The Importance of Using an Air Barrier in Residential Housing Construction in Hot and Humid Climates

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Abstract

Air leakage in buildings located in hot and humid climates can result in excessive energy costs. Additionally, if uncontrolled moisture carried on air currents condenses within building components, it can potentially lead to material deterioration or mold problems. The incorporation of air barriers into the building construction can help control air leakage. This paper reviews the potential benefits of residential air barrier construction in hot and humid climates and the efficacy of housewraps as air barriers.

Introduction

While the use of air barriers in residential construction is common in heating climates, it is not prevalent in hot and humid (cooling) climates. Control of air leakage is an important factor in the reduction of energy consumption and in helping to manage the moisture movement and accumulation in the wall systems. Two major components are required to reduce air leakage -- control of the driving force (pressure differences) and control of the holes in the building envelope (air barrier construction). A pressure differential driving force can result from mechanically induced (equipment/duct related) house depressurization, wind effects or stack pressure. A "hole" in a building can occur where any two building components meet. One of the most common air barrier materials used in residential construction is a housewrap.

Energy Savings from Controlling Air Leakage

The potential for the reduction of the cooling energy demand in hot and humid climates from controlling air leakage is primarily due to controlling the latent load on air conditioning equipment. Although the focus of energy savings through air leakage control has been on the heating climates, the savings in hot humid climates can be the same magnitude.

In a comparison of nine pairs of houses in Boca Raton, Florida with and without housewrap used to control air leakage, the houses with housewrap showed a 21% lower air change rate, resulting in an average of 11.3% lower cooling energy. [9, 10]

To determine an estimate of the savings potential in hot and humid climates in comparison to cold climates, an energy savings analysis program was developed to evaluate the annual heating and air conditioning requirements of houses with and without housewrap installed. [11] The program estimates heating and cooling season (winter and summer) energy costs separately based on local weather data and local fuel and electricity costs. The local weather and cost data required are:

- latitude in degrees for determining sun angle information,
- heating degree days in °F·days for the heating season (The base in 65°F.),
- average outdoor temperature during winter in °F,
- average outdoor relative humidity in winter,
- average wind speed in winter mph,
- average clearness index for solar radiation in winter,
- cooling degree days in °F·days for the cooling season (The base is 65°F.),
- average outdoor temperature during summer in °F,
- average outdoor relative humidity in summer,
- average wind speed in summer in mph,
- average clearness index for solar radiation in summer,
- cost of natural gas in dollars per therm,
- cost of electricity in dollars per kilowatt hour, and
- cost of No. 2 fuel oil in dollars per gallon.

An "example" house is used in the analysis. The example house is described by square footage, number of stories, type of foundation (basement, slab or crawlspace), window type, insulation levels, air leakage (expressed in air changes per hour) and the fuel source.

To estimate of the value of air leakage control in hot and humid climates in comparison to cold climates Tampa, Florida and Green Bay, Wisconsin were chosen as example cities. The weather data used for each of these cities is shown in Table 1.

Example houses were chosen with two air leakage levels: tight houses were represented by an ACH_{nat} of .28 and normal houses by an ACH_{nat} of .70. These air leakage levels were chosen as representative after reviewing literature of air leakage testing of houses in the south-eastern United States (hot / humid and temperate climates). Table 2 shows a summary of this review.

The comparison was conducted for a range of house square footage and number of stories. Insulation levels for the Tampa house were chosen as R-13 for the walls and R-30 for the ceiling. The Green Bay house was simulated at the R-13 wall / R-30 ceiling insulation level to enable to direct comparison with the Tampa house. An additional Green Bay case was run with higher insulation levels (R-19 wall / R-36 ceiling) that are more typical of northern climates. Other "example" house characteristics are shown in Table 3.

The results of the comparison show summertime energy savings due to reduced air leakage in hot humid climates ranged from $110 to $320 depending on house size and configuration in comparison to a wintertime energy savings in cold climates of $100 to $310. Although increasing the insulation level in the Green Bay case decreased the energy costs for any given house configuration, the energy savings due to air leakage reduction was relatively unchanged. Wintertime energy savings in this case were $100 to $310 depending on house configuration. Complete results are shown in Tables 4 and 5. The results show the potential for summertime energy cost saving in hot and humid climates is substantial and equal in magnitude to that of the wintertime saving in cold climates. Although it is fully recognized that a more detailed analysis using hourly weather data would be required to predict the performance of a specific building, these calculations provide an order of magnitude estimate of the energy benefits that can be achieved from air leakage control.

	Tampa, Florida	Green Bay, Wisconsin
Latitude		
HDD	739	8143
Avg. Winter Temp.	59.8 F	14 F
Avg. Winter RH	75.8	73.3
Avg. Winter Wind Speed	9	11
Avg. Winter Clearness Index	50.50%	40.60%
CDD	3324	381
Avg. Summer Temp.	82.2 F	69.5 F
Avg. Summer RH	77.30%	71
Avg. Summer Wind Speed	8	9
Avg. Summer Clearness Index	49.00%	52.50%
Natural Gas Cost		.4930/ccf
Electricity Cost	.072/kwh	.078/kwh

Table 1: Local Weather and Cost Data

ACH (50)	ACH (nat)	# Houses	Location	Reference	Comments
6.2 (3.7-10.2)	.29 (.17 - .49)	20	Kentucky / Tennessee	[15]	Air Leakage Control Used
4.6 (2.8-6.6)		20	Georgia	[15]	Air Leakage Control Used
4.8 (3.12-6.98)		11	Virginia, Maryland	[13]	Air Leakage Control Used
6.3	0.18	26	Florida	[13]	
5.42 (2.8 - 7.4)		18	Kansas, Maryland, Virginia	[13]	
12.7			Florida	[6]	
6.6 (6.2-7.2)	.43 (.41-.48)	6	Virginia	[14]	
4.8 (4.2-5.8)	.32 (.28-.38)	8	Virginia	[14]	Air Leakage Control Used
8.73 (7.64 - 9.45)	.61 (.51-.72)	9	Florida	[10]	
7.70 (6.54-9.11)	.48 (.41-.55)	9	Florida	[10]	Air Leakage Control Used
	.5 (.2 - 3.2)	312	North America	[1]	
	.9 (.2 - 3.5)	266	North America	[1]	Low-Income Housing

Table 2: Air Leakage Measurements from Previous Studies

		Tampa, Florida	Green Bay, Wisconsin	Green Bay, Wisconsin
Insulation Level				
	Wall R-value	13	13	19
	Ceiling R-value	30	30	36
Foundation type		Insulated Slab	Insulated Slab	Insulated Slab
Windows				
	Glazing	Double Pane, Clear Glass	Double Pane, Clear Glass	Double Pane, Clear Glass
	Frame	Vinyl	Vinyl	Vinyl
Heating Type		Electric Heat Pump	Natural Gas Furnace	Natural Gas Furnace
Cooling Type		Electric Heat Pump	Electric	Electric

Table 3: Example House Characteristics

Green Bay, Wisconsin (R-13 wall / R-30 ceiling)							
		Winter Energy Cost					
Conditioned Floor Area		**1000**	**1000**	**2000**	**2000**	**3000**	**3000**
No. of Stories		**1**	**2**	**1**	**2**	**1**	**2**
House Air Leakage							
	.28 ACH	**260**	**290**	**450**	**460**	**640**	**630**
	.70 ACH	**360**	**400**	**660**	**670**	**950**	**940**
	Difference	**100**	**110**	**210**	**210**	**310**	**310**
		Summer Energy Cost					
Conditioned Floor Area		1000	1000	2000	2000	3000	3000
No. of Stories		1	2	1	2	1	2
House Air Leakage							
	.28 ACH	40	50	60	70	90	90
	.70 ACH	40	60	70	80	100	110
	Difference	0	10	10	10	10	20
		Total Energy Cost					
Conditioned Floor Area		1000	1000	2000	2000	3000	3000
No. of Stories		1	2	1	2	1	2
House Air Leakage							
	.28 ACH	300	340	510	530	730	720
	.70 ACH	400	460	730	750	1050	1050
	Difference	100	120	220	220	320	330

Green Bay, Wisconsin (R-19 wall / R-36 ceiling)							
		Winter Energy Cost					
Conditioned Floor Area		**1000**	**1000**	**2000**	**2000**	**3000**	**3000**
No. of Stories		**1**	**2**	**1**	**2**	**1**	**2**
House Air Leakage							
	.28 ACH	**230**	**250**	**400**	**400**	**570**	**550**
	.70 ACH	**330**	**360**	**600**	**610**	**880**	**860**
	Difference	**100**	**110**	**200**	**210**	**310**	**310**
		Summer Energy Cost					
Conditioned Floor Area		1000	1000	2000	2000	3000	3000
No. of Stories		1	2	1	2	1	2
House Air Leakage							
	.28 ACH	40	50	60	70	80	90
	.70 ACH	40	50	70	80	100	100
	Difference	0	0	10	10	20	10
		Total Energy Cost					
Conditioned Floor Area		1000	1000	2000	2000	3000	3000
No. of Stories		1	2	1	2	1	2
House Air Leakage							
	.28 ACH	270	300	460	470	650	640
	.70 ACH	370	410	670	690	980	960
	Difference	100	110	210	220	330	320

Table 4: Green Bay, Wisconsin Energy Cost Calculations

Tampa, Florida (R-13 wall / R-30 ceiling)							
		Winter Energy Cost					
Conditioned Floor Area		1000	1000	2000	2000	3000	3000
No. of Stories		1	2	1	2	1	2
House Air Leakage							
	.28 ACH	20	20	40	40	50	50
	.70 ACH	30	30	50	50	70	70
	Difference	10	10	10	10	20	20
		Summer Energy Cost					
Conditioned Floor Area		**1000**	**1000**	**2000**	**2000**	**3000**	**3000**
No. of Stories		**1**	**2**	**1**	**2**	**1**	**2**
House Air Leakage							
	.28 ACH	**370**	**460**	**630**	**690**	**880**	**920**
	.70 ACH	**480**	**570**	**850**	**900**	**1220**	**1240**
	Difference	**110**	**110**	**220**	**210**	**340**	**320**
		Total Energy Cost					
Conditioned Floor Area		1000	1000	2000	2000	3000	3000
No. of Stories		1	2	1	2	1	2
House Air Leakage							
	.28 ACH	390	480	670	730	930	970
	.70 ACH	510	600	900	950	1290	1310
	Difference	120	120	230	220	360	340

Table 5: Tampa, Florida Energy Cost Calculations

Moisture Management from Leakage Control

Control of air leakage is recognized as a crucial part of the moisture control strategies for buildings. [1] The control of moisture was a major criterion used to establish the maximum air leakage rate allowed to meet the requirements of the National Building Code of Canada. [3] In regards to hot and humid climates, the most reported moisture problem due to air leakage, is caused by warm humid exterior air infiltrating into the wall system and then condensing when it comes in contact with a cold vapor barrier surface, such as provided by a polyethylene film vapor barrier or vinyl wall –paper with air conditioned internal conditions. This phenomenon has been reported especially in hotels where depressurization by mechanical equipment exacerbates the problem [8,12]. Placing an air infiltration barrier outside of the insulation can help control moisture condensation, as most moisture enters houses through infiltration rather than diffusion. [5]

Housewraps as a Residential Air Barrier

One common residential air barrier choice is an exterior 'breathable" sheet material, commonly referred to as a housewrap. Housewraps are thin flexible sheets, which are primary installed between the cladding and the sheathing (or studs if no sheathing is present). In this position, they function as both an air barrier and a secondary water resistant barrier. There are three types of housewrap materials: flash spun bonded non-wovens, perforated films, and microporous films. Housewraps are designed to be air resistant, water resistant, and water vapor permeable in order to meet building code requirements.

Other air barrier choices include exterior rigid foam sheathing, and polyethylene vapor barrier films. Both of these materials are vapor barriers and therefore care should be taken in their placement within wall constructions so moisture is not inadvertently trapped within the wall. Interior vapor barriers should not be used in hot, humid climate due to the moisture movement previously discussed.

Evaluation of Air Barrier Performance

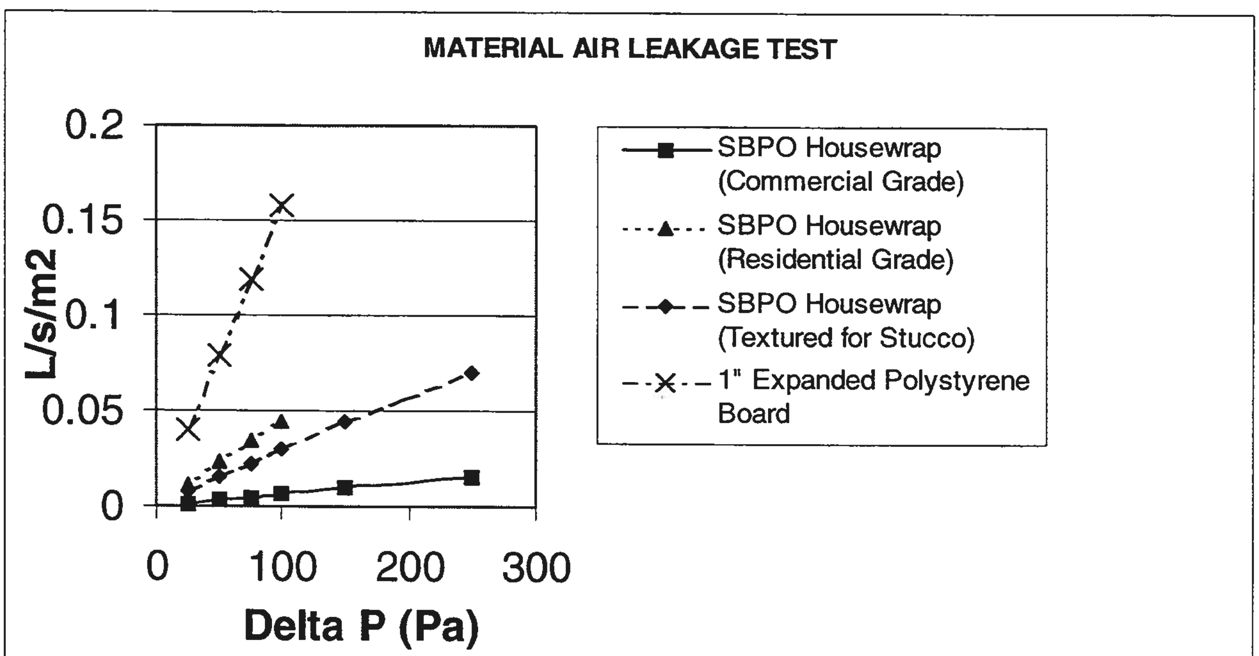
The performance of specific air barrier options can be evaluated by the base material properties, in sample wall installations and in their final end-use as installed on buildings. Table 6 compares several common test methods.

Air Barrier Material Testing

Testing of materials by the method described within the CCMC Air Barrier Material Technical

Method	Sample Type	Sample Size	Units	
TAPPI-T460 (Gurley-Hill)	Sheet or panel material	1 sq inch	Sec/100 ml	
CCMC Air Barrier Material Technical Guide	Sheet or panel material	1 sq meter	cfm/ft2 @ various pressure differences	Referenced in Canada NBC 1995
ASTM E283	Wall system	8' x 8' (standard)	cfm/ft2@ various pressure differences	Referenced in ASTM E1677
ASTM E1424	Wall system	8' x 8' (standard)	cfm/ft2 @ various pressure and temperature differences	Referenced in Canada AIB System Technical Guide
ASTM E779 (Blower Door)	Whole house	Whole house	Air changes per hour	Can be combined with IR analysis

Table 6: Common Methods of Testing Air Leakage Performance



Data from [4], and from testing conducted by AIR-INS, Inc. for the author.

Figure 1: Material Air Leakage Measurements by the Method Described in the CCMC Technical Guide for Air Barrier Materials

Guide exposes a square meter of material to a range of air pressures. A curve of the material air leakage as a function of the pressure is produced. Figure 1 shows the results of this testing comparing three flash spun bonded polyolefin housewrap products with a rigid sheathing product. The housewrap product showed higher resistance to air penetration than the expanded polystyrene foam.

Results from this method are often reported as the leakage rate at the reference pressure difference of 75 Pa. Comparison at this reference pressure shows the large differences between air leakage rate of perforated and non-perforated (flash spun polyolefin) housewraps. (Figure 2). Non-perforated (flash spun bonded polyolefin) housewraps are one to two orders of magnitude more effective as air barrier materials than perforated housewraps. The difference in air resistance performance results from the basic material structure of the different types of housewrap. Flash spun-bonded polyolefin housewrap is made using layers of randomly oriented fine filaments that are bonded together by heat and pressure resulting in an extremely fine porous structure. (Figure 3). Perforated products on the other hand are made of films that are punctured to allow for some "breathability". This puncturing or perforation creates much larger holes than the pores in flash spun bonded non-wovens. (Figure 4.)

Air Barrier System Testing

In 1995, a new ASTM standard, E1677-95 "Standard Specification for an Air Retarder (AR) Material or System for Low-Rise Framed Building Walls" was introduced. [2] This standard requires that the air barrier be tested in a sample wall (minimum 8' x 8') configuration. A maximum air leakage of </= .06 cfm/ft^2 at .3 in of H_2O (75 Pa) in both the infiltration and exfiltration directions is allowed. The air leakage performance is tested after the wall

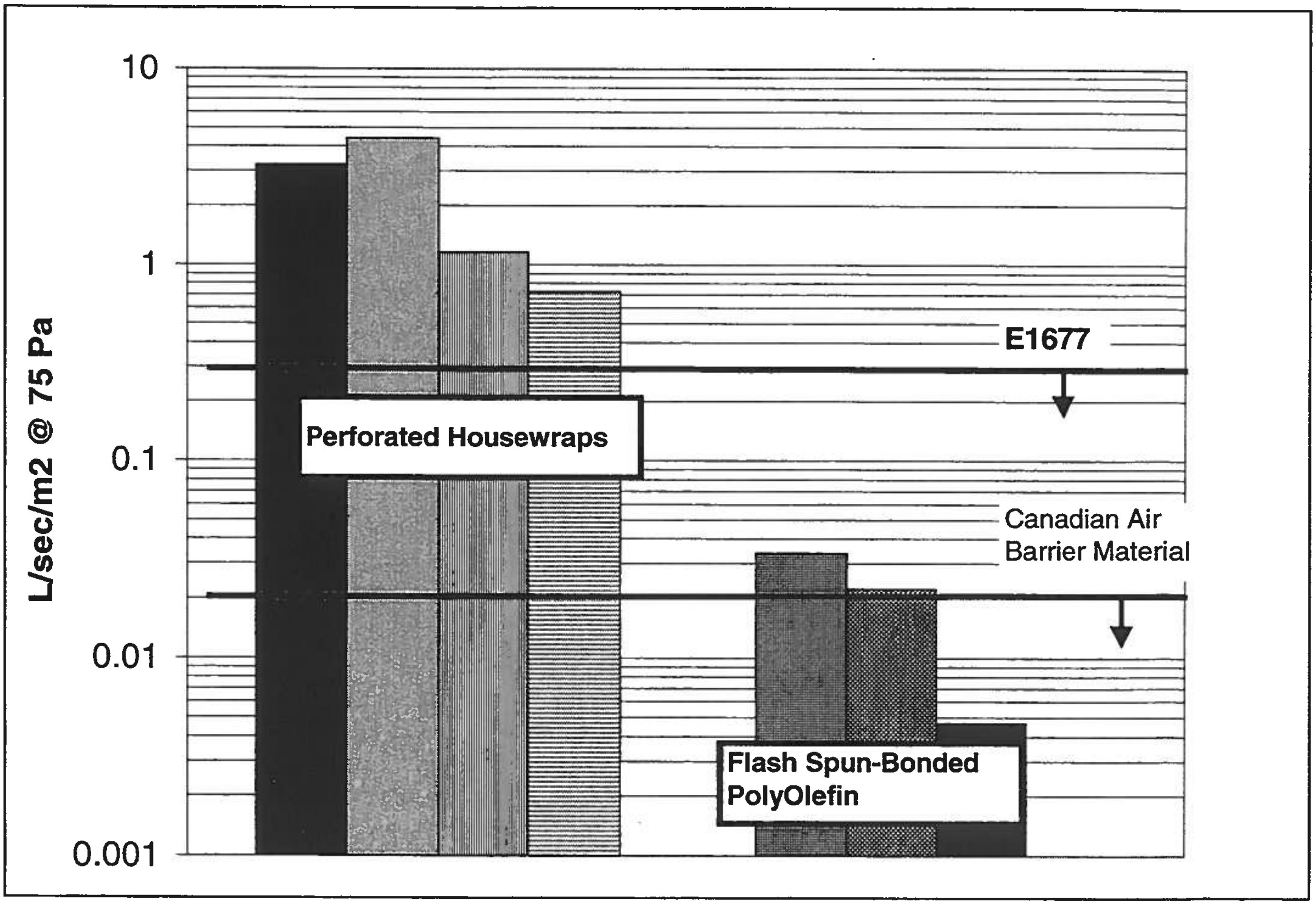


Figure 2: Material Air Leakage at 75 Pa.

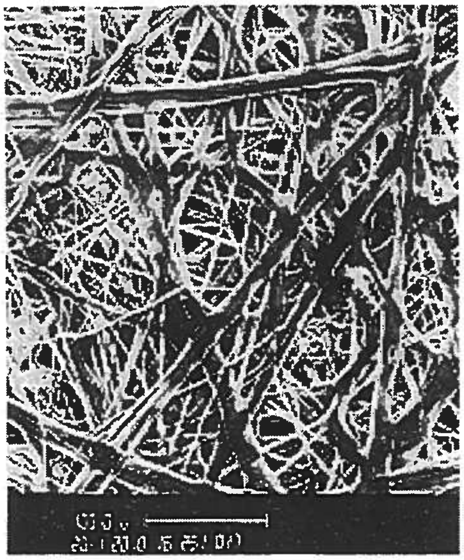


Figure 3: Scanning Electron Micrograph of Flash Spun Bonded Polyolefin Housewrap

specimen is stressed by structural loading of 500 Pa (approximately 65 mph) for 1 hour each in both the negative and positive directions.

Flash spun bonded polyolefin housewrap was evaluated against the requirements of ASTM E1677-95. The same housewrap was run in several wall configurations. The standard requires any material that is exterior to the studs to be considered part of the air barrier system. Cladding systems are not applied (unless they are to be part of the air barrier system) but the effect of their presence of the air barrier system is simulated by the addition of the cladding

Figure 4: Scanning Electron Micrograph of Perforated Housewrap.

fasteners. The standard specifies siding to be simulated by horizontal furring strips fastened at a 9" spacing. Brick cladding is simulated by a brick ties being installed in a 16" x16" grid pattern.

The specific wall configurations tested are shown in Table 7. All wall specimens were 8' x 8' in size, with the base construction being 2x4 16"oc wood stud construction. In wall specimens when sheathing was used in addition to the housewrap, the air leakage of the walls with sheathing alone (before the housewrap installation) was tested in addition to the final system. Tables 8 to 10 show the air leakage results for each of the wall configurations. In all configurations, air leakage at .3 in H_2O was </=

Wall Specimen	Sheathing	Housewrap Fasteners	Cladding Simulation
1	none	1" cap nails	Siding
2	OSB	Staples	Brick
3	1/2" Extruded Polystyrene Foam	1" cap nails	Siding

Table 7: Wall Specimens Tested by ASTM E1677

	Air Leakage Before Structural Loading		Air Leakage After Structural Loading	
Pressure (in H20)	Infiltration	Exfiltration	Infiltration	Exfiltration
0.1	<0.01	<0.01	<0.01	<0.01
0.2	<0.01	<0.01	<0.01	<0.01
0.3	<0.01	0.02	<0.01	0.02
0.4	<0.01	0.02	<0.01	0.02
0.6	<0.01	0.03	<0.01	0.02

Table 8: E1677 Measurements - Housewrap Over Open Stud

.01 cfm/ft^2 which is well below the.06 cfm/ft^2 requirement.

Wall specimen #1: Open Stud

In this specimen the housewrap was attached directly to the studs with cap headed nails. The housewrap met the E1677 requirements, and showed no significant reduction in air penetration resistance due to structural loading.

Wall specimen #2: OSB Sheathing

In this wall specimen 4' x 8' sheets of 3/8" thick Oriented Strand Board (OSB) sheathing were installed with the long dimension oriented horizontally. The sheathing was installed with a 1/8" gap between the sheets and extending across all of the stud spaces. Air infiltration results with the sheathing alone were not obtainable due to excessive air leakage. Once the housewrap was installed the specimen met the E1677 requirements. This specimen showed a small increase in air infiltration due to structural loading. This is probably a result of staples being used to attach the housewrap in this sample instead of the cap headed nails used for the other specimens.

Wall Specimen #3: Expanded Polystyrene Sheathing

In this wall specimen 4'x 8' sheets of ½" extruded polystyrene foam sheathing were installed horizontally and butted together in the center of the wall. Although foam sheathing is sometimes specified as an air barrier, the test results shows that as installed foam sheathing alone did not meet the E1677 requirements when installed with no housewrap or other seam sealing technique. When housewrap was installed, the specimen met the E1677 requirements. There was no significant reduction in air penetration resistance due to structural loading.

	Air Leakage Before Structural Loading		Air Leakage After Structural Loading	
Pressure (in H20)	Infiltration	Exfiltration	Infiltration	Exfiltration
0.1	<0.01	<0.01	<0.01	<0.01
0.2	<0.01	<0.01	0.01	<0.01
0.3	<0.01	0.02	0.01	<0.01
0.4	<0.01	0.02	0.02	<0.01
0.6	<0.01	0.02	0.02	0.01

Table 9: E1677 Measurements - Housewrap Over OSB

	Air Leakage Sheathing Alone		Air Leakage After HouseWrap Installation		Air Leakage After Structural Loading	
Pressure (in H20)	Infiltration	Exfiltration	Infiltration	Exfiltration	Infiltration	Exfiltration
0.1	0.28	0.28	<0.01	<0.01	<0.01	<0.01
0.2	0.4	0.43	<0.01	<0.01	<0.01	<0.01
0.3	0.49	0.58	<0.01	<0.01	<0.01	<0.01
0.4	0.57	0.69	<0.01	<0.01	<0.01	0.01
0.6	0.69	exceeds equipment abilities	<0.01	0.01	<0.01	0.02

Table 10: E1677 Measurements – Housewrap Over Foam Sheathing

The results of this testing agrees with previously reported results of the performance of foam sheathing and housewrap combinations. Jones [7] reported ASTM E283 testing of wall specimens (including siding, insulation and interior gypsum board) using ¾" Tongue and Groove expanded polystyrene sheathing with and without housewrap. The results showed air infiltration at .1 in H_2O pressure to be .01 cfm/ft^2 and .23 cfm/ft^2 for walls with and without housewrap, respectively. Yuill and Yuill [16] developed a new testing procedure to measure the air resistance of installed wall construction elements. In their work they found the airflow resistance of housewrap and untaped foam sheathing to be 5500 (s)(Pa$^{0.5}$)/m, taped foam sheathing to be 3500 (s)(Pa$^{0.5}$)/m and untaped foam sheathing alone to be 500 (s)(Pa$^{0.5}$)/m..

Conclusions

To increase energy savings and to provide for better moisture management air barriers should be a part of residential construction in hot and humid climates. Non-perforated housewraps have been shown to be an effective base material of an air barrier system, and also act as weather resistant barriers within the building system.
To complete the air barrier system the housewrap should be integrated into the overall building system. Special attention should be paid to the flashing and sealing details of windows, doors and other penetrations.

Acknowledgements

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