 percent of new homes in 1997 had warm air furnaces installed and 25 percent used electrical heat pumps.

- According to Will Biddle of the National Association of Home Builders, new home builders began using housewraps specifically for air infiltration in the late 1970s to early 1980s. This study uses a beginning year of 1980 to calculate the total number of new houses built through 1997. Using Census data, total new houses in the U.S. summed to 18.3 million between 1980 and 1997. Between 1990 and 1997, a total of 8.5 million new houses were constructed in the U.S.

- It is unclear what fraction of houses in the U.S. have either the newer plastic fiber housewraps or the conventional plastic film. We have assumed that most houses built since 1980 have a barrier to air infiltration through exterior walls. While there are some non-plastic barriers, most contractors across the U.S. use either plastic film or plastic fiber housewrap.

- Newer houses with low infiltration rates need external ventilation for health reasons and to insure make-up air for fuel combustion inside homes. In colder climates, heat exchange ventilators may be used to warm the incoming air. Because this practice is not common for most of the U.S., we did not estimate this effect.

- The following source was used for Global Warming Potentials: United Nations, Framework Convention on Climate Change (FCCC), Subsidiary Body for Scientific and Technological Advice, National Communications; Communications from Parties Included in Annex I to the Convention: Guidelines, Schedule and Process for Consideration; Possible revisions to the guidelines for preparation of national communications by Parties included in Annex I to the Convention; Addendum; Methodological issues; Note by the Secretariat (Geneva, Switzerland: FCCC Secretariat, 25 June 1996), FCCC/SBSTA/1996/9/Add.1.)

Carbon Dioxide	1
Methane	21
Nitrous Oxide	310

- The value of 20 pounds of CO_2 emitted per gallon of gasoline in a U.S. truck or automobile is from Franklin Associates' database, with values based upon EPA reports.

- To calculate home heating costs in the U.S., we used Table 788 of the 1998 Stat Abstracts, which lists fuel and energy prices for major metropolitan areas of the U.S. for 1997. The average for natural gas is $7.00/1000 cu ft. For electricity, the average price was $0.096/kWh. Using the DOE data, the energy for houses is 57% direct fuel (predominantly natural gas) and 43% fuels for electricity. To derive a factor for 1 million Btu (using DOE energy conversion factors), the natural gas is 570,000 Btu/1,032 Btu/cu ft = 552 cu ft * $0.007/cu ft = $3.87. For electricity, 430,000 Btu/10,272Btu/kWh = 41.9kWh x $0.096/kWh = $4.02. The total cost per million Btu is $7.89.

- The corresponding energy costs for Canada are calculated in Canadian dollars. The price of electricity is C$0.0814/kWh (from Electricity Information 1997, 1998 ed., International Energy Agency). The price of natural gas is C$ 20.60/100 cu m, or C$0.00583/cu ft (from Canadian Gas Association, and Statistics Canada 55-002). For Canada, only heating energy is used. For 1 million Btu, this requires 687 cu ft of natural gas and 29.3 kWh. The cost is C$6.39.

- Canadian Heating Degree day data from Climate Normal, Environment Canada website. www.cmc.ec.gc.ca. (These data are given in C°, but were converted to F° in order to provide a uniform reporting basis for this report.)

- Table 7 summarizes the calculations used to derive the average HDD for Canada.

- HDD data are for at least one major city in each Canadian province. Annual HDD were calculated using 1996 population census (Statistics Canada) of metropolitan areas as the weighted average. CDD data were not utilized since the energy used in space heating for cooling is estimated to be less than 1% of the energy used for heating. (Energy Efficiency Trends in Canada 1990 to 1996.)

TABLE 7

CLIMATE AND HOUSING STATISTICS BY PROVINCES

Province	Heating Degree Days (Based on °F) (Annual)	1996 Occupied Housing (thousands)
Ontario	7,061	3951
Quebec	8,494	2849
British Columbia	5,463	1434
Alberta	9,964	984
Manitoba	10,605	421
Saskatchewan	10,571	376
Nova Scotia	7,990	345
New Brunswick	8,699	273
Newfoundland	8,789	187
Prince Edward Island	8,578	49
NW Territories	15,291	19
Yukon Territory	12,537	12
Total Occupied Housing		10900
Weighted Average HDD	7,840	

Source: Environment Canada and Statistics Canada

- The average size of a Canadian home is based on:

Single-detached	55.3%	1,375 sq. ft.
Single-attached	10.5%	1,116 sq. ft.
Average	65.8%	1,333.7 sq. ft.

This data from "Energy Efficiency Trends in Canada 1990 to 1996", pg 15 June 1998, by Office of Energy Efficiency.

- Assuming a one story home with a square foundation, the total wall area used for heat loss calculation is 1169 square feet.

- Canadian Energy use is assumed to be 75% natural gas, 25% electric, same as U.S. The calculation shows 77% natural gas, 23% electric from data extracted from "Energy Efficiency Trends in Canada 1990 to 1996", pg 15 June 1998, by Office of Energy Efficiency.

- In Canada, CDD is not taken into account as it is less than 1% of the energy used for space heating.

	% energy use in household	normalized
Space Cooling	0.4%	0.65%
Space Heating	61.1%	99.35%

This data is from "Energy Efficiency Trends in Canada 1990 to 1996", pg 25 June 1998, by Office of Energy Efficiency.

- The following is a table showing the age of Canadian housing.

Age	% of Housing
Pre 1946	18.5
1946-1980	43.1
1981-1985	11.0
1986-1990	13.7
1991-1995	13.7

KEY ABBREVIATIONS/SYMBOLS

ACH	Air Changes per Hour
APC	American Plastics Council
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
Btu	British Thermal Units
C$	Canadian Dollars
CDD	Cooling Degree Days
CO2	Carbon Dioxide
Cu ft	Cubic Foot
DOE	Department of Energy
EJ	ExaJoules (exa = 10^{18})
ºF	Degrees Fahrenheit
FCCC	Framework Convention on Climate Change
GHG	Greenhouse Gas
HDD	Heating Degree Days
HDPE	High-Density Polyethylene
kWh	Kilowatt-Hours
Lb	Pounds
Mil Btu	Million British Thermal Units
NAHB	National Association of Home Builders
PP	Polypropylene
Quad	1 Quad = 10^{15} Btu
Sq ft	Square Foot

LIST OF SOURCES

High-Density Polyethylene and Polypropylene Resins

Data collected from American Plastics Council for HDPE and polypropylene resin.

Housewrap Manufacture

Data developed by Franklin Associates, Ltd., based on confidential information supplied by industrial sources. 1993.

Infiltration data for Housewrap

Sherman, M. H., N. E. Matson, "Residential Ventilation and Energy Characteristics" ASHRAE Trans. 103 (1), 1997, [LBNL-39036]. This can be downloaded from the Lawrence Berkeley Laboratory web site.

Discussions with M. Sherman, Department of Energy. March and April, 1999.

ASHRAE Standard 62-1989 on Ventilation for Acceptable Indoor Air Quality.

Kreith, Frank and Ronald E. West, Eds., **CRC Handbook of Energy Efficiency**, CRC Press, Inc., 1997.

Housing Data

U.S. Department of Commerce, **Statistical Abstract of the United States 1998.**

Discussions with Will Biddle, National Association of Home Builders. January and April, 1999.

Franklin Associates estimate.

Canadian Housing /Population Data

Statistics Canada, 1996, CANSIM, Matrix 6231**.**

Statistics Canada, 1996, Cat. No. 93-357-XPB.

Discussions with Ms. Madeline McBride, Office of Energy Efficiency, Natural Resources Canada, April 1999.

Natural Resources Canada, Office of Energy Efficiency, **Energy Efficiency Trends in Canada 1990 to 1996**, June, 1998.

Franklin Associates estimate.

APPENDIX A

CANADIAN TABLES IN METRIC UNITS

The following are unit revisions of Tables 5, 6, and 7. The revisions consist of converting from U.S. units to SI metric units. In Tables 5 and 6, energy is converted from Btu to Joules and pounds to kg. In Table 7, heating degree days (HDD) are converted from ºF to ºC.

Table 5 (metric units)

ENERGY SAVINGS AND GREENHOUSE GASES REDUCED FROM USING EITHER HIGH DENSITY POLYETHYLENE OR POLYPROPYLENE HOUSE WRAP FOR A TYPICAL HOUSE LOCATED IN CANADA

	Polyethylene	Polypropylene	Polyethylene	Polypropylene
	@10% ACH Reduction		@50% ACH Reduction	
Energy Savings (GJ)				
Annual	8.43	8.43	42.2	42.2
30 years	253	253	1,265	1,265
Plastics Life Cycle Energy (GJ)	1.18	1.72	1.18	1.72
Energy Payback (days)	51	75	10	15
Greenhouse Gases				
(CO2 equivalents in kilograms)				
Generated From Plastics	38.0	53.4	38.0	53.4
Avoided From Annual Energy Savings				
Annual	359	359	1,793	1,793
30 years	10,760	10,760	53,800	53,800
Greenhouse Gas Payback (days)	39	54	8	11

Source: Franklin Associates

Table 6 (metric units)

ENERGY SAVINGS AND REDUCTIONS IN GREENHOUSE GAS EMISSIONS USING A HOUSEWRAP ON ALL NEW HOUSES IN CANADA

	10% ACH Reduction	50% ACH Reduction
Energy Savings (GJ)		
from 1981 to 1995	2.57E+08	1.29E+09
from 1991 to 1995	3.78E+07	1.89E+08
Greenhouse Gases Avoided from Energy Savings (CO_2 equivalents in million metric tons)		
from 1981 to 1995	11	55
from 1991 to 1995	2	8

Note: This results in this table are based on all new houses built each year inclusive of each year the house remains standing through 1995.

Source: Franklin Associates

TABLE 7 (Metric)

CLIMATE AND HOUSING STATISTICS BY PROVINCES

Province	Heating Degree Days (Based on °C) (Annual)	1996 Occupied Housing (thousands)
Ontario	3905	3951
Quebec	4701	2849
British Columbia	3017	1434
Alberta	5518	984
Manitoba	5874	421
Saskatchewan	5855	376
Nova Scotia	4421	345
New Brunswick	4815	273
Newfoundland	4865	187
Prince Edward Island	4748	49
NW Territories	8477	19
Yukon Territory	6947	12

Source: Environment Canada and Statistics Canada