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ATTACHMENT #14
IMPACT OF TITLE 24 RESIDENTIAL LEAKAGE REDUCTION CREDIT ON WATER-RESISTIVE BARRIERS IN CALIFORNIA HOMES

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Impact of Title 24 Residential Air Leakage Reduction Credit on Water-Resistive Barriers in California Homes

Task 3.6 Report

California Energy Commission
Contract No. 500-03-013

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Preface

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1.0 Introduction

The 2005 California Title 24 Building Energy Efficiency Standards for Residential Buildings contains a provision to Section 150 (f) that provides compliance credit for including an "Air Retarding Wrap" in a proposed system design. Section 3.5 of the residential ACM contains the following compliance provision: "An air retarding wrap can qualify for a default reduction in Specific Leakage Area (SLA) of 0.50 without confirmation by diagnostic testing. The air retarding wrap shall 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." The air retarding wrap default credit can only be used when a field-verified performance air leakage credit is not used. The default credit is fixed and smaller than that potentially available through diagnostic testing. Unlike the default credit, a field-verified performance credit does not restrict any construction options.

Several types of water-resistive barriers (WRBs) are impacted by this provision. For instance, a WRB that meets ASTM E1677 requirements but has a perm rating below 10 does not qualify for this credit, even though it may provide equivalent or even superior air retarding performance. The use of single and double layer shingle-lapped building paper WRBs that typically do not comply with ASTM E1677 is also a common practice in California.

The purpose of this study was to investigate the technical and economic performance of alternative WRBs affected by the Title 24 air leakage reduction provision. The scope of the study focused on products used beneath stucco cladding and evaluated the technical basis for a 10 perm lower limit, including the following tasks:

1) Tabulate relevant statistics for WRBs commonly used in California residential construction.

2) Characterize the air leakage performance of qualifying products and products that do not qualify for the air leakage reduction credit.

3) Evaluate the relevance of the reduction provision in light of the requirement for mechanical ventilation when overall SLA is less than 3.0.

4) Analyze the technical basis for the 10 perm lower limit, including information from peer-reviewed technical publications, anecdotal information, and other sources as appropriate.

This research was conducted through a review of technical publications and direct correspondence with building science professionals, product manufacturers, and product sales specialists.

2.0 Product Statistics

The scope of this task was to tabulate performance statistics for WRBs used in California residential construction, including information on air leakage performance, permeance, and installed cost.

2.1 Terminology

The California Building Code uses the term "weather resistive barrier" for materials that protect the interior wall covering. Title 24 uses the term "air retarding wrap" for materials that qualify for the SLA credit. Relevant ASTM E1677 terminology includes:

- Air Retarder (AR): "a material or system in building construction that is designed and installed to reduce air leakage either into or through the opaque wall."
- Vapor Retarder: "a material or system that adequately impedes the transmission of water vapor under specified conditions."
- Water Resistance: "the capability of a material or system to retard penetration of water onto the exterior plane of framing or cavity insulation under specified conditions of air pressure difference across the AR during a test period."

Several codes and standards use the term "water-resistive barrier," or WRB, defined in the 2006 International Residential Code 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."

The wide range of terminology reflects the multiple properties of WRBs. They may act as air, vapor, and liquid water retarders or barriers in various combinations, whether explicitly designed or as an inherent property of the material. This report will use the term "Water-Resistive Barrier" when describing any of these materials.

2.2 Codes & Standards

The 2001 California Building Code requires only one layer of WRB for open frame construction. Section 1402.1 of the Code addresses WRB requirements as follows: "All weather-exposed surfaces shall have a weather-resistive barrier to protect the interior wall covering. Such barrier shall be equal to that provided for in UBC Standard 14-1 for kraft waterproof building paper or asphalt-saturated rag felt."

Two layers of WRB are required when using wood sheathing. Section 2506.4 of the Code states that, "Weather-resistive barriers shall be installed as required in Section 1402.1 and, when applied over wood base sheathing, shall include two layers of Grade D paper."

Housewraps typically demonstrate equivalency to building paper as alternate material subject to AC 38 Acceptance Criteria for Water-Resistive Barriers through evaluation reports (e.g., ES Report™ from ICC Evaluation Services, Inc.). A layer of qualifying housewrap can be combined with a layer of building paper to meet Section 2506.4 provisions, or two layers of housewrap can

be used. Decisions on equivalency are subject to local code requirements and are ultimately made by local code officials.

The International Building Code (IBC) and International Residential Code (IRC) address WRB requirements for much of the rest of the United States. Forty-seven states and Washington, D.C. use the International Building Code. Forty-five states and Washington, D.C. use the International Residential Code. The following changes contained in the 2006 editions of these model codes illustrate the evolving WRB performance requirements in other jurisdictions that may be considered for adoption in future California Code revisions.

International Building Code:

2003	**2006**
1404.2 Water-resistive barrier. A minimum of one layer of No. 15 asphalt felt, complying with ASTM D 226 for Type 1 felt, **shall be attached to the sheathing,** with flashing as described in Section 1405.3, in such a manner as to provide a continuous water-resistive barrier behind the exterior wall veneer.	1404.2 Water-resistive barrier. A minimum of one layer of No. 15 asphalt felt, complying with ASTM D 226 for Type 1 felt, **shall be attached to the studs or sheathing,** with flashing as described in Section 1405.3, in such a manner as to provide a continuous water-resistive barrier behind the exterior wall veneer.
2510.6 **Weather-resistant barriers**. **Weather-resistant** barriers shall be installed as required in Section 1404.2 and, where applied over wood-based sheathing, shall include a **weather-resistant** vapor-permeable barrier with a performance at least equivalent to two layers of Grade D paper.	2510.6 **Water-resistive barriers. Water-resistive** barriers shall be installed as required in Section 1404.2 and, where applied over wood-based sheathing, shall include a **water-resistive** vapor-permeable barrier with a performance at least equivalent to two layers of Grade D paper. **Exception: Where the water-resistive barrier that is applied over wood-based sheathing has a water resistance equal to or greater than that of 60 minute Grade D paper and is separated from the stucco by an intervening, substantially non-water-absorbing layer or drainage space.**

International Residential Code:

2003	**2006**
R703.2 **Weather-resistant sheathing paper**. **Asphalt saturated felt, free from holes and breaks, weighing not less than 14 pounds per 100 square feet (0.683 kg/m^2) and complying with ASTM D226 or other approved weather-resistant material shall be applied over studs or sheathing of all exterior walls as required by Table R703.4.** Such felt or material shall be applied horizontally, with the upper layer lapped over the lower layer not less than 2 inches (51 mm). Where joints occur, felt shall be lapped not less than 6 inches (152 mm). Exception: Such **felt or material** is permitted to be omitted in the following situations : 1. In detached accessory buildings. **2. Under panel siding with shiplap joints or battens.** 3. Under exterior wall finish materials as permitted in Table R703.4. 4. Under paperbacked stucco lath.	R703.2 **Water-Resistive Barrier. One layer of No. 15 asphalt felt, free from holes and breaks, complying with ASTM D 226 for Type 1 felt or other approved water-resistive barrier shall be applied over studs or sheathing of all exterior walls.** Such felt or material shall be applied horizontally, with the upper layer lapped over the lower layer not less than 2 inches (51 mm). Where joints occur, felt shall be lapped not less than 6 inches (152 mm). **Such felt or other approved material shall be continuous to the top of walls and terminated at penetrations and building appendages in such a manner to meet the requirements of the exterior wall envelope as described in Section R703.1.** Exception: Such **water-resistive barrier** is permitted to be omitted in the following situations: 1. In detached accessory buildings. 2. Under exterior wall finish materials as permitted in Table R703.4. 3. Under paperbacked stucco lath, **when the paper backing is an approved weather-resistive sheathing paper.**
No section	**R703.6.3 Water-resistive barriers. Water-resistive barriers shall be installed as required in Section 1404.2 and, where applied over wood-based sheathing, shall include a water-resistive vapor-permeable barrier with a performance at least equivalent to two layers of Grade D paper.** **Exception: Where the water-resistive barrier that is applied over wood-based sheathing has a water resistance equal to or greater than that of 60 minute Grade D paper and is separated from the stucco by an intervening, substantially non-water-absorbing layer or drainage space.**

International Residential Code (Continued):

2003	**2006**
R703.1 General. Exterior walls shall provide the building with a weather-resistant exterior wall envelope. The exterior wall envelope shall include flashing as described in Section R703.8. The exterior wall envelope shall be designed and constructed in such a manner as to prevent the accumulation of water within the wall assembly by providing a water-resistive barrier behind the exterior veneer as required by Section R703.2.	R703.1 General. Exterior walls shall provide the building with a weather-resistant exterior wall envelope. The exterior wall envelope shall include flashing as described in Section R703.8. The exterior wall envelope shall be designed and constructed in such a manner as to prevent the accumulation of water within the wall assembly by providing a water-resistive barrier behind the exterior veneer as required by Section R703.2 **and a means of draining water that enters the assembly to the exterior. Protection against condensation in the exterior wall assembly shall be provided in accordance with Chapter 11 of this code.**

The goal of the Title 24 provision is to provide a credit for reducing air leakage through the use of an air retarding wrap. To qualify for the air leakage reduction credit, the WRB must comply with ASTM E1677. Under this standard, a Type I WRB must pass three tests to qualify as an air retarding material: Air Leakage (ASTM E283), Structural Integrity (ASTM E330, Procedure A), and Water Resistance (ASTM E331). Type II WRBs are not required to pass the water resistance test. The Title 24 SLA credit makes no distinction between Type I and Type II air retarding materials for compliance. Although Water Vapor Permeance (ASTM E96, Procedure A) must be reported in all cases, there is no performance requirement specified in the standard.

Field installation instructions on how to install the WRB to achieve continuity are a supplemental requirement under ASTM E1677. Testing must be conducted on samples that are representative of those installation instructions. This is important when the standard is being applied to California construction that includes both open stud and sheathed construction. ASTM E1677 test data is needed in both open stud and sheathed wall system configurations to ensure intended performance in each application. Additionally, if testing is conducted with a cladding over the WRB, the cladding also becomes part of the retarder system and the only the entire system (WRB + cladding) would be considered an air retarder. Manufacturer's specifications reviewed for this report did not indicate which configurations were included in their compliance testing.

2.3 Manufacturer's Specifications

Two common types of WRBs in new residential California construction are asphalt-saturated kraft Grade D building paper and polymer-based housewraps. Building paper is not explicitly designed to perform as an air or vapor retarder, but has been used as a WRB in California for decades. Polymer-based housewraps are explicitly designed to provide specified combinations of air and vapor retarder performance in addition to the WRB function. Performance data was compiled for a range of housewrap products as well as a typical building paper product line.

Table 2-1 lists manufacturer's specifications for WRBs reviewed in this study. Specifications include performance properties considered relevant to this study as well as other physical properties of interest. Water vapor permeance data was available from all manufacturers. Air leakage or porosity data was available for nearly all housewraps, and for the building paper product explicitly designed to comply with ASTM E1677. Structural integrity and water resistance compliance under ASTM E1677 was identified in manufacturer's specifications for half of the housewrap products listed in Table 2-1.

2.4 Installed Performance with Stucco Cladding

A single layer of building paper has been used in California walls with stucco cladding for many decades. Historically, building paper was heavier and absorbed more water from the stucco exterior. A large capacity for absorption caused the paper to swell and shrink in the field. These cycles de-bonded the paper from the stucco fairly quickly, creating a thin drainage plane to channel water out of the wall cavity. Modern building paper is lighter, reducing its absorption capacity and making it more prone to sustained bonding with stucco. In addition, there are concerns that continuous wetting of single-ply paper will degrade its ability to resist water penetration (Butt, 2005).

California builders are increasingly using two-ply building paper on all stucco walls, irrespective of code requirements. However, two-ply is not a true two-layer WRB for water drainage purposes with stucco cladding since both plies are shingle-lapped together to form a single drainage path along the front layer. Using this option may address many of the concerns with single-ply paper, but the risk of water leakage to the interior remains when the two-ply single layer is breached. Still, there is a risk tradeoff when moving from two-ply paper to true two-layer WRBs due to the increased number of staples required to apply the second layer, especially a concern at all flashings. The additional staple holes provide an increased number of paths for water to penetrate behind the WRB. The relative risks of these two approaches to addressing concerns with single-ply building paper depend on a number of factors. Field data is essential to assist the building science community in making design recommendations on this issue.

Housewraps were designed to minimize air infiltration while providing an effective water barrier (US DOE, 2000). Application of WRBs to walls with stucco cladding requires special attention to design considerations. Building paper and housewrap products installed in direct contact with stucco have a risk of liquid water penetration to the interior surface. The wetted surface in contact with the stucco may allow water transport to the interior side of the WRB, defeating its purpose. Additionally, WRB water resistance can be reduced due to exposure to either the alkalinity of stucco or to surfactants (Weston, 2001). An air space between stucco and the WRB is strongly recommended to facilitate the drainage of liquid water to the exterior. This can be achieved either by using two layers of WRB, or by engineering a ventilated air space between the stucco and WRB. Building scientists currently recommend a second layer between the functional WRB and stucco to provide a proper drainage plane and avoid material degradation from constant wetting or contaminants (Lstiburek, 2005). The inner layer acts as the WRB (as well as an air barrier to limit infiltration and water vapor migration via air currents in the case of air retarding wraps), while the outer layer of building paper acts to shield the WRB from harmful contaminants and surfactants in the exterior cladding.

Table 2-1: WRB Performance Data

Product	Manufacturer	Material	Title 24 Air Retarder Wrap	Air Leakage Rate		Water Vapor Permeance	Water Resistance			Structural Integrity			UV Exposure	Thickness	Flame/Smoke
			ASTM E1677	ASTM E283*	TAPPI T-460	ASTM E96A*	ASTM E331	ASTM D779	AATCC-127	ASTM E330A*	ASTM D882	ASTM D1117	Mfr. Data	ASTM D1777	ASTM E84
			(meets requirements)	(cfm/ft2 @ 75 Pa)	(sec/ 100cc)	(Perms)	(15 min. @ 27 Pa)	(Dry Indicator)	(cm hydro.)	(1 Hr. @ 500 Pa)	(lb/in)	(lb)	(time)	(mils)	(index)
Vortec / WeatherTrek	Valeron / Ludlow	perforated, non-woven, cross-laminated polyethylene	Type I	< 0.06	8	6.5	Pass	> 60 min		Pass	27/24		1 year	3	Class A
Rufco-Wrap	Raven Industries	perforated, non-woven, cross-laminated polyethylene		0.017		6.5	Pass				27/24	31/21 (D751)	1 year	3	5/15
FirstWrap	Firstline	perforated, woven polypropylene			42	6.7		> 24 hrs			64/33	71/37		7	Class A
Weathermate Plus	Dow	non-perforated, non-woven polyolefin	Type I	0.02	1800	6.7	Pass		210	Pass	30/23	13/13	120 days	18	0/25
Dri-Shield	Protecto Wrap	perforated, woven polyethylene			9	7.5		112 min			50/46 (D822)		1 year	5	14/1
Weathermate / Air-Gard	Dow / Fabrene	perforated, woven polyethylene	Type II	0.01	14.4	7.7				Pass	47/36	50/50 (D2261)	60 days	6	Class A
Prime Wrap	CS Fabric	perforated, woven polyethylene			9	9		112 min			50/46 (D822)		1 year	5	14/1
Barricade Building Wrap	Ludlow	perforated, woven polyethylene			15.5	9					72/35 (D828)		1 year	5	Class A
GreenGuard RainDrop	Pactiv	non-perforated, woven polyolefin	Type I	0.03	14	10	Pass	> 60 min		Pass	56/30	25/41	120 days	15	0/15
Typar	Reemay	non-perforated, non-woven, spun-bonded polypropylene		0.001	2500	11.7		> 10 min	865			30/33	unlimited	13	
PinkWrap	Owens Corning	perforated, woven polypropylene		0.03		14		> 10 min			51/38	37/49	1 year	8	5/20
GreenGuard Classic Wrap	Pactiv	perforated, woven polyolefin	Type I	0.03		15	Pass	60 min		Pass	51/38	37/49	1 year	8	0/30
GreenGuard Value Wrap	Pactiv	perforated, woven polyolefin	Type I	0.03		15	Pass	36 min		Pass	45/29	32/41	1 year	8	0/25
ProWrap	Johns Manville	perforated, non-woven, cross-laminated polyethylene		0.017		18					27/24		1 year	3	5/15
Tyvek CommercialWrap	DuPont	non-perforated, non-woven, spun-bonded polyethylene	Type I	0.001	1500	28 (E96B)	Pass		280	Pass	38/35	12/10	120 days	7	10/10
GreenGuard Ultra Wrap	Pactiv	non-perforated, non-woven, polyolefin	Type I	0.03	600	48	Pass		132	Pass	35/28	14/15	120 days	8	0/15
WrapShield	VaproShield	non-perforated, non-woven, spun-bonded polypropylene	Type I	0.004		50	Pass	> 24 hrs	210	Pass	45/25		120 days	23	10/35
Tyvek StuccoWrap / DrainWrap	DuPont	non-perforated, non-woven, spun-bonded polyethylene	Type I	0.004	300	50 (E96B)	Pass		210	Pass	30/30	7/9	120 days	6	5/25
Tyvek HomeWrap	DuPont	non-perforated, non-woven, spun-bonded polyethylene	Type I	0.007	300	58 (E96B)	Pass		210	Pass	30/30	6/6	120 days	6	5/20
R-Wrap	Ludlow	non-perforated, non-woven polyethylene film			491	59		> 10 min	> 186		32/32		120 days	9	Class A
Two-Ply Super Jumbo Tex 60 Minute	Fortifiber	asphalt-saturated kraft paper, double ply				10		150 min			160/110 (D828)				
Super Jumbo Tex 60 Minute	Fortifiber	asphalt-saturated kraft paper, single ply				11		60 min			70/60 (D828)				
Fortify	Fortifiber	asphalt-saturated kraft paper, single ply	Type I	0.02		11	Pass	60 min		Pass	70/60 (D828)	76/145			35/70
Two-Ply Jumbo Tex	Fortifiber	asphalt-saturated kraft paper, double ply				14		110 min			144/58 (D828)				
Two-Ply Jumbo Tex HD 30 Minute	Fortifiber	asphalt-saturated kraft paper, double ply				15		133 min			144/58 (D828)				
Jumbo Tex HD 30 Minute	Fortifiber	asphalt-saturated kraft paper, single ply				24		30 min			68/31 (D828)				
Jumbo Tex	Fortifiber	asphalt-saturated kraft paper, single ply				29		20 min			70/29 (D828)				

*Test required under ASTM E1677

2.5 Installed Cost Case Study

The Title 24 SLA credit may have value to both the builder and the homeowner. However, the cost associated with designing a WRB to meet SLA credit criteria in addition to providing an effective drainage plane for moisture control can act as a deterrent to the builder. For example, according to the U.S. Department of Energy (2000), a single layer of housewrap typically costs about 50% more for material and labor than building paper ($450 vs. $300 for a 2,500 ft^2 home at the time of the DOE publication). An installed cost case study, including WRB material and labor costs for a hypothetical 2,000 ft^2 home, was conducted to assist Title 24 staff in understanding market factors affecting widespread implementation of the voluntary SLA reduction credit.

Material costs for selected WRBs were estimated by contacting approximately 50 building material distributors in the San Francisco Bay Area. Since the use of double-layer WRB is required by the California Building Code with wood sheathing, the cost analysis included single layer WRB options, two-ply single layer building paper, two layers of building paper, and housewrap with a layer of building paper. For purposes of this study, the outer layer of building paper installed with either the inner layer of building paper or housewrap was considered a 'sacrificial' layer since its key function is to separate the stucco from the inner layer of building paper or housewrap serving as the functional WRB. In this case, a less expensive Grade D paper was considered sufficient and was the basis of material costs for the two-layer options.

Table 2-2 shows prices quoted by Bay Area distributors for a number of WRB products. Material prices for the most common perforated and non-perforated housewraps were approximately $80 and $100 per 1,000 ft^2, respectively. Grade D 60 Minute two-ply building paper was approximately $75 per 1,000 ft^2, while the Grade D 20 Minute single-ply paper was around $24 per 1,000 ft^2. Tape for sealing housewrap seams (estimated at 3 rolls for a 2,000 ft^2 home) added $50 to the installed cost of the housewrap options. Excess material (due to overlapped seams and wrapping across window and door openings) was considered approximately equal for each WRB type. The total WRB square footage estimated for the 2,000 ft^2 home case, including excess material, was 2,500 ft^2.

Installation cost for WRBs was estimated using 2005 Quarter 4 building construction cost data from RSMeans CostWorks. The average labor cost in California is listed at $84 per 1,000 ft^2 of material for housewrap and $91 per 1,000 ft^2 for single-ply building paper. Labor cost to install double-ply building paper was assumed to be the same as single-ply installation.

Table 2-3 summarizes results of the case study. Installed cost of building paper is less expensive than housewrap options. The installation cost of two-ply building paper was considerably lower than two layer WRB options since both plies are installed at the same time. Since it functionally acts as a single layer WRB, it was compared to other single layer options in this analysis. The labor savings when installing two-ply building paper provides a significant incentive for builders to use this option rather than other double-layer options as long as it is interpreted to meet California Building Code requirements, even though it is not functionally equivalent to double-layer WRBs.

Table 2-2: WRB Material Cost in San Francisco Bay Area

Product	Manufacturer	Material	Size (ft)	*Price (per 1,000ft^2)
Rufco-Wrap	Raven Industries	perforated, non-woven, cross-laminated polyethylene	9x195	$74
Vortec	Valeron	perforated, non-woven, cross-laminated polyethylene	5x200	$115
Weathermate	Dow	perforated, woven polyethylene	9x150	$85
Barricade Building Wrap	Ludlow	perforated, woven polyethylene	9x150	$85
GreenGuard RainDrop	Pactiv	non-perforated, woven polyolefin	9x150	$100
Typar	Reemay	non-perforated, non-woven, spun-bonded polypropylene	9x150	$104
GreenGuard Ultra Wrap	Pactiv	non-perforated, non-woven polyolefin	9x150	$118
Tyvek StuccoWrap	DuPont	non-perforated, non-woven, spun-bonded polyethylene	5x200	$151
Tyvek DrainWrap	DuPont	non-perforated, non-woven, spun-bonded polyethylene	9x125	$187
Tyvek HomeWrap	DuPont	non-perforated, non-woven, spun-bonded polyethylene	9x150	$104
Two-Ply Super Jumbo Tex 60 Minute	Fortifiber	asphalt-saturated kraft paper, double ply	3.33x48.6	$75
Super Jumbo Tex 60 Minute	Fortifiber	asphalt-saturated kraft paper, single ply	3.33x97.2	$39
Jumbo Tex	Fortifiber	asphalt-saturated kraft paper, single ply	3.33x150	$24

**Lowest quoted price from Bay Area distributors based on size listed*

Table 2-3: Installed Cost Case Study

Table 2-3a Estimated Cost per 1,000 SF

Cost Component		Single Layer WRB				Double Layer WRB		
	Grade D 20 Minute Building Paper	Grade D 60 Minute Building Paper	Perforated Housewrap	Non-Perforated Housewrap	Grade D 60 Minute 2 Ply Building Paper	Grade D 60/20 Minute Building Paper	Perforated Housewrap/20 Min. Paper	Non-Perforated Housewrap/20 Min. Paper
Materials*	24	39	80	100	75	63	104	124
Labor**	91	91	84	84	91	182	175	175
Tape	-	-	20	20	-	-	20	20
Total	115	130	184	204	166	245	299	319

Table 2-3b Estimated Installed Cost for 2,000 SF Home (Assuming 2,500 SF Materials)

Cost Component		Single Layer WRB				Double Layer WRB		
	Grade D 20 Minute Building Paper	Grade D 60 Minute Building Paper	Perforated Housewrap	Non-Perforated Housewrap	Grade D 60 Minute 2-Ply Building Paper	Grade D 60/20 Minute Building Paper	Perforated Housewrap/20 Min. Paper	Non-Perforated Housewrap/20 Min. Paper
Materials*	60	98	200	250	188	158	260	310
Labor**	228	228	210	210	228	455	438	438
Tape	-	-	50	50	-	-	50	50
Total	288	325	460	510	415	613	748	798
% Increase	-12%	Baseline	42%	57%	28%	Baseline	22%	30%

*Materials Costs Based on San Francisco Bay Area Contractor Quotes
**Labor Costs Based on California Average from RSMeans CostWorks

3.0 Relevance of SLA Reduction Credit

If the Title 24 air leakage reduction credit were to result in a design SLA below 3.0, the 2005 Standard would require that some form of mechanical ventilation be included to provide adequate ventilation, potentially offsetting the energy saving benefit of the credit to the homeowner. This section addresses the potential for required mechanical ventilation associated with the SLA reduction credit as well as factors affecting the practical implementation of the credit.

3.1 Impact on Mechanical Ventilation Requirement

According to Section 3.5 of the 2005 Residential Alternative Calculation Method (ACM) Approval Manual, "The Standard Design does not use mechanical ventilation and assumes infiltration corresponding to a Specific Leakage Area (SLA) of 4.9 for ducted HVAC systems and a SLA of 3.8 for non-ducted HVAC systems."

For a house with a non-ducted HVAC system, the air leakage reduction credit would reduce the design SLA to 3.3. Since mechanical ventilation is only required when design or measured SLA is less than 3.0, the reduction provision is unaffected by this requirement. A house with a ducted HVAC system can qualify for a duct leakage reduction credit in addition to the air leakage reduction credit without field diagnostic testing. Even assuming both of these credits, the resulting SLA will be 3.9, well above the mandatory ventilation requirement of 3.0.

SLA below 3.0 can only be claimed through diagnostic testing, as there are no prescriptive design criteria to build to a specified SLA other than using the default values. Since the SLA reduction credit cannot be claimed through diagnostic testing, there is no way to achieve a level of tightness requiring mechanical ventilation by claiming this credit.

Regardless of the type of HVAC system, the SLA reduction provision has benefits to the builder for all Title 24 design calculations.

3.2 Implementation of Credit

The air leakage reduction credit for qualifying housewraps is designed to promote tight residential construction. The credit will also provide a compliance margin beyond the Title 24 requirements for the baseline design, allowing additional flexibility in other design aspects. It is useful to look at how this credit is affecting current building practices.

Based on information provided by Title 24 compliance software providers and analysts, the performance approach is used to demonstrate compliance with the Title 24 Standards for the majority of residential construction. It is estimated that only about 10% of submittals claim the air leakage reduction credit. Some builders using housewrap do not claim the credit on compliance forms. Other credits are also seldom claimed. Home Energy Rating System (HERS) verification is only used on a small fraction of compliance jobs. Building infiltration testing is only specified on a fraction of the verification cases. Most verification is done as part of California Energy Star homes programs run by utilities. As a result, homes that may in reality be built tighter than an SLA of 3.0 will assume the default SLA value and will not be required to incorporate mechanical ventilation.

While there are energy efficiency benefits to tight construction, several elements of the Title 24 Residential Standard may act as deterrents to building tight, mechanically ventilated homes using air retarding wraps. First, the requirement for blower door testing adds significant cost and compliance risk to the builder with limited perceived benefit. Also, the ACM Manual includes a modeling rule assuming that operable windows or doors will be opened to provide natural ventilation when the air infiltration rate is less than 0.35 air changes per hour (ACH).

For compliance credit of a reduced SLA using the field-verified performance method, Title 24 does not prevent the use of housewraps with a perm rating below 10. However, due to the extremely limited use of infiltration testing in practice, the Title 24 SLA reduction credit provisions under the prescriptive method may be discouraging the use of non-qualifying housewraps with equivalent or possibly superior air leakage performance compared to qualifying housewraps.

4.0 Technical Basis of SLA Reduction Credit

The scope of this section is to analyze the technical basis of the air leakage reduction credit with regard to air leakage reduction and the 10 perm minimum.

4.1 Air Leakage Reduction

Commission staff stated in a 1995 Initial Evaluation Report that field testing was needed in California homes using typical California construction practices to provide data on the energy savings potential of housewrap for Standards compliance (California Energy Commission, 1998). In response to this finding, DuPont sponsored a study that was submitted to the Commission on May 30, 1997, that analyzed the envelope air leakage reduction potential of housewraps in eight new California production houses. Blower door testing indicated that the replacement of two layers of Grade D building paper with a spun-bonded polyolefin housewrap reduced the SLA by an average of 13% (Wilcox, 2001). The reduction in SLA had a direct impact on energy savings as verified subsequently by computer performance results (Nittler 1999). Results of the DuPont study were persuasive to Title 24 staff as a reasonable technical basis for the SLA reduction credit. The allowable credit was set at a somewhat more conservative level than the data suggested since it was a default credit.

4.2 Basis for 10 Perm Minimum in 1998 Title 24 Standard

The minimum permeance requirement to qualify for the SLA credit was a conscious effort by Title 24 staff and committee members representing affected stakeholder groups to minimize unintended consequences associated with low perm WRBs that fully comply with ASTM E1677 requirements. During the deliberations, builders had expressed great concern that the reduction in airflow through a taped housewrap compared to building paper would inhibit the drying associated with air infiltration. Low perm options, from their viewpoint, would create additional and unacceptable risk of building failure. Field data correlating housewrap perm levels and installed performance in California homes was not available to the Title 24 committee at the time of the deliberations.

The Title 24 committee also had concerns that multiple water vapor permeance requirements based on climate zone or other parameters would be confusing and ultimately counter-productive, and determined that a single perm requirement was the most appropriate option. The committee considered a 10 perm minimum requirement to be a reasonable value for taped wraps based on a comparison with the 5 perm minimum requirement for shingle-lapped building paper. The goal was to avoid unintended risks associated with the SLA reduction credit while minimizing the impact on available housewrap products. The 10 perm limit was the consensus decision of the Title 24 committee and was issued for public review and comment. After discussions at public hearings for the California Energy Commission, the 10 perm minimum was adopted in the 1998 Title 24 Residential Standards.

Dow Chemical Company submitted an appeal to the California Energy Commission on October 3, 2003, to revise the 10 perm minimum requirement. Dow appealed to reduce the 10 perm requirement for air retarding wraps to match the 5 perm minimum requirement for building paper. “The Commission requirement for an air retarding wrap with a higher perm rating than required of building paper, which has been used successfully for years in North America, is

unnecessarily restrictive. It prevents air retarding wraps which meet ASTM E1677-95, Standard Specification for an Air Retarder (AR) Material or System for Low-Rise Framed Building Walls, but have perm ratings of between 5 and 10 from claiming the default reduction in Specific Leakage Area (SLA) of 0.50 without diagnostic testing. There is no basis in building science to keep this value at 10 perms," (Greeley, 2003). Dow did not provide published technical data that supported the recommended reduction to 5 perms, and the appeal was denied.

4.3 Technical Basis of 10 Perm Limit for California Homes

Sources interviewed and literature examined for this report did not identify any peer-reviewed publications containing field data on California homes that specifically address WRB permeance and long term wall performance. No qualitative or quantitative field evidence from forensic investigations cited by these sources and from previous interviews in Task 2 of this project (Walker, 2004) identified any causal linkage between perm rating of air retarding wraps and widespread moisture problems in California homes. Without such information, the relevance of the 10 perm limit for California homes is unknown.

Peer-reviewed results of computer modeling, laboratory evaluations, and field investigations have been published related to permeance and drying rates for other areas in North America. In addition, hygrothermal modeling conducted under this project provided some insights about California construction and climate effects. However, as acknowledged in other reports on this topic, "there is a critical need to develop and test building models that subject WRBs to conditions that replicate those in actual service and to develop standards that reflect actual service needs," (Butt, 2005). With that caution in mind, the following paragraphs summarize findings from several recent research efforts that included information of interest on permeance and wall performance.

Hygrothermal modeling using WUFI Pro 4.0 was conducted under Task 3.4 of this contract to compare drying rates of several stucco wall assemblies (Walker, 2006). Simulations did not consider water intrusion events and addressed only vapor diffusion through the wall assemblies. Results in California Climate Zone 16 (considered the most adverse climate zone for managing moisture) showed only a small reduction in moisture content in OSB sheathing as WRB permeance increased. The wall systems in 15 of the 16 Climate Zones generally showed little potential for OSB decay irrespective of wall construction or WRB option. Except for Climate Zone 1 (Arcata weather data), only modest annual hours, if any, with OSB moisture content over 20% were exhibited by any of the wall systems. The report recommended further research to encompass multi-dimensional analyses and other additional hygrothermal phenomena that can ultimately play a more dominant role in wall system performance.

Hygrothermal modeling by Oak Ridge National Laboratory using the ORNL MOISTURE-EXPERT program to simulate stucco construction in Seattle did consider water intrusion events and water penetration. Results of this modeling showed that water penetration is the most critical influence on moisture management of wall systems (Karagiozis, 2002). Water penetration due to wind-driven rain or leaks may be several orders of magnitude greater than vapor diffusion. The simulations included a parametric analysis of single versus double layer building paper. Double layer building paper improved the drying rate for the wall, primarily due to better performing liquid drainage. The additional vapor resistance of the second layer of building paper did not significantly affect the drying performance of the wall. The study concluded that two-layers of weather-resistive building papers play a very important role in a stucco-clad wall system, but vapor diffusion control is only part of what these membranes offer.

After rain penetration, air leakage was identified as the second most important factor in moisture movement in walls. Field data on two test buildings in southern Florida demonstrated the importance of airtightness for purposes of moisture control, and provided the basis for a method for coordinating the design for airtightness with the design for control of vapor diffusion (TenWolde, 1998). Without sufficient airtightness, low perm vapor retarders may have little effect on moisture movement into or out of the wall due to moisture flows from air movement through the wall cavity.

A research program conducted under controlled laboratory conditions in Vancouver, BC, evaluated the relative drying rates of complete wall assemblies, including stucco cladding, housewrap, and building paper (Hazledon, 2001). Drying rates were evaluated based on "calculated permeance" from material properties and "effective permeance" that accounted for both vapor diffusion and air flow through the WRB. Laboratory data on a limited number of wall specimens indicated that drying rates of a wall with stucco cladding and 26 perm single ply housewrap with taped seams were roughly equivalent to similar assemblies with double-ply shingle-lapped Grade D 30 minute building paper.

Research conducted under Task 3.2 of this contract under controlled laboratory conditions in Des Plaines, IL, also evaluated the relative drying rates of four complete wall assemblies with stucco cladding, including higher permeance (>50 perm) housewrap with a second layer of building paper and lower permeance exterior polystyrene insulation with two-layer building paper (Leslie, 2006). No lower permeance housewraps were included in this study. Laboratory data indicated slower drying rates through exterior cladding with exterior insulation compared to higher permeance housewrap. The report recommended further research to develop and evaluate laboratory and field performance test methods for integrated cladding and wall assemblies through voluntary standards development processes such as ASTM. The test methods should be realistic and relevant, supported by field data and validated models.

A laboratory and modeling research program on wall drying in hot and humid climates identified air leakage and point source water intrusion as prime contributors to moisture accumulation in wall systems. The research cites two studies, one that reports air leakage accounting for 6 to 100 times as much moisture transfer as vapor diffusion, and another that concludes that point source water intrusion accounting for 20 times the moisture associated with air infiltration, while air infiltration accounts for 25 times the moisture movement associated with diffused moisture (Boone, 2004). This study also compared drying rates of OSB samples inside WRBs with various perm ratings in a controlled laboratory environment. In addition, it included hygrothermal modeling of wall assemblies with vinyl siding and different WRB options. The study concluded that at laboratory conditions of 75ºF and 55% RH, the breakpoint for promoting drying a wet OSB specimen was between 18 and 24 perms. It also recommended further work in computer modeling, laboratory testing, and field studies designed to study the impact of the drying capability of a wall system and vapor permeable membranes.

Laboratory testing and hygrothermal modeling coupled with field data from a construction site in North Carolina identified a situation during the construction period under which higher perm housewrap can be more effective than lower perm housewrap at transferring condensed moisture from the OSB sheathing to outdoors before it causes moisture distress on the OSB (Weston, 2004). The relevance of this finding to California construction and climate is unknown.

Oak Ridge National Laboratory and ASHRAE are currently working to determine appropriate design permeance levels for buildings in different geographic regions of California. Information based on this effort is expected sometime during 2006.

There appears to be increasing consensus in the building science community about using a double layer WRB to resist liquid water penetration more effectively with stucco cladding. Conversely, optimal water vapor management strategies depend on numerous factors including climate, solar-driven vapor drives, and type of materials. The appropriate range of permeance for a WRB under any specific service condition is still very much a subject of debate among experts (Butt, 2005). Absorbent materials such as stucco and brick may benefit from lower permeance WRBs, but there may be just as many arguments for maximum permeance (Reed, 2004).

Ideally, water vapor from the conditioned side of the WRB would be able to easily pass through the WRB and out of the wall cavity, while water vapor from the exterior would be blocked from entering the wall cavity. However, due to a lack of 'one-way' vapor permeable membranes on the market, the primary direction of water vapor flow must be determined prior to selecting an appropriate design permeance.

The intention of the minimum perm requirement for qualifying products was to promote outward drying of the wall cavity when using air retarding wraps. A higher vapor permeance is desirable to dissipate moisture trapped in the wall cavity or when the water vapor drive is from the conditioned space to the outdoors to prevent the accumulation of water vapor within the wall cavity. However, when the vapor drive acts in the opposite direction, a higher permeance will permit water vapor from the unconditioned space to enter the wall cavity. Aside from infiltration, vapor concentration and temperature gradients are primarily responsible for vapor migration through a building envelope. When stucco cladding gets wet and the sun shines on it, water vapor will be driven into the wall cavity by both a temperature gradient and a concentration gradient. In this event, a lower water vapor permeance is desirable to minimize exterior water vapor penetration into the wall cavity.

The combined vapor permeability of double-layer systems, especially when one layer is installed as an air retarder and the other is just lapped, further complicates the design of walls for optimal vapor permeance. Additionally, stucco coatings and interior surface treatments (paint and wall paper) influence overall air retarder functionality, water vapor permeance, and drying rate of wall assemblies with stucco cladding. WRB permeance is just one factor in the overall wall performance.

5.0 Summary of Results

Key findings regarding the Title 24 SLA reduction credit are summarized below.

- This research effort was not able to identify any peer-reviewed field data or other technical studies that support or refute a specific perm limit in walls with stucco cladding in California homes. The current limit in Title 24 reflects consensus engineering judgment and risk management decisions in the absence of authoritative technical data.

- The 10 perm minimum requirement for the SLA credit was established by consensus to address potential moisture concerns associated with building tighter homes. In the absence of field data relating housewrap permeance to installed performance, the justification for the specific value was based on the Committee's interest in maintaining drying capability equivalent to 5 perm building paper without taped seams. No peer-reviewed field evidence to date in California homes on causes of building failures has identified any linkage between WRB perm rating and widespread moisture problems.

- Moisture loading from water penetration and air infiltration into wall cavities can be orders of magnitude higher than that due to vapor diffusion. Without sufficient airtightness, low perm vapor retarders may have little effect on moisture movement into or out of the wall due to moisture flows from air movement through the wall cavity.

- The SLA credit does not distinguish between E1677 Type I and Type II air retarding wraps, even though only Type I wraps are required to pass a water resistance test. This may be an oversight if the intent of the credit is to ensure acceptable performance as both an air retarder and water-resistive barrier.

- Product data listed in this study showed no significant correlation between air leakage rate and water vapor permeance. The SLA credit excludes WRB options that may provide equivalent or superior air leakage performance in California climates.

- Double-layer WRBs with an airspace for drainage are strongly recommended by building scientists. The lower installation cost of two-ply building paper provides a significant incentive for builders to use this option rather than double-layer options as long as it meets code requirements, even though it is not functionally equivalent to double-layer WRBs. Benefits of the SLA reduction credit alone may not be sufficient to offset this incentive for the builder, potentially reducing the market impact of the SLA reduction credit.

- Since an SLA below 3.0 can only be claimed through diagnostic testing, there is no way to achieve a design level of tightness requiring mechanical ventilation by claiming the default SLA reduction credit. As such, homes that actually have an SLA below 3.0 as constructed with air retarding wraps may not be required to incorporate mechanical ventilation.

- Further research is needed to develop and evaluate laboratory and field performance test methods for integrated cladding and wall assemblies through voluntary standards development processes such as ASTM. The test methods should be realistic and relevant, supported by field data and validated models.

6.0 References

Boone, Kimdolyn et. al, "Wall Drying in Hot and Humid Climates," *Proceedings Symposium on Hot and Humid Climates*, Richardson, TX, May 2004.

Butt, Thomas K., FAIA, "Water Resistance and Vapor Permeance of Weather Resistive Barriers," *Journal of ASTM International, November/December 2005, Vol. 2, No. 10*, www.intres.com/about/pub/WeatherBarriers.pdf, November 2005.

Greeley, David, PE, Dow Chemical, *Recommendation Letter to CEC regarding 10 perm limit*, October 3, 2003.

Hazleden, Donald G., and Paul I. Morris, Ph.D., "The Influence of Design on Drying of Wood-Frame Walls Under Controlled Conditions," in *Proceedings: Performance of Exterior Envelopes of Whole Buildings VIII*, Integration of Building Envelopes, Clearwater Beach, Florida, December 2-7, 2001.

Karagiozis, A.N., *Building Enclosure Hygrothermal Performance Study, Phase 1*, ORNL/TM-2002/89, April 2002.

Leslie, Neil P., *Building Assemblies Laboratory Evaluation Results Task 3.2 Draft Report*, March 2006.

Lstiburek, Joseph, "Problems with Housewraps," Building Science Corporation, www.buildingscience.com/resources/walls/problems_with_housewraps.htm, 2005.

Nittler, Ken, *Computer Performance Results for New Residential Construction*, Presented at CABEC Annual Business Meeting, May 1999.

Reed, Ryan, "Housewrap Felt or Paper: Comparing specs on weather barriers," *Builder News*, www.buildernewsmag.com/viewnews.pl?id=21, May 2004.

RSMeans CostWorks, Reed Construction Data, Software, 2005.

"Summary of Staff Position on Default Compliance Credit for Air Retarding Wrap," California Energy Commission, October 13, 1998.

TenWolde, Anton, Charles G. Carll, Vyto Malinauskas, "Air Pressures in Wood Frame Walls," in *Conference Proceedings: Thermal Performance of the Exterior Envelopes of Buildings VII*, Clearwater Beach, Florida, December 6-10, 1998.

Walker, Christine, Ph.D., Douglas Kosar, *Hygrothermal Modeling of Building Wall Assemblies, Task 3.4 Draft Report*, March 2006.

Walker, Christine, Ph.D., Mike Chimack P.E., and Douglas Kosar, "Database Development of Mold Incidences in California Homes Task 2 Situation Analysis Final Report on Subtask 2.1 Literature Review Summary Report," July 2004.

"Weather-Resistive Barriers: How to select and install housewrap and other types of weather-resistive barriers," U.S. Department of Energy, www.eere.energy.gov/buildings/info/documents/pdfs/28600.pdf, October 2000.

Weston, Theresa A., Ph.D., and Xuaco Pascual, "The Function and Performance of Weather-Resistive Barriers During Building Construction," *Performance of Exterior Envelope of Whole Buildings IX International Conference*, December 5-10, 2004.

Weston, Theresa A., Ph.D., Michel Stachnik, Ph.D., James Waggoner, "Development of a Textured Spun-Bonded Polyolefin Water Barrier for Stucco and EIFS," *ASHRAE Transactions 2001, V. 107, Pt. 1*, 2001.

Wilcox, Bruce and Theresa Weston, "Measured Infiltration Reduction in California Production Houses using Housewrap," in *Proceedings: Performance of Exterior Envelopes of Whole Buildings VIII*, Integration of Building Envelopes, Clearwater Beach, Florida, December 2-7, 2001.