A Review of Housewrap Performance and Its Implications for Energy Savings

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ABSTRACT

Housewrap air infiltration barriers were introduced to the building market in the early 1980's. In the past twenty years as their use increased, the energy impact of these materials has been the subject of testing and modeling research. Although very little energy is used in the manufacture of building wraps, they can provide significant energy savings by controlling energy losses due to air leakage. A 2000 study estimated that housewraps could recover the energy embodied in their manufacture in only 7 to 54 days. (Franklin Associates 2000) This paper will review studies of building wrap properties and performance including laboratory testing, and field testing. Highlighted topics will include a review of whole house air leakage reduction by the use of housewraps. Additionally, the treatment of building wraps in guidelines, codes and standards over the last two decades will be reviewed.

Introduction

The 1970's energy crisis led to the introduction of a number of new products to the construction industry. One of these products was housewrap, first introduced in 1979 to provide a simple way to seal the exterior of a building and reduce air leakage. (Alfano 1997) Although the housewrap's primary function was to control air leakage in buildings, it was reported to have a larger, unique set of material properties (*Chicago Dodge Construction News* 1980):

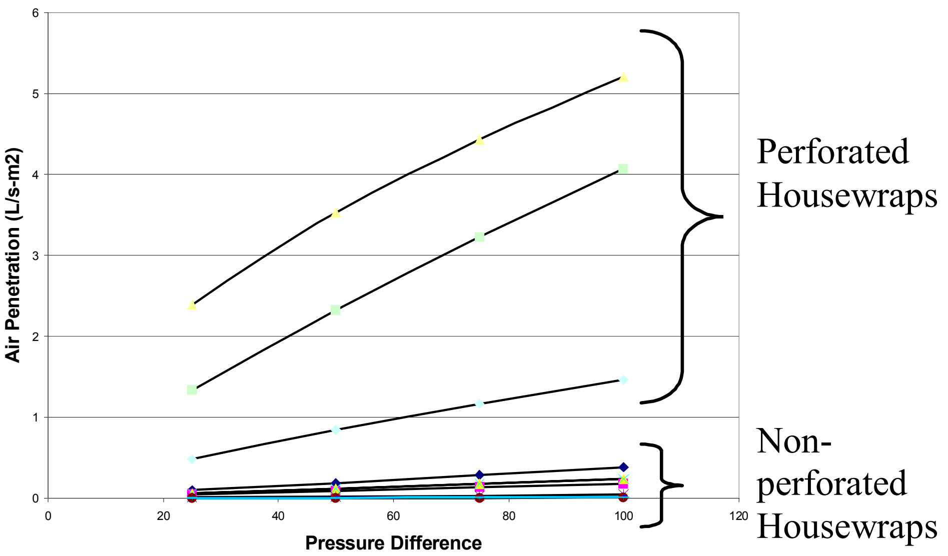
- Ability to withstand relatively high winds,
- Remaining flexible at low temperatures,
- Light weight,
- Water resistant,
- Ability to restrict airflow, and
- Vapor transmissible, reducing the potential for condensation.

While initially the air infiltration reduction and resulting energy savings were the focus of research and marketing of housewraps, in recent years the water-resistive barrier performance has gained prominence. The 2006 edition of the International Residential Code (IRC) has increased the requirement for water-resistive barriers, resulting in the incorporation of a water-resistive barrier being virtually required on all houses.(ICC 2006) The goal of this code change is to prevent moisture damage in buildings, not air leakage reduction or energy savings, but as housewraps are one of the most commonly used water-resistive barriers it is useful to review research into the air leakage reduction which may accompany the increased use of housewraps facilitated by this code change.

Housewrap Composition and Properties

The first housewrap introduced was a spun bonded polyolefin sheet that inherently resisted air movement but allowed vapor transmission. In the last 25 years, the housewrap category has grown from the original single spun-bonded olefin product offering to as many as 40 different housewraps on the market in some regions. Many of the subsequent product introductions were “perforated housewraps”; sheet materials that are inherently vapor barriers and, therefore, had to be punched with small holes to allow for vapor transmission. Although several different material compositions are used to make housewraps, housewraps are still often categorized as being either perforated or non-perforated. (Bomberg & Onysko 2004; DOE 2000) Non-perforated housewraps have been reported to have higher water resistance and air resistance than perforated housewraps. . (Lies & Hall 2004; Lstiburek 2005; Weston, et. al. 2004). Non-perforated housewraps also have higher resistance to air penetration than perforated wraps. Figure 1 shows air permeance of several perforated and non-perforated housewraps measured according to ASTM (American Society for Testing and Materials) E2178 (ASTM 2003). Some practitioners have questioned whether perforated housewraps should be considered air barriers (Anis 2006).

Figure 1. Measured Air Permeance (ASTM E2178) of Housewraps

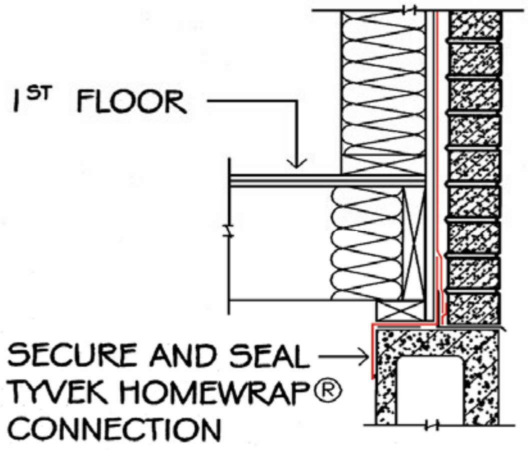


Housewrap Function and Installation

Housewraps are specified to serve two barrier functions: water-resistive barrier and air barrier. A water-resistive barrier is defined as “a material behind an exterior wall covering that is intended to resist liquid water that has penetrated behind the exterior covering from further intruding into the exterior wall assembly.” (ICC 2006) currently there is no consensus standard specification for water-resistive barriers, but most housewraps are evaluated against ICC-ES Acceptance Criteria AC-38.(ICC-ES 2004) An air barrier, often referred to as an air retarder, is defined as "a material or system in building construction that is designed and installed to reduce air leakage either into or through the opaque wall." (ASTM 2000) In 1995, ASTM published E1677 Standard Specification for an Air Retarder (AR) Material or System for Low-Rise Framed Building Walls (ASTM 2000). Housewraps can be qualified as air barriers by meeting the requirements of this standard. The Canadian Construction Materials Center does not rely on ASTM E1677, and instead qualifies air barrier materials and air barrier systems by its own Technical Guides. Only five housewraps, all of which are non-perforated, qualify under Canadian criteria as air barrier materials.[1]

When a housewrap is installed as a water-resistive barrier it is wrapped horizontally around the house starting at the bottom of the wall. Each subsequent course is lapped over the previous course shingle-fashion to allow water to drain down the exterior surface. Many manufacturers recommend taping laps to aid in durability of the housewrap during construction. When housewrap is installed as an air barrier, laps are taped or sealed and the wrap is integrated with other building components by sealing at terminations and penetrations. There is often more than one technique for sealing at a termination. For example, there are two methods of sealing at the bottom plate which are cited in the field studies of housewrap performance. The simplest one is simply to tape the housewrap covering the bottom plate. Another method is to use a "header-wrap" detail, in which a narrow piece of housewrap is wrapped under the bottom plate and sill sealer and then integrated with the housewrap on the exterior and the interior of the basement or foundation wall as shown in Figure 2.

Figure 2. Basement "Headerwrap" Schematic



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[1] See Canadian Construction Materials Center website (http://irc.nrc-cnrc.gc.ca/ccmc/home_e.shtml) for product listings.

Field investigations have noted the effects of holes in or bypasses around the housewrap and demonstrate the importance of continuity. In one study air leakage passed the top plate into the wall cavity, bypassing the housewrap and causing the gypsum wallboard to carry a larger portion of the air barrier function.(TenWolde, et. al. 1998) In another study, the air barrier did not extend up an entire knee-wall to the roof intersection and a 1 ½ inch gap was left. Infrared imagery of this area clearly shows the thermal short in the area with no air barrier. (Otto 1998)

Demonstration of Housewrap Energy Savings

Reducing air leakage has been identified as a significant pathway to the overall reduction in energy consumption of a building. The U. S. Department of Energy states that, "Air infiltration can account for 30 percent or more of a home's heating and cooling costs and contribute to problems with moisture, noise, dust and the entry of pollutants, insects and rodents."(DOE 1999) A 2000 study has analyzed the energy savings associated with the use of housewraps to reduce air leakage (Franklin Associates 2000). This study estimated the energy savings and an energy payback based on a plastics life cycle energy analysis. The embodied energy in the housewraps was based on energy analysis of the manufacture of high-density polyethylene and polypropylene resins and the range of type basis weights (lb/ 1000 sq ft) of the housewrap products. Annual energy savings was based on an estimated range of Air Changes per Hour (ACH) reduction, combined with DOE data for average residential air leakage. Since very little energy is used in the manufacture of building wraps, they were estimated to provide significant energy savings by controlling energy losses due to air leakage. A summary of the study's findings are in Table 1.

Table 1. Housewrap Energy Payback

	Million Btu
Housewrap Embodied Energy	1.21 to 1.77
Annual Energy Savings* low estimate (based on 10% ACH Reduction)	12
Annual Energy Savings* high estimate (based on 50% ACH Reduction)	60.2
Energy Payback = 7 to 54 days	

**based on DOE data on annual house statistics*

From the studies reviewed in this paper it is clear that housewrap usage contributes to the reduction of air leakage in building envelopes. The use of housewraps to control air leakage in residential housing has been included in the provisions of energy codes and standards, examples of which are shown in Table 2.

Table 2. Housewrap-Related Provisions in Energy Codes and Standards

Code / Standard	
ASHRAE 90.2 - 2001	Air infiltration retarders are recommended provided they are continuous and have a vapor permeance greater than or equal to 5.0 perms.
2003 International Residential Code (IRC)	N1102.1.10 Air leakage. All joints, seams, penetrations; site-built windows, doors, and skylights; openings between window and door assemblies and their respective jambs and framing; and other sources of air leakage (infiltration and exfiltration) through the building thermal envelope shall be caulked, gasketed, weatherstripped, **wrapped**, or otherwise sealed to limit uncontrolled air movement.
2006 International Residential Code (IRC)	N1102.4.1 Building thermal envelope. The building thermal envelope shall be durably sealed to limit infiltration. The sealing methods between dissimilar materials shall allow for differential expansion and contraction. The following shall be caulked, gasketed, weatherstripped or otherwise sealed with an **air barrier material, suitable film** or solid material....
2003 International Energy Conservation Code (IECC)	802.3.3 Sealing of the building envelope. Openings and penetrations in the building envelope shall be sealed with caulking materials or closed with gasketing systems compatible with the construction materials and location. Joints and seams shall be sealed in the same manner or taped or covered with **a moisture vapor permeable wrapping material.** Sealing materials spanning joints between construction materials shall allow for expansion and contraction of the construction materials.
2006 International Energy Conservation Code (IECC)	402.4.1 Building thermal envelope. The building thermal envelope shall be durably sealed to limit infiltration. The sealing methods between dissimilar materials shall allow for differential expansion and contraction. The following shall be caulked, gasketed, weatherstripped or otherwise sealed with **an air barrier material, suitable film** or solid material:
California Energy Efficiency Standards - 1998	I. Air Retarding Wrap Credit If compliance credit is not taken for reduced building envelope air leakage through diagnostic testing, a special “default” compliance credit can be taken for building envelope leakage reduction resulting from installation of **an air retarding wrap (i.e., housewrap)**. To qualify for the “default” compliance credit, an air retarding wrap must be tested and labeled by the manufacturer to **comply with ASTM E1677-95, Standard Specification for an Air Retarder (AR) Material or System for Low-Rise Framed Building Walls, and have a minimum perm rating of 10.** Insulative sheathing and building paper do not qualify as air retarding wraps. The air-retarding wrap must be installed per the manu-facturer’s specifications that must be provided to comply with ASTM E1677-95. In particular, the air retarding wrap must meet the following installation requirements: • The air retarding wrap must be applied continuously; • All tears or breaks must be repaired with manufac-turer approved tape. • All horizontal seams must be lapped in a shingle-like manner and taped. • All vertical seams must be lapped and. • All windows and penetrations must be taped or caulked. • The air retarding wrap must be taped or otherwise sealed at the slab junction.
Minnesota Energy Code	7672.0600 MINIMUM ENVELOPE CRITERIA.Subp. 7. Exterior wind wash barrier. A barrier must be provided to resist wind wash. Where sealing is required, the wind wash barrier must be caulked, be gasketed, have sealed exterior wrap, or be otherwise sealed in an approved manner to provide a permanent air seal and to prevent entry of wind and wind-driven rain. In wood framing construction, wind wash barrier penetrations must occur through rigid material or approved hardware to enable effective sealing. Penetrations in the wind wash barrier must be sealed prior to covering or making inaccessible so that a continuous win wash barrier is maintained.
Washington Energy Code	502.4.3 Seals and Weatherstripping: a. Exterior joints around windows and door frames, openings between walls and foundation, between walls and roof and wall panels; openings at penetratins of utility services through walls, floors, and roofs; and all other openings in between units in R-1 and R-2 occupancies ashall be sealed, caulked, gasketed or weatherstripped to limit air leakage. Other exterior joints and seams shall be similarly treated, or taped, or **covered with moisture vapor permeable housewrap.**

The efficacy of housewraps at reducing air leakage has been demonstrated through laboratory material and assembly testing, although different test show results can vary based on housewrap type and installation procedures. In many test studies housewrap performance was compared to other common construction materials. Two basic approaches have been used to try to quantify the energy savings related to housewrap usage:

1. Large scale laboratory measurement of thermal transmission under simulated wind-loads.
2. Field studies of whole house air leakage which can then be related to energy savings in various climates through modeling.

Most studies have been conducted using the original non-perforated spun bonded olefin product. The following is a review of laboratory assembly and field studies which were performed to quantify the air leakage reduction due to housewrap usage.

Laboratory Measurements of Thermal Transmission Under Simulated Wind-Loads

A review of published literature showed that there were two studies that used this pathway to try to quantify the energy savings value of housewraps. Other studies demonstrated the reduction in air leakage that housewraps provide. Considered together, these studies show that without air barrier protection the insulation's thermal performance is significantly decayed when exposed to wind pressures. The decay of wall thermal performance was observed across a wide range of insulations and sheathing choices. In all cases housewrap effectively reduced the degree of degradation in wall thermal performance.

Henning 1981. This study used a base wall construction consisting of aluminum siding, sheathing with small gaps in some cases, 2x4 studs with fiber glass insulation, plywood panel. The housewrap used in this study was a non-perforated 42 g/m^2 SBPO with air permeability estimated to be .4 $L/s \cdot m^2$ @ 75 Pa. Thermal transmission was measured using a heat flux transducer mounted the interior wall surface. Winds were simulated using a variable-speed industrial fan. The measurements showed that thermal transmittance increased linearly with wind velocity when no housewrap was installed. When a housewrap was installed however thermal transmission was relatively independent of wind velocity. Results from the study are shown Table 3.

Table 3. Reduction in Thermal Transmission under Simulated Wind-Load Resulting from Housewrap Usage

		% Reduction Thermal Transmittance (Wm^2K)	
	Simulated Wind	**15 mph**	**34 mph**
Sheathing	None	20	42
	"Broken" Sheathing	n/a	36
	Sheathing with 1/8" Gaps (Site-built)	14	n/a

Ober and Goodrow 1994. This study measured air infiltration using ASTM E1424 in walls with different types of insulation and with and without housewrap. The basic wall construction was hardboard siding, polyisocyanurate foam sheathing, insulated stud space and gypsum wall-board.

Results are shown in Table 4. Housewrap reduced the air infiltration through all the insulations tested.

Table 4. Mean Air Flow Results With and Without Housewrap

Insulation	Infiltration without Housewrap (cfm)	Infiltration with Housewrap (cfm)	% Reduction in Infiltration with Housewrap
R-13 Inset Stapled Fiber Glass	1.32	0.54	78%
Fiber Glass BIBS (@ 1.5 pcf design density)	1.18	0.76	42%
Wet Spray Cellulose (@2.95 pcf)	1.45	0.77	68%

Jones 1995. This study used a combination of ASTM E1424, ASTM E283 and ASTM C976 to determine the effect of airflow on thermal performance of a series of residential wall constructions. Wall construction included typical 2x4 and 2x6 fiber glass insulated wall cavities and a sub-floor area. The walls were covered with five types of exterior sheathing and were either with or without a housewrap. Results expressed as effective R-values under simulated wind loads are shown in Table 5.

Field Studies of Whole House Air Leakage

Some of the studies reviewed had as their primary goal the assessment of housewrap performance. Other studies, while not having the assessment of housewrap as a primary objective, contained a portion of their data which add to the overall assessment of housewrap performance. Some of the studies assessed both air leakage measurements and measured energy usage directly. The combined results of studies (see Table 6) clearly indicate that housewraps can reduce air leakage of houses and provide the associated energy savings. Many of the studies are quite old and were conducted on constructions that do not meet current energy code requirements.

Weimar and Luebs 1986. This study assessed the effect of retrofitting a single five-year old house in Mt. Airy, Maryland with housewrap. The house was a single-story with a basement. Wall construction prior to housewrap installation was:

- Brick/Aluminum Siding combination,
- Sheathing,
- R-11 fiberglass batt insulation, and
- Gypsum wall-board.

The air leakage of the house was measured both by SF6 tracer gas analysis and by blower door measurements. In addition energy usage during a heating season was monitored. The study results were:

- SF6 Tracer Gas – Reduction in ACH from .35 to .22 (35%).

- Blower Door Tests – Reduction in ACH_{50} from 8.6 to 5.6 (35%), Reduction in ACH_4 from 1.4 to .8 (43%).
- Energy consumption – 24% for heating season, projected 28% over life of house.

Table 5. Effective R-Values ($^oF \cdot h \cdot ft^2/Btu$)

Wall Description	Simulated Wind Speed (kph)	Effective R-Value	
		Without Housewrap	With Housewrap
Pressure-laminated cellulose sheathing	0	11.63	11.68
Pressure-laminated cellulose sheathing	14.6	4.39	10.64
Pressure-laminated cellulose sheathing	23.2	3.32	10.29
OSB Sheathing + Air Tight Drywall	0	14.01	14.43
OSB Sheathing + Air Tight Drywall	12.9	12.83	14.77
OSB Sheathing + Air Tight Drywall	24.1	11	15.05
"Reside wall" = Hardboard siding covered with XPS fan-fold leveling board, then covered with Vinyl Siding	0	17.85	18.42
"Reside wall" = Hardboard siding covered with XPS fan-fold leveling board, then covered with Vinyl Siding	14.6	9.27	15.38
"Reside wall" = Hardboard siding covered with XPS fan-fold leveling board, then covered with Vinyl Siding	23.2	6.15	13.17
XPS T&G Sheathing	0	18.18	18.69
XPS T&G Sheathing	14.6	4.12	16.17
XPS T&G Sheathing	23.2*	2.78	14.34
Foil-faced Isocyanurate Sheathing	0	17.65	16.05
Foil-faced Isocyanurate Sheathing	14.6	7.36	14.93
Foil-faced Isocyanurate Sheathing	23.2	4.29	17.54
Foil-faced Isocyanurate Sheathing + 3 Caulked Joints	0	17.54	not tested
Foil-faced Isocyanurate Sheathing + 3 Caulked Joints	14.6	8.55	15.95
Foil-faced Isocyanurate Sheathing + 3 Caulked Joints	23.2	5.71	15.95

**20.8 for wall without housewrap as the wall sample leakage rate exceeded the capacity of the blower and did not permit this test to be conducted at 23.2 kph*

Table 6. ACH and Energy Consumption Measurements from the Combined Studies

			% Reduction with Housewrap			
Study	Location	Type of Study	Tracer Gas ACH	Blower Door ACH_{50}	Energy Usage - Heating Season	Energy Usage - Cooling Season
Weimar and Luebs, 1986	Maryland	Retrofit - 1 house	35%	35%	24%	n/a
NAHB, 1984/6.	Florida	Paired Comparison -- 9 pairs	21.30%	11.80%	n/a	11.30%
Saum, 1993	Virginia	Paired Comparison -- 6 control, 8 with Housewrap	n/a	27%	n/a	n/a
Wilcox and Weston, 2001	California	Paired Comparison -- 4 pairs	n/a	21%	n/a	n/a

NAHB 1984/6. This study was designed to examine performance in a cooling climate and was conducted in Boca Raton, Florida. Nine pairs of houses (construction differing by whether housewrap or #15 felt was installed) were examined. Basic house construction was aluminum siding over felt or housewrap, 2x4 frame construction with R-11 fiberglass batt insulation, 4-mil polyethylene vapor barrier and gypsum wallboard. The air leakage of the house was measured both by SF6 tracer gas analysis and by blower door measurements. In addition, cooling energy consumption usage during a cooling season was monitored. To ensure uniformity of indoor temperature across all the houses single set-point thermostats were installed. The study results were:

- SF6 Tracer Gas – Reduction in ACH from .61 to .48 (21.3%).
- Blower Door Tests – Reduction in ACH_{50} from 8.73 to 7.7 (11.8%).
- Cooling energy consumption – 11.3% reduction for housewrap over felt.

Saum 1993. This study evaluated 14 production built houses (6 control and 8 with housewrap) using blower door and infrared analysis. The houses were located in Charlottesville, VA. The basic wall construction was vinyl siding, OSB/Fiberboard Sheathing, and 2x4 insulated with fiberglass. The houses were two-stories with garages attached in several different configurations. Blower door tests were conducted under infiltration and exfiltration conditions. Additionally, two independent blower door tests were conducted with ducts sealed and ducts open. The blower door test results show that housewrap can lower ACH levels up to 29%. The infrared analysis performed in conjunction with the blower door testing further supported wall air flow reduction due to housewrap installation.

Yuill and Yuill 1998. This study used a series of retrofits of two houses to compare the air leakage performance of several sheathing and housewrap options. The houses were single story homes located in Granville, OH. The basic wall construction was aluminum siding, various sheathings and/or housewrap, 2x4 framing with fiber glass insulation, and gypsum wallboard.

Air leakage was measured with a series of blower door tests. The results of the tests were expressed as "Flow Resistance" of the various materials. (Table 7)

Table 7. Flow Resistance of Tested Housewrap/Sheathing Combinations

Material	Flow Resistance ($s \cdot Pa^{0.5}/m$) House 1	Flow Resistance ($s \cdot Pa^{0.5}/m$) House 2
Housewrap & untaped Foam Sheathing	5000	n/a
Untaped Foam Sheathing	500	n/a
Housewrap over Fiberboard Sheathing	3000	2500
Taped Foam Sheathing	3500	n/a
Polyethylene film	4000	2500

Pesce and Gilg 1998. This was a survey of production built houses in Virginia and Maryland. Four different builders were included. The houses compared had vinyl siding and three-ply kraft sheathing. The blower door tests conducted showed reduced air leakage (Table 8) when a combination of foaming/caulking the rough openings and the installation of an air barrier (housewrap) over the band joists was used.

Table 8. Blower Test Results

Air Sealing Techniques	ACH_{50}
Chinking rough openings with fiber glass	5.0 - 5.2
Foaming/Caulking rough openings + air barrier on band joists	</= 3.9

Wilcox and Weston 2001. This study compared four pairs of production built houses in Sacramento, CA. This study is unique from previous studies because the cladding was stucco instead of siding. The basic wall construction was stucco on foam over 2-ply Grade D building paper. The blower door tests indicate that replacement of the two layers of building paper with housewrap reduced the specific leakage area (SLA) in the four houses by 7% to 18% with an average reduction of 13%.

Summary and Recommendations

Significant research has been conducted to characterize the performance of housewrap materials and their ability to control air leakage in residential construction. The research clearly shows that housewraps if installed correctly can significantly reduce air leakage and provide the associated energy savings. Housewraps have been included in the provisions of residential energy codes and standards.

The amount of air leakage reduction in any specific scenario will depend on the entire wall construction, the housewrap material properties and installation practices. However, the research to date has not established detailed relationships between these factors. Additional research, especially field studies, is recommended to establish these relationships and enable full advantage of the air leakage reduction potential of housewraps.

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