CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Advanced Envelope Assemblies

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team September 2011

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1. Purpose

The 2008 California Building Energy Efficiency Standards offer limited prescriptive and performance options for envelope construction assemblies, and exclude some advanced envelope assemblies that are well established and energy efficient. The purpose of this CASE report is to show the potential energy savings and benefits of including Advanced Wood Framing (AWF) and Insulating Concrete Forms (ICFs) as compliance options in the 2013 California Building Energy Efficiency Standards, and to expand compliance options for Structural Insulated Panels (SIPs).

2. Overview

a. Measure Title	Advanced Envelope Assemblies
b. Description	This measure includes compliance options for three building envelope assembly types, described below, and is applicable to single family new residential construction. **Advanced Wood Framing (AWF**) refers to a set of techniques and practices designed to minimize the amount of wood necessary to build a structurally sound, safe and durable, energy efficient building. Having fewer wood studs reduces the effects of "thermal bridging" and increases the amount of insulation in the wall, resulting in a more energy efficient building envelope. When AWF is chosen as a compliance option in the Standards, the framing factor is reduced to 17%, reflecting the improved energy performance of the wall. HMG recommends Quality Insulation Installation inspection as a prerequisite when using AWF techniques and taking compliance credit. **Insulating Concrete Forms (ICFs)** are concrete forming systems that use stay-in-place panels made from a variety of insulating materials for constructing cast-in-place solid concrete walls. There are three basic types of ICFs: flat wall, waffle-grid and screen-grid. The insulating panels for all three ICF types are most commonly made from expanded polystyrene (EPS) and extruded polystyrene (XPS) rigid insulation boards. Plastic or metal cross-ties separate the insulating panels and provide structural integrity during the pour. The ICF system is modular and stackable with interlocking edges. The materials can be delivered as pre-assembled blocks or as planks that require the flanges and web to be assembled during construction. **Structural Insulated Panels (SIPs)** consist of a foam plastic insulation core securely bonded between two structural facings, to form a structural sandwich panel. The foam core in a SIP performs a structural, insulating and air-sealing function in wall, roof, floor and foundation systems. The most common foam plastic insulations used are expanded polystyrene (EPS), polyisocyanurate (polyiso) and polyurethane. The most common structural facings used are oriented strand board and plywood. Little or no structural framing penetrates the insulation layer resulting in less thermal bridging across the insulation when compared to a framed wall. Panels are typically manufactured at a factory and shipped to the job site.
c. Type of Change	AWF and ICF assemblies are proposed compliance options for the 2013 California Building Energy Efficiency Standards. The measures would modify Joint Appendix 4 to include look-up tables for AWF and ICFs assemblies. The proposed change also includes revision of the look-up table for SIPs assemblies.

d. Energy Benefits	The following energy savings figures were estimated using methodology described in Section 3.2 of this report.
e. Non-Energy Benefits	Non-energy benefits of AWF include reduced materials costs and increased occupant comfort. Benefits of ICFs include increased fire resistance, and increased occupant comfort.

	Electricity Savings (kWh/yr)	Demand Savings (kW)	Natural Gas Savings (Therms/yr)	MTDV Electricity Savings	MTDV Gas Savings
Per Home AWF CZ 1	71	0.00	57	1.33	9.61
Per Home AWF CZ 2	179	0.12	92	7.10	16.20
Per Home AWF CZ 3	77	0.00	71	1.51	12.77
Per Home AWF CZ 4	164	0.12	78	6.23	13.94
Per Home AWF CZ 5	111	0.00	88	2.03	15.34
Per Home AWF CZ 6	66	0.06	41	2.92	7.62
Per Home AWF CZ 7	32	0.04	16	1.87	2.89
Per Home AWF CZ 8	119	0.15	33	5.72	5.92
Per Home AWF CZ 9	211	0.27	43	10.56	7.78
Per Home AWF CZ 10	251	0.35	49	12.85	8.86
Per Home AWF CZ 11	164	0.13	39	6.86	7.02
Per Home AWF CZ 12	72	0.07	39	3.50	6.88
Per Home AWF CZ 13	172	0.41	35	13.45	6.26
Per Home AWF CZ 14	143	0.12	39	5.73	7.07
Per Home AWF CZ 15	395	0.27	7	13.72	1.41
Per Home AWF CZ 16	53	(0.04)	71	0.02	12.56

f. Environmental Impact

Material Increase, (Decrease), or No Change (NC): (All units are lbs/year)

	Mercury	Lead	Copper	Steel	Plastic	Wood
Per Prototype D Building AWF[2]	(NC)	(NC)	(NC)	(NC)	(NC)	(600)
Per Prototype D Building ICF[2]	(NC)	(NC)	(NC)	(NC)	(NC)	(NC)

AWF has a one time savings of approximately 600lbs of lumber.

Water Quantity and Quality Increase, (Decrease), or No Change (NC):

	Water Savings (or Increase) (Gallons/Year)	Mercury Content	Other Contaminants, Specify
Per Prototype D Building AWF[2]	(NC)	(NC)	(NC)
Per Prototype D Building ICF[2]	(NC)	(NC)	(NC)

Air Quality in lbs/Year, Increase, (Decrease), or No Change (NC)[3]:

	CO_2	CO	PM10	NOx	SOx	VOC
Per Prototype D Building AWF	(199)	(0.0791)	(0.0256)	(0.0544)	(0.326)	(NC)
Per Prototype D Building ICF	(193)	(0.0766)	(0.0247)	(0.0526)	(0.316)	(NC)

g. Technology Measures

Measure Availability and Cost:

AWF is an installation technique. Therefore, there are no major manufacturers/suppliers. The measure technique is readily available for framing crew training.

ICF systems are available from at least 30 manufacturers in the United States. These are listed in Appendix Section 7.1. The large number of established ICF manufacturers should easily meet an increased demand for the product.

Useful Life, Persistence and Maintenance:

AWF and ICFs have an expected useful life equal to that of the house itself. For this study, we assume that to be 30 years, assuming alterations and repairs may be performed after that time. Replacement and maintenance are no different than a conventional home.

h. Performance Verification of the Proposed Measure

Verification that the framing meets the definition of AWF, described in Section 5, is proposed as a requirement for AWF credit. This inspection should occur in conjunction with a quality insulation installation (QII) inspection.

<table>
<tr><td>i. Cost Effectiveness</td><td>
Since the AWF measure requires using less lumber, the additional cost is negative (reduction in lumber costs, reduction in framing time and reduction in energy use).
Though ICF materials are more expensive than traditional framing, the reduced energy costs more than offset the additional cost of materials. Average cost effectiveness is shown in the table below. More detail is provided in Section 4.2.
The table below shows the cost-effectiveness of the measure using the LCC methodology defined by the CEC. A negative LCC value indicates that the measure is cost-effective.
<table>
<tr><th>Measure Name</th><th>Additional Cost Per Unit (Relative to Basecase) ($)</th><th>Additional Maintenance Costs (Relative to Basecase) ($)</th><th>Measure Life (Years)</th><th>LCC Per Prototype Building</th></tr>
<tr><td>AWF</td><td>$54</td><td>NC</td><td>30</td><td>$(2,621)</td></tr>
<tr><td>ICF</td><td>$6,036</td><td>NC</td><td>30</td><td>$(11,269)</td></tr>
</table>
The materials, labor, and verification costs are further discussed in sections 3.3.1 and 4.2 of this report.
</td></tr>
<tr><td>j. Analysis Tools</td><td>Energy savings can be quantified using CALRES. The wall, roof, and floor assembly libraries will need to contain assemblies listed in the proposed look-up tables for AWF, ICFs, and SIPs, included in Section 5 of this report.</td></tr>
<tr><td>k. Relationship to Other Measures</td><td>AWF requires QII as a prerequisite. Otherwise, this measure does not relate to any other measures.</td></tr>
</table>

3. Methodology

This section outlines the methodology used to determine u-factors and heat capacities for the proposed assemblies, estimated energy and cost savings, and calculate lifecycle costs.

3.1 Look-up Tables: U-factor and Heat Capacity Calculations

In order to propose advanced envelope assemblies as compliance options in the 2013 California Building Energy Efficiency Standards, HMG established U-factors for AWF and U-factors and heat capacity for ICF assembly types, and created look-up tables for Joint Appendix 4 (JA4). We also calculated U-factors for additions to the SIPS look-up table. The methodology used to calculate the U-factors and heat capacities for each assembly type are described in this section.

3.1.1 Advanced Wood Framing (AWF)

U-factor values for AWF were calculated using EZFRAME effective U-factor calculation software (CEC, V 2.0B). This approach is consistent with the parallel heat flow calculation method used to calculate the U-factors in the look-up tables for traditional wood framing, and mentioned in the 2008 Joint Appendices..

The AWF framing factor used in the calculation was 17% for 24-inch on-center framing. This value is based on the 2008 Title 24 framing factors of 22% for 24-inch on-center framing with a 5% framing factor reduction for advanced wood framing. The 5% framing factor reduction is based on a framing factor calculator developed by Jon Leber[1] and modified by HMG to account for AWF practices.

The proposed "whole assembly" AWF framing factors mentioned above were used to generate input for modeling equivalent "stud-only" assemblies in EZFRAME. The EZFRAME stud spacing necessary to simulate a framing factor equivalent to the "whole assembly" framing factor was determined with the following equation:

$$S = (FW/FF) \times 100$$

Where:

FW = frame member (stud) width

FF = framing factor

S= frame member (stud) spacing

EZFRAME adds a 5% framing factor to U-factor calculations for constructed assemblies to account for non-stud framing at windows, doors, top and sill plates, etc. The framing member spacing calculation inputs were adjusted to account for this.

The advanced framing techniques included in the framing factor calculation include reduced framing at windows and doors, exterior/interior wall intersections, and exterior corners. The modeled construction assemblies assume an exterior air film of R-0.17, a 7/8 inch layer of stucco of R-0.18, building paper of R-0.06, continuous insulation (where applicable), cavity insulation in the faming layer, ½ inch gypsum board of R-0.45, and an interior air film of R-0.68. All cavity

[1] Leber, Jon. CEC. 20071010SteelWallZonalRes.xls. October 2007

R-values are consistent with those calculated for HMG's Increased Insulation Codes and Standards Enhancement (CASE) topic. All framing members were modeled at 1.5" in width and depths corresponding to the following nominal sizes:

2x6: 5.5"

2x8: 7.25"

2x10: 9.25"

2x12: 11.25"

3.1.2 Insulating Concrete Forms (ICF)

U-factors for ICF assemblies were calculated using the one dimensional calculation method documented in the 2007 ASHRAE Handbook of HVAC Applications[2]. The calculations assume an exterior air film of R-0.17, a 7/8 inch layer of stucco of R-0.18, building paper of R-0.06, an exterior insulating form of varying resistance, a concrete core of varying thickness at R-0.11 per inch, an interior insulating form of varying resistance, and an interior air film of R-0.68. The R-value of the cement/EPC compound is assumed to be R-3.0 per inch, the XPS insulation assumed to be R-5.0 per inch, and the polyurethane assumed to be aged and dried in 1.5", 2.0", and 4.5" thickness, with the performance values taken from the 2009 ASHRAE Handbook of Fundamentals.

Unlike the flat ICF types, which have a solid concrete core with consistent thickness, the waffle grid and screen grid ICF types utilize vertical and horizontal concrete cores that form waffle and screen grid patterns. The effect of this is that the insulating form is thicker in the areas where there is a void between the vertical and horizontal concrete cores. The approach to account for the varying thickness of the concrete core and insulating form is to calculate an effective concrete core thickness and effective insulation thickness and use these revised values in the one dimensional U-factor and heat capacity calculations.

The effective concrete core thickness and effective insulation thickness calculations assume the standard dimensional requirements for cores and webs in waffle and screen grid ICF walls obtained from Table 2.1 of the Prescriptive Method for Insulating Concrete Forms for Residential Construction, 2nd Edition. The relevant components of the cores and webs include the horizontal/vertical core width and thickness, the concrete web thickness, and spacing between vertical and horizontal cores. These dimensions vary slightly for the three types of waffle and screen grid ICF types as shown below in Figure 1.

ICF Type	Min Width of Vertical Core (W) inches	Min. Thickness of Vertical Core (T)	Max Spacing of Vertical Cores	Min Width of Horizontal Core (W)	Min. Thickness of Horizontal Core (T)	Max Spacing of Horizontal Cores	Min. Concrete Web Thickness
Waffle 6"	6.25	5.00	12.00	6.25	5.00	16.00	2
Waffle 8"	7.00	7.00	12.00	7.00	7.00	16.00	2
Screen 6"	5.50	5.50	12.00	5.50	5.50	12.00	n/a

Figure 1: ICF Dimensions

[2] 2007 ASHRAE HVAC Applications Chapter 43.4

Figure 2 shows the calculated effective concrete thickness and additional insulation attributed to the web or void in concrete core.

ICF System	Nominal Thickness	Calculated Effective Concrete Thickness (inches)	Calculated Effective Additional Insulation (inches)
Waffle 6"	6"	5.01	0.99
Waffle 8"	8"	5.83	2.17
Screen 6"	6"	4.26	1.74

Figure 2: ICF Effective Thickness

3.1.3 Structurally Insulated Panels (SIPS)

The U-factors for SIP roofs/ceilings, walls, and floors were calculated using the parallel path method documented in the 2005 ASHRAE Handbook of Fundamentals.

Roof/ceiling assemblies assume an exterior air film of R-0.17, asphalt shingles of R-0.44, building paper of R-0.06, 7/16 inch of OSB of R-0.69, rigid insulation of varying R-values per inch, another layer of OSB, ½ inch gypsum board of R-0.45, and an interior air film of R-0.62. If an addition layer of insulation is used, this may be installed on either the interior or exterior of the SIPS panel assembly.

Wall assemblies assume an exterior air film of R-0.17, a 7/8 inch layer of stucco of R-0.18, building paper of R-0.06, 7/16 inch of OSB of R-0.44, insulation at carrying R-values (as specified), 7/16 inch of OSB of R-0.44, ½ inch gypsum board of R-0.45, and in interior air film of R-0.68. A framing factor of 13 percent is assumed for wood spacers and 7 percent for the OSB spline system. Framing includes the sill plate, the header and framing around windows and doors.

SIP floor assemblies assume an exterior air film of R-0.17, a vented crawlspace of R-6, 7/16 inch of OSB at R-0.44, framing factor of 2, 7/16 inch of OSB, carpet and pad of R-2.08 and an interior air film of R-0.92.

3.2 Energy Savings

The methodologies and assumptions used to calculate projected energy savings per home are described in this section.

3.2.1 Building Prototype

To assess the energy savings, demand costs, and environmental impacts HMG used the 2,700 square foot, two-story Prototype D building, pictured in Figure 4-11 of the Residential ACM Manual. HMG also requested a file from the California Energy Commission to confirm the dimensions and specification of the Prototype D building. For consistency with that model, wall areas and 20% fenestration were equally distributed across building facades.

3.2.2 Energy Modeling

Advanced Wood Framing (AWF)

HMG conducted energy analysis for all sixteen climate zones (CZs) using CALRES with 2013 weather files and TDV values. All simulation runs for advanced wall framing included 2x6, 24-inch on-center framing with a reduced framing factor of 17% and QII. We simulated cavity insulation values ranging from R-19 to R-29 in a 6-inch cavity, per research and recommendations from the Increased Insulation CASE topic.[3] Wall framing and cavity insulation values were the only variations from the 2008 prescriptive standard used at base case in each climate zone.

Insulating Concrete Forms (ICFs)

HMG conducted energy analysis using U-factors from the look-up tables in six representative climate zones (CZs). Because the 2008 code compliance software was not yet available, HMG used EnergyPro 4 to conduct the initial energy analysis. This analysis utilized 2008 weather files and TDV values.

The climate zones were selected based on data from the Construction Industry Research Board (CIRB) reporting new single family construction starts in 2008 and 2009, and assuming that each climate zone is representative of one or more similar climate zones. CIRB data reported the majority of new single family construction occurring in climate zones 4, 8, 10, 13, 14 and 16, as described below.

The only variation from the base case to the proposed case in each of the representative climate zones was the u-factor of the wall assembly. Because 2008 code compliance software does not allow for modeling of custom wall assemblies, we manipulated the assemblies available in the software to match the u-factors of the advanced wood framing and ICF assemblies

3.3 Cost-effectiveness

HMG determined cost effectiveness through collection of costs estimates for materials and labor for advanced wood framing and insulating concrete forms, as compared to traditional wood frame construction and use of LCC Methodology prepared for the CEC by AEC.[4] Cost collection and LCC methodology are discussed in this section.

3.3.1 Cost Data Collection

Cost data collection was achieved through a combination of contractor/builder, HERS Rater estimates, and R.S. Means data, described in more detail below.

Advanced Wood Framing (AWF)

HMG used R.S. Means cost data for 2x4 and 2x6 framing, as well as all cavity insulation costs. To translate the costs for 16-inch on center framing to 24-inch on-center framing, HMG used

[3] Heschong Mahone Group, "Increased Insulation: 2013 Building Energy Efficiency Standards," July 2011.

4 Architectural Energy Corporation, Life Cycle Cost Methodology 2008 California Building Energy Efficiency Standards, October 21, 2005.

ratios consistent with the change in framing factor to reduce the lumber costs and increase insulation costs.

Though cavity insulation values can be reached with multiple types of insulation, the assumed insulation types for the purposes of this study are shown in Figure 3 below.

Nominal Framing Size	Cavity Insulation R-value	
2x4	R-11	R-11 batt
2x4	R-13	R-13 batt
2x4	R-15	R-15 batt
2x4	R-17	3" med-density foam
2x6	R-19	R-19 batt
2x6	R-21[3]	R-21 batt
2x6	R-24[5]	2" med-density foam, plus R-13 batt
2x6	R-26[5]	2" med-density foam, plus R-15 batt
2x6	R-29[5]	5" med-density foam

Figure 3: Cavity Insulation Type Assumptions

A few cavity insulation costs were not available in R.S. Means. For high density R-21 batt insulation, we divided the cost of high density R-15 insulation by 15 and multiplied by 21 to estimate the cost of an R-21 high density batt insulation. For flash and batt insulation, the cost of two inches of medium density foam and the cost of batt insulation to fill the remainder of the cavity, both from R.S. Means, were added together.

HMG contacted several HERS Raters with experience conducting Quality Insulation Installation (QII) inspections to request estimates on verification of advanced wood framing techniques. Each HERS Rater was asked for a quote for QII inspection on a single family home, as well as the additional charge for verification of AWF techniques described in the Overview Measure Description section of this report. Because QII is recommended as a prerequisite for AWF credit, only the incremental cost of adding AWF verification is included in the total measure cost difference form traditional wood framing.

3.3.2 Lifecycle Cost Calculation

HMG utilized 2008 and 2013 Life Cycle Cost Methodology, as available to analyze cost effectiveness of AWF and ICF assemblies.

Advanced Wood Framing (AWF)

HMG calculated lifecycle cost analysis using methodology explained in the California Energy Commission report Life Cycle Cost Methodology 2013 California Building Energy Efficiency Standards, written by Architectural Energy Corporation, using the following equation:

$$\Delta LCC = \text{Cost Premium} - \text{Present Value of Energy Savings}$$

$$\Delta LCC = \Delta C - (PVTDV\text{-}E * \Delta TDVE + PVTDV\text{-}G * \Delta TDVG)$$

Where:

ΔLCC change in life-cycle cost

ΔC cost premium associated with the measure, relative to the base case

PVTDV-E present value of a TDV unit of electricity

PVTDV-G present value of a TDV unit of gas

$\Delta TDVE$ TDV of electricity

$\Delta TDVG$ TDV of gas

We used a 30-year lifecycle as per the LCC methodology for all residential measures.

LCC calculations were completed for each wall assembly in all sixteen (16) climate zones.

Insulating Concrete Forms (ICFs)

HMG calculated lifecycle cost analysis using methodology explained in the California Energy Commission report *Life Cycle Cost Methodology 2008 California Building Energy Efficiency Standards*, written by Architectural Energy Corporation, using the following equation:

$$\Delta LCC = \Delta C - (PV_{TDV} * \Delta TDV)$$

Where:

ΔLCC change in lifecycle cost, ($/sqft)

ΔC cost premium associated with the measure, ($/sqft)

PV_{TDV} present value of a TDV unit (30-year), ($)

ΔTDV TDV energy savings

We used a 30-year lifecycle as per the LCC methodology for residential measures. LCC calculations were completed for the Prototype D building, in all six (6) climate zones analyzed. This provided a cost effectiveness range.

Because 2005 compliance software was used to run the energy analysis for advanced envelope measures, HMG used the multipliers in *Table 4 - TDV Net Present Value 2008$/kBtu for Climate Zones* in the above mentioned California Energy Commission for translation into 2008 TDV energy values.

3.4 Environmental Impacts

Environmental impacts were calculated for the Prototype D building for each assembly type, as compared to the traditionally framed Prototype D building. HMG used emissions factors provided by the Energy Commission, listed in Figure 4.

	NOX	SOX	CO	PM10	CO2
Pounds per MWh	0.158	0.948	0.230	0.074	578.960
Pounds per mmbtu	0.099	0.067	0.030	0.010	115.000

Figure 4: 2013 Emissions Factors

Wood savings for AWF were calculated by a savings in the number of 2x6 studs used. Framing plans showed a reduction from 211 studs in conventional framing to 181 using AWF techniques. 30 fewer 10ft studs, at 2lbs per board foot[5], equals 600lbs of savings per home.

[5] http://www.engineersedge.com/commercial_lumber_sizes.htm

4. Analysis and Results

This section describes calculated energy and cost savings associated with AWF and ICFs.

4.1 Energy Savings

HMG estimated site, peak and TDV savings, as described in the sections below, by assembly type and climate zone. The savings are predicted based on lower wall assembly U-factors, as a result of reduced thermal bridging across studs and increased insulation to wall area ratio.

TDV energy savings are reported in Figure 5 for AWF and Figure 6**Error! Reference source not found.** for ICF assemblies. The savings estimates are compared to each climate zone's standard prototype D building 2008 vintage. In climate zones where the 2008 prescriptive standard is R-21, the cells for R-19 insulation are intentionally left blank. Climate Zone 10 shows the highest potential for TDV energy savings from AWF and ICF framing techniques compared to conventional stick framing.

Climate Zone	Cavity Wall Insulation Value				
	R-19	**R-21**	**R-24**	**R-26**	**R-29**
1		4.04	4.91	5.38	5.97
2	8.91	9.56	10.34	10.77	11.31
3	5.47	5.83	6.25	6.42	6.69
4	7.71	8.27	8.94	9.3	9.77
5	6.58	7.04	7.59	7.9	8.27
6	4.01	4.26	4.55	4.71	4.89
7	1.84	1.92	2.02	2.08	2.13
8	4.48	4.77	5.1	5.3	5.53
9	6.99	7.51	8.1	8.44	8.83
10	8.36	9.0	10.42	10.83	11.32
11	5.2	6.28	7.54	8.27	9.14
12	3.87	4.68	5.65	6.21	6.86
13	7.47	8.48	9.65	10.34	11.13
14		4.85	6.11	6.82	7.69
15		5.77	7.26	8.14	9.12
16		4.78	5.86	6.46	7.21

Figure 5: TDV Energy Savings AWF

Climate Zone	4" flat core 2" EPS each side	8" flat core 2.5" EPS each side	8" flat core 2.5" XPS each side	10" flat core 4.5" polyurethane each side
4	4.44	5.68	6.64	7.99
8	3.28	4.18	4.83	5.78
10	5.78	7.41	8.55	10.3
13	2.65	4.74	6.28	8.63
14	2.19	4.71	6.57	9.42
16	2.62	5.65	7.84	11.21

Figure 6: TDV Energy Savings ICF

Figure 7 and Figure 8 show the annual kWh, kW, and Therm savings estimated through the CALRES runs for the minimum AWF credit in each climate zone, and through EnergyPro for ICFs in representative climate zones.

Climate Zone	Total kWh	kWh Saved	Total kW	kW Saved	Total Therms	Therms Saved
1	525	71	0.02	0.00	586	57
2	712	179	0.68	0.12	529	92
3	461	77	0.50	0.00	393	71
4	957	164	1.52	0.12	454	78
5	364	111	0.02	0.00	448	88
6	820	66	1.36	0.06	313	41
7	585	32	1.05	0.04	267	16
8	1,458	119	2.36	0.15	295	33
9	2,178	211	3.65	0.27	321	43
10	2,547	251	4.15	0.35	331	49
11	4,496	164	5.31	0.13	505	39
12	2,212	72	3.39	0.07	512	39
13	4,778	172	5.33	0.41	475	35
14	4,124	143	5.07	0.12	476	39
15	10,274	395	7.78	0.27	247	7
16	2,157	53	3.04	-0.04	735	71

Figure 7: AWF Site Energy Modeling Results

Climate Zone	Case Description	Wall U-factor	Annual kWh Use	Annual kWh Savings
4	4" flat core 2" EPS each side	0.058	293	118
4	8" flat core 2.5" EPS each side	0.046	260	151
4	8" flat core 2.5" XPS each side	0.036	232	179
4	10" flat core 4.5" polyurethane each side	0.022	198	213
8	4" flat core 2" EPS each side	0.058	602	165
8	8" flat core 2.5" EPS each side	0.046	558	209
8	8" flat core 2.5" XPS each side	0.036	526	241
8	10" flat core 4.5" polyurethane each side	0.022	480	287
10	4" flat core 2" EPS each side	0.058	1,886	419
10	8" flat core 2.5" EPS each side	0.046	1,743	562
10	8" flat core 2.5" XPS each side	0.036	1,659	646
10	10" flat core 4.5" polyurethane each side	0.022	1,528	777
13	4" flat core 2" EPS each side	0.058	3,576	212
13	8" flat core 2.5" EPS each side	0.046	3,411	377
13	8" flat core 2.5" XPS each side	0.036	3,289	499
13	10" flat core 4.5" polyurethane each side	0.022	3,102	686
14	4" flat core 2" EPS each side	0.058	3,414	155
14	8" flat core 2.5" EPS each side	0.046	3,239	330
14	8" flat core 2.5" XPS each side	0.036	3,110	459
14	10" flat core 4.5" polyurethane each side	0.022	2,909	660
16	4" flat core 2" EPS each side	0.058	1,324	65
16	8" flat core 2.5" EPS each side	0.046	1,254	135
16	8" flat core 2.5" XPS each side	0.036	1,204	185
16	10" flat core 4.5" polyurethane each side	0.022	1,130	259

Figure 8: ICF Site Energy Modeling Results

4.2 Cost-effectiveness

4.2.1 Advanced Wood Framing

HMG quantified the costs for all aspects of advanced wood framing practice: labor, materials, inspection and building energy use. In each category, advanced wood framing provides savings (has lower costs) than conventional wood framing. Therefore, advanced wood framing is cost effective compared to conventional framing. Figure 9 shows the cost effectiveness of AWF. The biggest contribution to savings is due to the energy savings realized by reducing thermal bridging and increasing envelope overall U-factor. While labor savings are reported (and supported by the US Department of Energy) to be less, HMG expects each contractor to undergo a period of retraining in order to adjust to new framing practices; this adjustment will increase the cost of labor in the short term, however the eventual savings realized by contractors once the framing crew is effectively trained will provide a net savings (in labor costs) for contractors over the long term. The cost of retraining is not included in the cost analysis in this report.

A breakdown of costs is included in the appendices. The incremental cost difference is illustrated in Figure 9.

	CZ 2-10	CZ 11-13	CZ 1, 14-16
R-19	$498.08	($645.44)	($1,441.27)
R-21[3]	$1,378.80	$235.28	($560.55)
R-24[5]	$3,532.07	$2,388.55	$1,592.72
R-26[5]	$3,947.92	$2,804.40	$2,008.57
R-29[5]	$6,928.45	$5,784.93	$4,989.10

Figure 9: Incremental Cost of AWF over 2008 Base Case

Though cost effectiveness is not a requirement for inclusion of compliance options in the Building Energy Efficiency Standards, HMG calculated life cycle cost analysis with 2013 methodology described in section 3.3.2. The results are shown in Figure 10. Negative numbers indicate cost-effectiveness.

In climate zones 1 and 11 through 16, AWF technique applied to the 2008 prescriptive standard wall assembly is cost effective. This is true because AWF results in a construction cost reduction. In climate zones 2 through 10 - where the current prescriptive standard of R-13 cavity insulation only requires 4-inch framing - it is cost-effective to upgrade to 6-inch AWF with R-19 cavity insulation. In most climate zones, it is cost affective to upgrade to wall with R-26 (flash and batt) cavity insulation, and use of AWF techniques.

Climate Zone	Cavity Wall Insulation Value				
	R-19	R-21	R-24	R-26	R-29
1		($2,449.69)	($703.23)	($507.15)	$2,197.49
2	($3,668.30)	($3,091.53)	($1,302.99)	($1,088.21)	$1,639.81
3	($2,059.73)	($1,347.35)	$609.52	$945.88	$3,800.16
4	($3,107.18)	($2,488.32)	($648.34)	($400.83)	$2,359.93
5	($2,578.78)	($1,913.16)	($17.07)	$253.82	$3,061.34
6	($1,377.03)	($613.21)	$1,404.45	$1,745.49	$4,641.85
7	($362.32)	$480.99	$2,587.50	$2,975.30	$5,932.45
8	($1,596.80)	($851.69)	$1,147.27	$1,469.60	$4,342.58
9	($2,770.50)	($2,132.94)	($255.55)	$1.32	$2,799.48
10	($3,411.12)	($2,829.67)	($1,340.40)	($1,116.27)	$1,635.14
11	($3,077.00)	($2,701.30)	($1,137.21)	($1,062.71)	$1,511.00
12	($2,455.08)	($1,953.13)	($253.43)	($99.44)	$2,577.15
13	($4,138.47)	($3,730.03)	($2,123.86)	($2,030.66)	$580.46
14		($2,828.45)	($1,264.36)	($1,180.51)	$1,393.20
15		($3,258.65)	($1,802.11)	($1,797.75)	$724.52
16		($2,795.72)	($1,147.46)	($1,012.17)	$1,617.65

Figure 10: Life-cycle cost analysis for advanced wall framing

4.2.2 Insulated Concrete Forms (ICF)

To calculate the cost effectiveness of ICF wall assemblies, HMG reviewed numerous quantitative studies of residential construction projects where ICF assemblies were installed. The most recent study found that ICF assemblies cost $6.37/sf of wall area to install (this cost includes labor cost estimates)[6]. ICF assemblies cost to install (labor and materials) have not changed much in the past decade; previous studies found similar results: $6.65/sf wall area (for a 2,775 sf single family 1 story home)[7] and $5.95/sf wall area (for 1-story/2-story mix 3,895 sf)[8]. Using the most recent figure, the comparison between ICF and conventional wood framing is summarized in Figure 11. ICF is noticeably more expensive to install, but clearly less expensive to operate (based on TDV energy simulations in EnergyPro).

<table>
<tr><th></th><th>Conventional</th><th>ICF</th><th>Savings</th></tr>
<tr><td>Lumber</td><td>$ 7,113</td><td rowspan="2">$ 17,326.40</td><td rowspan="2">$ (6,013.40)</td></tr>
<tr><td>Labor</td><td>$ 4,200</td></tr>
<tr><td>Energy</td><td>$ 20,426</td><td>$3,142.74</td><td>$17,282.82</td></tr>
</table>

Figure 11: Cost Effectiveness ICF, Conventional Framing Comparison

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6 *Insulating Concrete Forms Construction Cost Analysis*, NAHB Research Center, Inc. 2004

7 *Insulating Concrete Forms: Installed Cost and Acoustic Performance*, HUD, March 1999.

8 *Insulating Concrete Forms for Residential Construction – Demonstration Homes*, HUD, July 1997

5. Recommended Language for the Standards Document, ACM Manuals, and the Reference Appendices

There will be no necessary changes to the standards language for inclusion of Advanced Envelope Assemblies as compliance options. The compliance options would require the addition of JA4 look-up tables for Advanced Wall Framing, and ICFs, and addition to the 2008 JA4 look-up table for SIPS. The proposed table additions and replacements are shown in Figure 12 through Figure 16 below.

				Rated R-value of Continuous Insulation [1] Cost Per SF							
				R-0	R-2	R-4	R-6	R-7	R-8	R-10	R-14
Spacing	Nominal Framing Size	Cavity Insulation R-value[2]		A	B	C	D	E	F	G	H
24 in. OC	Any	R-0	34	0.381	0.213	0.149	0.114	0.103	0.093	0.078	0.060
	2x6	R-19	39	0.065	0.056	0.049	0.044	0.042	0.040	0.037	0.032
	2x6	R-21[3]	40	0.061	0.053	0.047	0.042	0.040	0.039	0.036	0.031
	2x6	R-24[5]	41	0.057	0.049	0.044	0.039	0.038	0.036	0.033	0.029
	2x6	R-26[5]	42	0.054	0.047	0.042	0.038	0.036	0.035	0.032	0.028
	2x6	R-29[5]	43	0.052	0.044	0.040	0.036	0.034	0.033	0.030	0.027
	2x8	R-19	44	0.060	0.053	0.047	0.043	0.041	0.039	0.036	0.032
	2x8	R-22	45	0.055	0.048	0.044	0.040	0.038	0.036	0.034	0.030
	2x8	R-25	46	0.051	0.045	0.041	0.037	0.036	0.034	0.032	0.028
	2x8	R-27[4]	47	0.049	0.043	0.039	0.036	0.034	0.033	0.031	0.027
	2x8	R-30[3]	48	0.046	0.041	0.037	0.034	0.032	0.031	0.029	0.026
	2x8	R-33[5]	49	0.044	0.039	0.035	0.032	0.031	0.030	0.028	0.025
	2x8	R-35[5]	50	0.042	0.037	0.034	0.031	0.030	0.029	0.027	0.024
	2x8	R-37[5]	51	0.041	0.036	0.033	0.030	0.029	0.028	0.026	0.023
	2x10	R-30	52	0.042	0.038	0.035	0.032	0.031	0.030	0.028	0.025
	2x10	R-33	53	0.04	0.036	0.033	0.031	0.03	0.029	0.027	0.024
	2x10	R-36	54	0.038	0.034	0.032	0.029	0.028	0.027	0.026	0.023
	2x10	R-38	55	0.037	0.033	0.031	0.028	0.027	0.027	0.025	0.022
	2x10	R-41[5]	56	0.035	0.032	0.029	0.027	0.026	0.026	0.024	0.022
	2x10	R-43[5]	57	0.035	0.031	0.029	0.027	0.026	0.025	0.023	0.021
	2x10	R-45[5]	58	0.034	0.030	0.028	0.026	0.025	0.024	0.023	0.021
	2x10	R-47[5]	59	0.033	0.030	0.028	0.025	0.025	0.024	0.022	0.020
	2x10	R-49[5]	60	0.032	0.029	0.027	0.025	0.024	0.023	0.022	0.020
	2x12	R-38	61	0.034	0.032	0.029	0.027	0.026	0.026	0.024	0.022
	2x12	R-41[4]	62	0.033	0.030	0.028	0.026	0.025	0.025	0.023	0.021
	2x12	R-44[5]	63	0.032	0.029	0.027	0.025	0.024	0.024	0.022	0.020
	2x12	R-47[5]	64	0.031	0.028	0.026	0.024	0.024	0.023	0.022	0.020
	2x12	R-49[5]	65	0.030	0.027	0.025	0.024	0.023	0.022	0.021	0.019
	2x12	R-52[5]	66	0.029	0.027	0.025	0.023	0.022	0.022	0.021	0.019

Notes

1. Continuous insulation may be installed on either the interior or the exterior of the wall, or both.
2. R-values can be met using one or multiple insulation types within a cavity.
   Open cell spray-in insulation shall fill the entire cavity, when used independent of closed cell insulation.
   When used alone or in combination with another insulation type, closed cell insulation must be applied as a first layer and need not fill tl
   The R-value of open cell insulation shall be 3.6 per inch thickness. Cellulose shall have a binder to prevent sagging.
   The R-value of closed cell insulation shall be 5.7 per inch thickness.
3. Requires high-density batt insulation or closed cell insulation. Closed cell insulation may be used in combination with batt or spray-in cellulose ir
4. Requires spray-in insulation (open or closed cell). Closed cell insulation may be used in combination with batt or spray-in cellulose insulation to
5. Requires use of closed cell insulation. May be used in combination with batt or spray-in cellulose insulation to reach cavity insulation r-value

Figure 12: Table and notes to replace Table 4.3.1 in JA4-25

To qualify for the AWF compliance credit in Title 24, verification of Quality Insulation Installation (QII) by a HERS rater is required, and all of the following practices must be followed:

- 2 x 6 at 24-inch on-center wall framing[9]
- Precise engineering of headers on load-bearing walls
- 2 x 4 headers on non-load-bearing walls
- Eliminate cripple studs at window and door openings less than four (4) feet in width
- Align window/door openings with standard stud spacing[10]
- Two-stud corners[11] instead of three (3)-stud corners
- Ladder block where interior partitions intersect exterior walls, instead of three (3)-stud channels
- Eliminate unnecessary double floor joists underneath non-bearing walls
- Use metal let-in T-bracing on non-shear walls
- Include detailed framing plans and elevations on permit set

[9] Although 2 x 4 o.c. framing is allowed structurally when engineered, for T24 compliance credit, 2 x 6 framing is required.

[10] The king stud, on at least one side of the window/door opening, must take the place of an on-layout AWF stud

[11] Nailing for interior gypsum board can be accomplished with drywall clips, 1x nailer strip, recycled plastic nailing strip. Drywall clips reduce the potential for drywall cracking.

Table 4.x.x - Properties of Insulating Concrete Forms

Insulation Type	Insulation Thickness Per Side (Total R-value)	Performance Factor		Flat[1]					Waffle Grid[2]		Screen Grid[2]
				Concrete Core Thickness (inches)							
				4"	6"	8"	10"	12"	6"	8"	6"
				A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
EPS[3]	2.0 (15.4)	U-factor		0.058	0.057	0.056	0.055	0.055	0.045	0.036	0.039
		C-factor	**1**								
		HC		12.20	17.00	21.80	26.60	31.40	13.90	15.87	12.10
	2.25 (18.9)	U-factor		0.052	0.051	0.051	0.050	0.050	0.041	0.033	0.036
		C-factor	**2**								
		HC		12.22	17.02	21.82	26.62	31.42	13.92	15.89	12.11
	2.5 (19.25)	U-factor		0.047	0.047	0.046	0.046	0.045	0.038	0.031	0.034
		C-factor	**3**								
		HC		12.24	17.04	21.84	26.64	31.44	13.94	15.91	12.13
	2.625 (20.2)	U-factor		0.045	0.045	0.044	0.044	0.043	0.037	0.030	0.033
		C-factor	**4**								
		HC		12.25	17.05	21.85	26.65	31.45	13.95	15.92	12.14
	2.75 (21.2)	U-factor		0.043	0.043	0.042	0.042	0.042	0.036	0.030	0.032
		C-factor	**5**								
		HC		12.26	17.06	21.86	26.66	31.46	13.96	15.92	12.15
	3.0 (23.1)	U-factor		0.040	0.040	0.039	0.039	0.039	0.033	0.028	0.030
		C-factor	**6**								
		HC		12.27	17.07	21.87	26.67	31.47	13.98	15.94	12.17
	3.5 (27.0)	U-factor		0.035	0.034	0.034	0.034	0.034	0.030	0.025	0.027
		C-factor	**7**								
		HC		12.31	17.11	21.91	26.71	31.51	14.01	15.98	12.21
	4.0 (30.8)	U-factor		0.031	0.030	0.030	0.030	0.030	0.027	0.023	0.024
		C-factor	**8**								
		HC		12.35	17.15	21.95	26.75	31.55	14.05	16.02	12.24
XPS	2.0 (20.0)	U-factor		0.045	0.045	0.045	0.044	0.044	NA	NA	NA
		C-factor	**9**								
		HC		12.29	17.09	21.89	26.69	31.49	NA	NA	NA
	2.5 (25.0)	U-factor		0.037	0.037	0.036	0.036	0.036	NA	NA	NA
		C-factor	**10**								
		HC		12.35	17.15	21.95	26.75	31.55	NA	NA	NA
	2.625 (26.3)	U-factor		0.035	0.035	0.035	0.035	0.034	NA	NA	NA
		C-factor	**11**								
		HC		12.36	17.16	21.96	26.76	31.56	NA	NA	NA
	2.75 (27.5)	U-factor		0.034	0.034	0.033	0.033	0.033	NA	NA	NA
		C-factor	**12**								
		HC		12.38	17.18	21.98	26.78	31.58	NA	NA	NA
	3.0 (30.0)	U-factor		0.031	0.031	0.031	0.031	0.030	NA	NA	NA
		C-factor	**13**								
		HC		12.41	17.21	22.01	26.81	31.61	NA	NA	NA
	3.5 (35.0)	U-factor		0.027	0.027	0.027	0.027	0.026	NA	NA	NA
		C-factor	**14**								
		HC		12.46	17.26	22.06	26.86	31.66	NA	NA	NA
	4.0 (40)	U-factor		0.024	0.024	0.024	0.023	0.023	NA	NA	NA
		C-factor	**15**								
		HC		12.52	17.32	22.12	26.92	31.72	NA	NA	NA
Polyurethane	1.5 (9.09)	U-factor		0.050	0.049	0.049	0.048	0.048	NA	NA	NA
		C-factor	**16**								
		HC		12.23	17.03	21.83	26.63	31.43	NA	NA	NA
	2.0 (10.9)	U-factor		0.042	0.042	0.041	0.041	0.041	NA	NA	NA
		C-factor	**17**								
		HC		12.41	17.21	22.01	26.81	31.61	NA	NA	NA
	4.5 (20.95)	U-factor		0.023	0.023	0.023	0.022	0.022	NA	NA	NA
		C-factor	**18**								
		HC		12.58	17.38	22.18	26.98	31.78	NA	NA	NA
Cement/EPS Compound	2.0 (12.0)	U-factor		NA	NA	NA	NA	NA	0.055	0.044	0.048
		C-factor	**19**								
		HC		NA	NA	NA	NA	NA	16.49	18.46	14.69
	3.0 (18.0)	U-factor		NA	NA	NA	NA	NA	0.042	0.035	0.037
		C-factor	**20**								
		HC		NA	NA	NA	NA	NA	17.50	19.47	15.69
	4.0 (24.0)	U-factor		NA	NA	NA	NA	NA	0.033	0.029	0.030
		C-factor	**21**								
		HC		NA	NA	NA	NA	NA	18.51	20.47	16.70

Notes

1 Flat Insulated Concrete Forms utilizes rigid insulation as the form and do not use a cement compound as the form.

2 Waffle and screen type Insulated Concrete Forms typically utilize either a cement/EPS compound or EPS insulation as the form. ICF's using the cemen

3 1.5 lb density EPS insulation at R-3.85 per inch except for the 2.25" insulation thickness which uses 2.0 lb density EPS at R-4.2 per inch

Figure 13: Table to be added to JA4 Properties of Concrete Insulating Forms

Table 4.x - U-factors of Structural Insulated Panels (SIPs) Roof/Ceilings

Insulation Core R-value[1]	Wood Framing Connection Type (spline)	Typical Panel Thickness		Rated R-value of Additional Layer of Continuous Insulation[4,5]							
				None	R-2	R-4	R-6	R-7	R-8	R-10	R-14
				A	B	C	D	E	F	G	H
R-21.7	OSB Spline	6.5"	1	0.041	0.038	0.035	0.033	0.032	0.031	0.029	0.026
R-21.7	Single 2x Spline	6.5"	2	0.044	0.040	0.037	0.034	0.033	0.032	0.030	0.027
R-21.7	Double 2x Spline	6.5"	3	0.046	0.042	0.038	0.035	0.034	0.033	0.031	0.027
R-21.7	I-Joist Spline	6.5"	4	0.043	0.039	0.036	0.034	0.033	0.032	0.030	0.026
R-28.4	OSB Spline	8.25"	5	0.033	0.031	0.029	0.028	0.027	0.026	0.025	0.023
R-28.4	Single 2x Spline	8.25"	6	0.034	0.032	0.030	0.028	0.027	0.027	0.025	0.023
R-28.4	Double 2x Spline	8.25"	7	0.037	0.034	0.031	0.029	0.028	0.028	0.026	0.023
R-28.4	I-Joist Spline	8.25"	8	0.033	0.310	0.029	0.028	0.027	0.026	0.025	0.023
R-33.2[2]	OSB Spline	6.5"	9	0.030	0.027	0.026	0.024	0.024	0.023	0.022	0.020
R-33.2[2]	Single 2x Spline	6.5"	10	0.031	0.029	0.027	0.025	0.025	0.024	0.023	0.021
R-33.2[2]	Double 2x Spline	6.5"	11	0.034	0.031	0.029	0.027	0.026	0.025	0.024	0.022
R-33.2[2]	I-Joist Spline	6.5"	12	0.031	0.028	0.027	0.025	0.025	0.024	0.023	0.021
R-36.1	OSB Spline	10.25"	13	0.026	0.025	0.024	0.022	0.022	0.022	0.021	0.019
R-36.1	Single 2x Spline	10.25"	14	0.028	0.026	0.025	0.023	0.023	0.022	0.021	0.020
R-36.1	Double 2x Spline	10.25"	15	0.029	0.028	0.026	0.024	0.024	0.023	0.022	0.020
R-36.1	I-Joist Spline	10.25"	16	0.027	0.025	0.024	0.023	0.022	0.022	0.021	0.019
R-43.8	OSB Spline	12.25"	17	0.021	0.020	0.019	0.018	0.018	0.018	0.017	0.016
R-43.8	Single 2x Spline	12.25"	18	0.023	0.022	0.021	0.020	0.020	0.019	0.018	0.017
R-43.8	Double 2x Spline	12.25"	19	0.025	0.023	0.022	0.021	0.021	0.020	0.019	0.018
R-43.8	I-Joist Spline	12.25"	20	0.022	0.021	0.020	0.019	0.019	0.019	0.018	0.017
R-55.3[3]	OSB Spline	10.25	21	0.017	0.016	0.016	0.016	0.016	0.016	0.015	0.014
R-55.3[3]	Single 2x Spline	10.25	22	0.019	0.018	0.018	0.017	0.017	0.016	0.016	0.015
R-55.3[3]	Double 2x Spline	10.25	23	0.021	0.020	0.019	0.018	0.018	0.017	0.017	0.015
R-55.3[3]	I-Joist Spline	10.25	24	0.018	0.017	0.017	0.016	0.016	0.016	0.015	0.014

Notes: 12 3.75

[1] The insulation R-value must be at least R-21.7 in order to use this table. This table assumes moulded expanded polystyrene (EPS) unless noted otherwise. Although other insulation types are used by some SIP manufacturers, such as polyurethane and extruded expanded insulation (XPS), EPS is the most common insulation used in SIP construction.

[2] R-33.2 is achievable using polyurethane insulation in 6.5" panels.

[3] R-55.3 is achievable using polyurethane insulation in 10.25" panels

[4] For credit, continuous insulation shall be at least R-2 and may be installed on either the inside or the exterior of the roof/ceiling.

[5] In climate zones 1 and 16 the insulating R-value of continuous insulation materials installed above the roof waterproof membrane shall be multiplied times 0.8 before choosing the table column for determining assembly U-factor.

Figure 14: SIP Roof U-factor Table

Table 4.x - U-factors of Structural Insulated Panels (SIPs) Walls

Insulation Core R-value[1]	Wood Framing Connection Type (spline)	Typical Panel Thickness		Rated R-value of Additional Layer of Continuous Insulation[5]							
				None	**R-2**	**R-4**	**R-6**	**R-7**	**R-8**	**R-10**	**R-14**
				A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
R-14.0	**OSB Spline**	**4.5"**	**1**	0.061	0.055	0.049	0.045	0.043	0.041	0.038	0.033
R-14.0	**Single 2x Spline**	**4.5"**	**2**	0.071	0.061	0.054	0.048	0.046	0.044	0.040	0.035
R-14.0	**Double 2x Spline**	**4.5"**	**3**	0.077	0.065	0.057	0.050	0.048	0.046	0.042	0.035
R-14.0	**I-Joist Spline**	**4.5"**	**4**	0.070	0.060	0.053	0.048	0.046	0.044	0.040	0.034
R-18.1[2]	**OSB Spline**	**4.5"**	**5**	0.053	0.045	0.041	0.037	0.036	0.034	0.031	0.028
R-18.1[2]	**Single 2x Spline**	**4.5"**	**6**	0.061	0.052	0.047	0.042	0.040	0.039	0.036	0.031
R-18.1[2]	**Double 2x Spline**	**4.5"**	**7**	0.066	0.056	0.050	0.045	0.042	0.041	0.037	0.032
R-18.1[2]	**I-Joist Spline**	**4.5"**	**8**	0.059	0.051	0.046	0.042	0.040	0.038	0.035	0.031
R-21.7	**OSB Spline**	**6.5"**	**9**	0.041	0.038	0.036	0.033	0.032	0.031	0.029	0.026
R-21.7	**Single 2x Spline**	**6.5"**	**10**	0.050	0.044	0.040	0.037	0.036	0.034	0.032	0.028
R-21.7	**Double 2x Spline**	**6.5"**	**11**	0.054	0.048	0.043	0.039	0.037	0.036	0.033	0.029
R-21.7	**I-Joist Spline**	**6.5"**	**12**	0.048	0.043	0.039	0.036	0.035	0.033	0.031	0.028
R-28.4	**OSB Spline**	**8.25"**	**13**	0.032	0.030	0.029	0.027	0.026	0.026	0.024	0.022
R-28.4	**Single 2x Spline**	**8.25"**	**14**	0.039	0.036	0.033	0.031	0.030	0.029	0.027	0.024
R-28.4	**Double 2x Spline**	**8.25"**	**15**	0.043	0.039	0.035	0.033	0.031	0.030	0.028	0.025
R-28.4	**I-Joist Spline**	**8.25"**	**16**	0.037	0.034	0.032	0.030	0.029	0.028	0.026	0.024
R-33.2[3]	**OSB Spline**	**6.5"**	**17**	0.032	0.029	0.027	0.025	0.024	0.023	0.022	0.020
R-33.2[3]	**Single 2x Spline**	**6.5"**	**18**	0.038	0.034	0.031	0.029	0.028	0.027	0.025	0.023
R-33.2[3]	**Double 2x Spline**	**6.5"**	**19**	0.043	0.038	0.034	0.031	0.030	0.029	0.027	0.024
R-33.2[3]	**I-Joist Spline**	**6.5"**	**20**	0.036	0.033	0.030	0.028	0.027	0.026	0.025	0.022
R-36.1	**OSB Spline**	**10.25"**	**21**	0.026	0.024	0.023	0.022	0.022	0.021	0.020	0.019
R-36.1	**Single 2x Spline**	**10.25"**	**22**	0.032	0.030	0.028	0.026	0.025	0.024	0.023	0.021
R-36.1	**Double 2x Spline**	**10.25"**	**23**	0.035	0.032	0.030	0.028	0.027	0.026	0.024	0.022
R-36.1	**I-Joist Spline**	**10.25"**	**24**	0.030	0.028	0.026	0.025	0.024	0.023	0.022	0.020
R-43.8	**OSB Spline**	**12.25"**	**25**	0.022	0.021	0.020	0.019	0.019	0.018	0.018	0.017
R-43.8	**Single 2x Spline**	**12.25"**	**26**	0.027	0.025	0.024	0.022	0.022	0.021	0.020	0.019
R-43.8	**Double 2x Spline**	**12.25"**	**27**	0.028	0.027	0.025	0.024	0.023	0.023	0.021	0.020
R-43.8	**I-Joist Spline**	**12.25"**	**28**	0.025	0.024	0.022	0.021	0.021	0.020	0.019	0.018
R-55.3[4]	**OSB Spline**	**10.25"**	**29**	0.020	0.019	0.017	0.016	0.016	0.016	0.015	0.014
R-55.3[4]	**Single 2x Spline**	**10.25"**	**30**	0.024	0.022	0.021	0.020	0.019	0.019	0.018	0.016
R-55.3[4]	**Double 2x Spline**	**10.25"**	**31**	0.028	0.025	0.023	0.022	0.021	0.021	0.019	0.018
R-55.3[4]	**I-Joist Spline**	**10.25"**	**32**	0.022	0.021	0.019	0.018	0.018	0.018	0.017	0.016

Notes:

[1] The insulation R-value must be at least R-14 in order to use this table. This table assumes moulded expanded polystyrene (EPS) unless noted otherwise. Although other insulation types are used by some SIP manufacturers, such as polyurethane and extruded expanded insulation (XPS), EPS is the most common insulation used in SIP construction.

[2] R-18.1 is achievable using extruded expanded polystyrene (XPS) insulation in 4.5" thick panels

[3] R-33.2 is achievable using polyurethane insulation in 6.5" panels.

[4] R-55.3 is achievable using polyurethane insulation in 10.25" panels

[5] For credit, continuous insulation shall be at least R-2 and may be installed on either the inside or the exterior of the roof/ceiling.

Figure 15: SIP Wall U-factor Table

Table 4.x - U-factors of Structural Insulated Panels (SIPs) Floors

Crawlspace?	Insulation R-value[1]	Wood Framing Spline Connection Type (Splines)	Typical Panel Thickness		Rated R-value of Additional Layer of Continuous Insulation[3]							
					None	R-2	R-4	R-6	R-7	R-8	R-10	R-14
					A	B	C	D	E	F	G	H
YES	R-21.7	Single 2x splines	6.5"	1	0.033	0.030	0.029	0.027	0.026	0.026	0.024	0.022
	R-21.7	Double 2x splines	6.5"	2	0.034	0.031	0.029	0.028	0.027	0.026	0.025	0.023
	R-21.7	I-Joist splines	6.5"	3	0.032	0.030	0.028	0.027	0.026	0.025	0.024	0.022
	R-28.4	Single 2x splines	8.25"	4	0.027	0.026	0.024	0.023	0.023	0.022	0.021	0.019
	R-28.4	Double 2x splines	8.25"	5	0.028	0.026	0.025	0.024	0.023	0.023	0.022	0.020
	R-28.4	I-Joist splines	8.25"	6	0.027	0.025	0.024	0.023	0.022	0.022	0.021	0.019
	R-33.2[2]	Single 2x splines	6.5"	7	0.024	0.023	0.022	0.021	0.021	0.020	0.019	0.018
	R-33.2[2]	Double 2x splines	6.5"	8	0.026	0.024	0.023	0.022	0.021	0.021	0.020	0.018
	R-33.2[2]	I-Joist splines	6.5"	9	0.024	0.023	0.022	0.021	0.020	0.020	0.019	0.018
	R-36.1	Single 2x splines	10.25"	10	0.023	0.022	0.021	0.020	0.019	0.019	0.018	0.017
	R-36.1	Double 2x splines	10.25"	11	0.024	0.022	0.021	0.020	0.020	0.020	0.019	0.017
	R-36.1	I-Joist splines	10.25"	12	0.022	0.021	0.020	0.019	0.019	0.019	0.018	0.017
NO	R-21.7	Single 2x splines	6.5"	13	0.041	0.038	0.035	0.033	0.031	0.030	0.029	0.026
	R-21.7	Double 2x splines	6.5"	14	0.043	0.039	0.036	0.034	0.032	0.031	0.029	0.026
	R-21.7	I-Joist splines	6.5"	15	0.040	0.037	0.034	0.032	0.031	0.030	0.028	0.026
	R-28.4	Single 2x splines	8.25"	16	0.033	0.030	0.029	0.027	0.026	0.026	0.024	0.022
	R-28.4	Double 2x splines	8.25"	17	0.034	0.032	0.030	0.028	0.027	0.026	0.025	0.023
	R-28.4	I-Joist splines	8.25"	18	0.032	0.030	0.028	0.027	0.026	0.025	0.024	0.022
	R-33.2[2]	Single 2x splines	6.5"	19	0.029	0.027	0.026	0.024	0.024	0.023	0.022	0.020
	R-33.2[2]	Double 2x splines	6.5"	20	0.032	0.029	0.027	0.026	0.025	0.024	0.023	0.021
	R-33.2[2]	I-Joist splines	6.5"	21	0.028	0.027	0.025	0.024	0.023	0.023	0.022	0.020
	R-36.1	Single 2x splines	10.25"	22	0.026	0.025	0.024	0.023	0.022	0.022	0.021	0.019
	R-36.1	Double 2x splines	10.25"	23	0.028	0.026	0.025	0.024	0.023	0.022	0.021	0.020
	R-36.1	I-Joist splines	10.25"	24	0.026	0.024	0.023	0.022	0.021	0.021	0.020	0.018

Notes:

[1] The insulation R-value must be at least R-21.7 in order to use this table. This table assumes moulded expanded polystyrene (EPS) unless noted otherwise. Although other insulation types are used by some SIP manufacturers, such as polyurethane and extruded expanded insulation (XPS), EPS is the most common insulation used in SIP construction.

[2] R-33.2 is achievable using polyurethane insulation in 6.5" panels.

[3] For credit, continuous insulation shall be at least R-2 and may be installed on either the inside or the exterior of the roof/ceiling.

Figure 16: SIP Floor Insulation R-Value Table

6. Bibliography and Other Research

HMG conducted literature review and gathered experts to determine the state of the market for advanced envelope assemblies. Research included collection of information on available assembly types and specifications, market penetration, cost data, barriers to implementation, environmental impacts, and non-energy benefits.

Key resources that informed and guided this study are summarized below in section 6.1.

To solicit input from a range of stakeholders, HMG assembled a project advisory committee (PAC) and established a broader corresponding group for alternate perspectives and communication with the PAC. The PAC met on four (4) conference calls and took part in additional e-mail and phone correspondence to discuss the three construction assemblies. The group was responsible for defining the three assembly types, contributing market and product information to the study, revealing possible barriers to measure adoption into the 2013 California Building Energy Efficiency Standards, influencing analysis strategies, and approving resulting look-up tables. The core PAC members are listed in section 6.2 below.

6.1 Referenced Documents

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6.2 Personal Communications

Sharon Block, HERS Rater

Payam Bozorgchami, California Energy Commission

Ann Edminster, LEED for Homes

Geroge Estrell, Building Official

Dave Hegerty, HERS Rater

Mike Hodgson, California Building Industry Association

Rob Hudler, California Energy Commission

Joe Lstiburek, Building America Corp

Alan Marshall, California Energy Commission

Mike Moore, Newport Ventures, Inc.

Adam Neugebauer, ConSol

Ken Nittler, Enercomp

Vera Novak, Insulating Concrete Forms Association

Dave Springer, Davis Energy Group

Frank Stewart, Western Wood Products Association

Martha VanGeem, Construction Tech Laboratories, Inc.

Bill Wachtler, Structural Insulated Panel Association

Bruce Wilcox, P.E.

Nick Zigelbaum, Natural Resources Defense Council

7. Appendices

7.1 ICF Product Availability

ICF products available on the market today are diverse and the trend of the market is an increase in ICF product types and volume. Figure 17 shows the increase in diversity of ICF products over the past 17 years. Masonry Block systems have been available since before 1993, however new types of products have come available since 1993. Foam forms are projected to exceed masonry block systems in 2010 residential concrete wall assemblies, based on the National Association of Home Builders (NAHB) projections. The various smaller market segment products (precast, poured wall, removable forms) are on a trend to become over 5% of residential wall assembly products at the end of 2010. Though ICF are not used as prevalently as wood framing in the residential market, these assemblies are a significant portion of the overall market (~15%) and are manufactured in a wide array of configurations providing ample product availability for an effective market shift towards employing ICF in lieu of conventional or advanced wood framing.

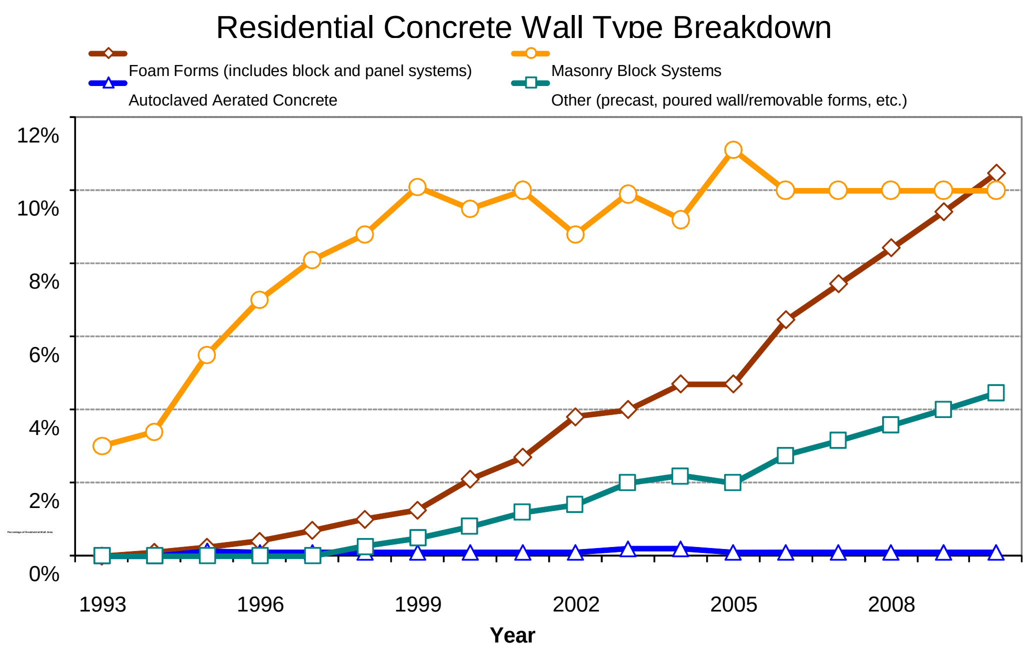

Figure 17: Residential Concrete Wall Trends 1993-2010[12]

ICF assemblies are manufactured in various types: Flat (varying depth), Screen and Waffle. More than 30 manufacturers are available that actively produce ICF panels. **Error! Reference source not found.**lists the ICF products evaluated for energy savings and life cycle cost analysis.

[12] NAHB Research Center, Insulating Concrete Form Association and PCA Market Research Surveys

Types	Product	Details
Flat	Quad lock	Flat
	TF Insulated Concrete Forms	Flat
	Amazon Forms	Flat
	Polysteel	Flat (6" and 8" cores): PS-4000 and waffle (6", 8", 10" cores) PS-3000
	Commercial block	Flat : 8"
	Hobbs Building Systems	Flat vertical ICF wall system
	Greenblock	Flat: 4",6",8",10",12" all nominal concrete core thickness
	Amvic	Flat: 4",6",8",10",12" all nominal concrete core thickness
	Cellblox	Flat: 4",6",8",10",12" all nominal concrete core thickness
	IntegraSpec	Flat: 4",6",8",10",12" all nominal concrete core thickness
	Logix	Flat: 4",6",8",10",12" all nominal concrete core thickness
	Smart Block	Flat: 4",6",8",10",12" all nominal concrete core thickness
	Buildblock	Flat: 4", 6", 8"
	Eco-block	Flat: 4", 6", 8"
Screen	Faswall	screen type
	Apex Block	screen: 6"
	Insulock	screen: 6" nominal.
Waffle	Rastra	waffle
	Reddiform	waffle: 6" and 8" core
	ICE Form	waffle: 6" and 8" core
	Tech Block International	screen: 6" core
	Reward wall systems	e-form is the waffle grid system, i-form is flat system
	Thermoblock	

Figure 18: ICF Product Types

7.2 Barriers to Adoption

7.2.1 Advanced Wood Framing (AWF)

The barriers to adoption are dependent on the training required for advanced framing practices. Additional project coordination and planning is required to ensure that structural engineers and framing contractors collaborate to calculate sheering and stress throughout the building. With reduced wood members in the framing plan, architects and engineers may need additional planning time for each building to meet seismic requirements and construct a structurally sound building.

7.2.2 Insulating Concrete Forms (ICF)

More than 30 manufacturers actively market ICF assemblies and HMG discovered over 20 products available on the market. ICF use at job sites has been shown to reduce site man-hours, and the assemblies can be manufactured for cheaper than whole house stick framing. HMG can only identify market inertia (resistance to changing framing techniques) as the major barrier to adoption of using ICF panels in place of traditional or advanced wood framing. Insulated Concrete Form (ICF) assemblies are widely available and sometimes the preferred choice of framing material. Having panels constructed at a lumber yard or warehouse reduces site man-hours and site generated waste (trimming framing members).

7.3 AWF Cost Tables

The tables in this section include cost information used to calculate total wall assembly costs for use in the Life-cycle cost calculations.

Batt Insulation R-value	RS Means Description			Palo Alto	Richmond	Sacramento	San Jose	O&P Mean Across Regions per square foot	O&P Mean across products per square foot	Number of units in Prototype Home	Cost per Prototype Home
R-13	Kraft faced fiberglass, 3-1/2" thick, 11" wide			$ 0.78	$ 0.78	$ 0.78	$ 0.78	$ 0.78	$ 0.83	1,539	$ 1,712.14
	Foil faced fiberglass, 3-1/2" thick, 11" wide			$ 1.10	$ 1.12	$ 1.04	$ 1.05	$ 1.08			
	Unfaced 3-1/2" thick, 11" wide			$ 0.80	$ 0.83	$ 0.77	$ 0.80	$ 0.80			
	Unfaced, 3-1/2" thick, incl. spring type wire			$ 0.68	$ 0.68	$ 0.68	$ 0.68	$ 0.68			
R-15	Kraft faced fiberglass, 3-1/2" thick, 11" wide			$ 1.00	$ 1.02	$ 0.95	$ 0.96	$ 0.98	$ 1.02	1,539	$ 2,087.91
	Foil faced fiberglass, 3-1/2" thick, 11" wide			$ 1.13	$ 1.16	$ 1.07	$ 1.08	$ 1.11			
	Unfaced fiberglass, 3-1/2" thick, 11" wide			$ 0.97	$ 1.00	$ 0.93	$ 0.94	$ 0.96			
R-19	Kraft faced fiberglass, 6" thick, 11" wide			$ 0.90	$ 0.90	$ 0.90	$ 0.90	$ 0.90	$ 1.04	1,539	$ 2,127.24
	Foil faced fiberglass, 6" thick, 15" wide			$ 1.27	$ 1.27	$ 1.27	$ 1.27	$ 1.27			
	Unfaced fiberglass, 6" thick, 15" wide			$ 0.94	$ 0.94	$ 0.94	$ 0.94	$ 0.94			
R-21								R-15 cost per Sq. ft./R-value x 21	$ 1.42	1,539	$ 2,923.07

Med Density Spray-in Insulaiton	RS Means Description	Bakersfield	Eureka	Oakland	Redding	Sacramento	San Diego	O&P Mean Across Regions per square foot	O&P Mean across products per square foot	Number of units in Prototype Home	Cost per Prototype Home
R-11	Insulation, polyurethane foam, 2#/CF density, 2" thick, R13, sprayed	$ 1.41	$ 1.47	$ 1.70	$ 1.55	$ 1.57	$ 1.53	$ 1.54	$ 1.54	1,539	$ 2,367.50
R-17	Insulation, polyurethane foam, 2#/CF density, 3" thick, R19.5, sprayed	$ 2.12	$ 2.23	$ 2.56	$ 2.34	$ 2.37	$ 2.31	$ 2.32	$ 2.32	1,539	$ 3,573.05
R-29	Insulation, polyurethane foam, 2#/CF density, 5" thick, R32.5, sprayed	$ 3.53	$ 3.71	$ 4.26	$ 3.90	$ 3.95	$ 3.86	$ 3.87	$ 3.87	1,539	$ 5,953.37

Flash & Batt									O&P Mean across products per square foot	Number of units in Prototype Home	Cost per Prototype Home
R-24	2" foam, plus R-13 batt								$ 2.37	1,539	$ 4,868.80
R-26	2" foam, plus R-15 batt								$ 2.56	1,539	$ 5,244.57

Figure 19: Table of R.S. Means Cavity Insulation Costs

Description	Square Feet	Bakersfield	Eureka	Oakland	Redding	Sacramento	San Diego	Average Cost per wall	O&P Mean Across Regions per square foot	O&P Mean across products per square foot	Number of units in Prototype Home	Cost per Prototype Home
Wall framing, door buck, king studs, jack studs, header and accessories, 2" x 4" wall, 3' wide, 8' high	24	$ 29.06	$ 36.06	$ 34.75	$ 32.09	$ 32.87	$ 29.27	$ 32.35	$ 1.35			
Wall framing, door buck, king studs, jack studs, header and accessories, 2" x 4" wall, 4' wide, 8' high	32	$ 30.07	$ 37.51	$ 35.92	$ 33.24	$ 34.04	$ 30.42	$ 33.53	$ 1.05			
Wall framing, door buck, king studs, jack studs, header and accessories, 2" x 4" wall, 5' wide, 8' high	40	$ 33.10	$ 41.84	$ 39.44	$ 36.68	$ 37.56	$ 33.88	$ 37.08	$ 0.93			
Wall framing, door buck, king studs, jack studs, header and accessories, 2" x 4" wall, 6' wide, 8' high	48	$ 34.42	$ 43.72	$ 40.97	$ 38.18	$ 39.09	$ 35.38	$ 38.63	$ 0.80			
Wall framing, door buck, king studs, jack studs, header and accessories, 2" x 4" wall, 8' wide, 8' high	64	$ 44.70	$ 58.04	$ 52.96	$ 49.79	$ 50.96	$ 46.85	$ 50.55	$ 0.79			
Wall framing, door buck, king studs, jack studs, header and accessories, 2" x 4" wall, 10' wide, 8' high	80	$ 53.93	$ 71.23	$ 63.67	$ 60.27	$ 61.67	$ 57.38	$ 61.36	$ 0.77			
Wall framing, door buck, king studs, jack studs, header and accessories, 2" x 4" wall, 12' wide, 8' high	96	$ 67.11	$ 90.07	$ 78.97	$ 75.24	$ 76.97	$ 72.42	$ 76.80	$ 0.80			
Wall framing, window buck, king studs, jack studs, rough sill, cripples, header and accessories, 2" x 4" wall, 2' wide, 8' high	16	$ 34.94	$ 42.64	$ 41.90	$ 38.46	$ 39.40	$ 34.68	$ 38.67	$ 2.42	$1.14	2,592	$2,966.49
Wall framing, window buck, king studs, jack studs, rough sill, cripples, header and accessories, 2" x 4" wall, 3' wide, 8' high	24	$ 37.44	$ 46.22	$ 44.81	$ 41.30	$ 42.31	$ 37.54	$ 41.60	$ 1.73			
Wall framing, window buck, king studs, jack studs, rough sill, cripples, header and accessories, 2" x 4" wall, 4' wide, 8' high	32	$ 39.16	$ 48.67	$ 46.80	$ 43.25	$ 44.30	$ 39.49	$ 43.61	$ 1.36			
Wall framing, window buck, king studs, jack studs, rough sill, cripples, header and accessories, 2" x 4" wall, 5' wide, 8' high	40	$ 42.24	$ 53.06	$ 50.37	$ 46.74	$ 47.87	$ 43.00	$ 47.21	$ 1.18			
Wall framing, window buck, king studs, jack studs, rough sill, cripples, header and accessories, 2" x 4" wall, 6' wide, 8' high	48	$ 44.43	$ 56.20	$ 52.92	$ 49.24	$ 50.42	$ 45.51	$ 49.79	$ 1.04			
Wall framing, window buck, king studs, jack studs, rough sill, cripples, header and accessories, 2" x 4" wall, 8' wide, 8' high	64	$ 57.33	$ 73.96	$ 68.02	$ 63.77	$ 65.28	$ 59.75	$ 64.69	$ 1.01			
Wall framing, window buck, king studs, jack studs, rough sill, cripples, header and accessories, 2" x 4" wall, 10' wide, 8' high	80	$ 67.44	$ 88.41	$ 79.75	$ 75.25	$ 77.01	$ 71.28	$ 76.52	$ 0.96			
Wall framing, window buck, king studs, jack studs, rough sill, cripples, header and accessories, 2" x 4" wall, 12' wide, 8' high	96	$ 82.82	$ 110.39	$ 97.60	$ 92.71	$ 94.86	$ 88.84	$ 94.54	$ 0.98			

Figure 20: Table of R.S. Means 2x4 Framing Costs

Description	Square Feet	Bakersfield	Eureka	Oakland	Redding	Sacramento	San Diego	Average Cost per wall	O&P Mean Across Regions per square foot	O&P Mean across products per square foot	Number of units in Prototype Home	Cost per Prototype Home
Wall framing, door buck, king studs, jack studs, header and accessories, 2" x 6" wall, 3' wide, 8' high	24	$ 35.30	$ 44.98	$ 41.99	$ 39.18	$ 40.11	$ 36.39	$ 39.66	$ 1.65			
Wall framing, door buck, king studs, jack studs, header and accessories, 2" x 6" wall, 4' wide, 8' high	32	$ 36.18	$ 46.24	$ 43.01	$ 40.17	$ 41.13	$ 37.39	$ 40.69	$ 1.27			
Wall framing, door buck, king studs, jack studs, header and accessories, 2" x 6" wall, 5' wide, 8' high	40	$ 39.25	$ 50.63	$ 46.58	$ 43.67	$ 44.70	$ 40.90	$ 44.29	$ 1.11			
Wall framing, door buck, king studs, jack studs, header and accessories, 2" x 6" wall, 6' wide, 8' high	48	$ 40.57	$ 52.52	$ 48.11	$ 45.16	$ 46.23	$ 42.41	$ 45.83	$ 0.95			
Wall framing, door buck, king studs, jack studs, header and accessories, 2" x 6" wall, 8' wide, 8' high	64	$ 50.85	$ 66.83	$ 60.10	$ 56.77	$ 58.10	$ 53.87	$ 57.75	$ 0.90			
Wall framing, door buck, king studs, jack studs, header and accessories, 2" x 6" wall, 10' wide, 8' high	80	$ 59.64	$ 79.39	$ 70.30	$ 66.75	$ 68.30	$ 63.90	$ 68.05	$ 0.85			
Wall framing, door buck, king studs, jack studs, header and accessories, 2" x 6" wall, 12' wide, 8' high	96	$ 73.27	$ 98.86	$ 86.11	$ 82.22	$ 84.11	$ 79.44	$ 84.00	$ 0.88			
Wall framing, window buck, king studs, jack studs, rough sill, cripples, header and accessories, 2" x 6" wall, 2' wide, 8' high	16	$ 42.68	$ 53.69	$ 50.88	$ 47.24	$ 48.38	$ 43.51	$ 47.73	$ 2.98	$1.36	2,592	$3,537.89
Wall framing, window buck, king studs, jack studs, rough sill, cripples, header and accessories, 2" x 6" wall, 3' wide, 8' high	24	$ 45.31	$ 57.46	$ 53.94	$ 50.23	$ 51.44	$ 46.51	$ 50.82	$ 2.12			
Wall framing, window buck, king studs, jack studs, rough sill, cripples, header and accessories, 2" x 6" wall, 4' wide, 8' high	32	$ 47.07	$ 59.97	$ 55.98	$ 52.23	$ 53.48	$ 48.52	$ 52.88	$ 1.65			
Wall framing, window buck, king studs, jack studs, rough sill, cripples, header and accessories, 2" x 6" wall, 5' wide, 8' high	40	$ 50.59	$ 64.99	$ 60.06	$ 56.22	$ 57.56	$ 52.53	$ 56.99	$ 1.42			
Wall framing, window buck, king studs, jack studs, rough sill, cripples, header and accessories, 2" x 6" wall, 6' wide, 8' high	48	$ 53.22	$ 68.76	$ 63.12	$ 59.22	$ 60.62	$ 55.54	$ 60.08	$ 1.25			
Wall framing, window buck, king studs, jack studs, rough sill, cripples, header and accessories, 2" x 6" wall, 8' wide, 8' high	64	$ 67.44	$ 88.41	$ 79.75	$ 75.25	$ 77.01	$ 71.28	$ 76.52	$ 1.20			
Wall framing, window buck, king studs, jack studs, rough sill, cripples, header and accessories, 2" x 6" wall, 10' wide, 8' high	80	$ 77.99	$ 103.48	$ 91.99	$ 87.22	$ 89.25	$ 83.32	$ 88.88	$ 1.11			
Wall framing, window buck, king studs, jack studs, rough sill, cripples, header and accessories, 2" x 6" wall, 12' wide, 8' high	96	$ 94.25	$ 126.71	$ 110.86	$ 105.69	$ 108.12	$ 101.87	$ 107.92	$ 1.12			

Figure 21: Figure 22: Table of R.S. Means 2x6 Framing Costs

7.4 Energy Analysis Tables

PKG D	Climate Zone	Framing (Std or Adv)	QII (Q=yes, X=no)	2x	Cavity Ins.	Stud Spacing, in.	PROPOSED	PROPOSED	PROPOSED	Annual Savings per Prototype Home					TDV savings	
							TOTAL	**HEATING**	**COOLING**	KW	KWH	THERMS	MTDVElec	MTDVGas	kTDV/sf/yr	%
PKGD 2008	01	S	X	6	21	16	44.28	26.67	0.00							
	01	A	Q	6	21	24	40.23	22.62	0.00	0.00	71	57	1.33	9.61	4.1	9.1%
PKGD 2008	02	S	X	4	13	16	54.88	26.36	11.40							
	02	A	Q	6	19	24	46.25	19.57	9.56	0.12	179	92	7.10	16.20	8.6	15.7%
PKGD 2008	03	S	X	4	13	16	38.40	14.85	6.47							
	03	A	Q	6	19	24	33.11	9.48	6.55	0.00	77	71	1.51	12.77	5.3	13.8%
PKGD 2008	04	S	X	4	13	16	56.10	20.10	19.11							
	04	A	Q	6	19	24	48.63	14.26	17.48	0.12	164	78	6.23	13.94	7.5	13.3%
PKGD 2008	05	S	X	4	13	16	36.75	19.71	0.00							
	05	A	Q	6	19	24	30.32	13.28	0.00	0.00	111	88	2.03	15.34	6.4	17.5%
PKGD 2008	06	S	X	4	13	16	40.61	7.17	16.86							
	06	A	Q	6	19	24	36.71	3.99	16.14	0.06	66	41	2.92	7.62	3.9	9.6%
PKGD 2008	07	S	X	4	13	16	32.06	1.89	13.96							
	07	A	Q	6	19	24	30.30	0.67	13.42	0.04	32	16	1.87	2.89	1.8	5.5%
PKGD 2008	08	S	X	4	13	16	52.08	5.42	30.27							
	08	A	Q	6	19	24	47.77	2.95	28.43	0.15	119	33	5.72	5.92	4.3	8.3%
PKGD 2008	09	S	X	4	13	16	74.54	8.22	50.05							
	09	A	Q	6	19	24	67.75	4.98	46.50	0.27	211	43	10.56	7.78	6.8	9.1%
PKGD 2008	10	S	X	4	13	16	81.00	9.15	55.57							
	10	A	Q	6	19	24	72.96	5.57	51.11	0.35	251	49	12.85	8.86	8.0	9.9%
PKGD 2008	11	S	X	6	19	16	122.67	20.80	85.23							
	11	A	Q	6	19	24	117.53	17.96	82.93	0.13	164	39	6.86	7.02	5.1	4.2%
PKGD 2008	12	S	X	6	19	16	86.31	21.12	48.37							
	12	A	Q	6	19	24	82.46	18.32	47.32	0.07	72	39	3.50	6.88	3.9	4.5%
PKGD 2008	13	S	X	6	19	16	121.17	18.97	85.98							
	13	A	Q	6	19	24	113.87	16.42	81.23	0.41	172	35	13.45	6.26	7.3	6.0%
PKGD 2008	14	S	X	6	21	16	109.97	18.81	74.53							
	14	A	Q	6	21	24	105.23	15.96	72.64	0.12	143	39	5.73	7.07	4.7	4.3%
PKGD 2008	15	S	X	6	21	16	161.15	1.71	144.56							
	15	A	Q	6	21	24	155.55	1.15	139.52	0.27	395	7	13.72	1.41	5.6	3.5%
PKGD 2008	16	S	X	6	21	16	94.87	38.23	38.48							
	16	A	Q	6	21	24	90.21	33.01	39.04	-0.04	53	71	0.02	12.56	4.7	4.9%

Figure 23: Advanced Wood Framing Energy Analysis Outputs

Climate Zone	JA Code	Case Description	Wall U-value	Heating	Cooling	Fans	DHW	Total	Annual kWh	Annual kWh Savings	Peak kW Demand	Annual Therms	Annual Therm Savings	Peak kBtu/h Demand
	Base Case	Climate Zone 4 Prototype D	0.102	12.36	2.37	0.99	9.35	25.07	411		6	608		83
	A1	4" flat core 2" EPS each side	0.058	8.95	1.63	0.7	9.35	20.63	293	118	5	513	95	77
4	C3	8" flat core 2.5" EPS each side	0.046	7.98	1.43	0.63	9.35	19.39	260	151	5	486	122	75
	C10	8" flat core 2.5" XPS each side	0.036	7.27	1.25	0.56	9.35	18.43	232	179	4	466	142	74
	D18	10" flat core 4.5" polyurethane each side	0.022	6.19	1.06	0.48	9.35	17.08	198	213	4	436	172	72
	Base Case	Climate Zone 8 Prototype D	0.102	4.31	7.17	1.41	9.99	22.88	767		6	374		63
	A1	4" flat core 2" EPS each side	0.058	2.67	5.83	1.11	9.99	19.6	602	165	5	330	44	58
8	C3	8" flat core 2.5" EPS each side	0.046	2.23	5.45	1.03	9.99	18.7	558	209	5	318	56	57
	C10	8" flat core 2.5" XPS each side	0.036	1.93	5.17	0.96	9.99	18.05	526	241	5	310	64	56
	D18	10" flat core 4.5" polyurethane each side	0.022	1.48	4.76	0.87	9.99	17.1	480	287	5	297	77	52
	Base Case	Climate Zone 10 Prototype D	0.102	6.57	18.7	3.15	9.9	38.32	2305		7	433		72
	A1	4" flat core 2" EPS each side	0.058	4.3	15.75	2.59	9.9	32.54	1886	419	6	372	61	65
10	C3	8" flat core 2.5" EPS each side	0.046	3.69	14.89	2.43	9.9	30.91	1743	562	6	355	78	63
	C10	8" flat core 2.5" XPS each side	0.036	3.27	14.28	2.32	9.9	29.77	1659	646	6	344	89	62
	D18	10" flat core 4.5" polyurethane each side	0.022	2.65	13.32	2.15	9.9	28.02	1528	777	5	327	106	60
	Base Case	Climate Zone 13 Prototype D	0.074	10.4	24.63	4.1	8.93	48.06	3788		7	537		77
	A1	4" flat core 2" EPS each side	0.058	9.19	23.42	3.87	8.93	45.41	3576	212	7	504	33	75
13	C3	8" flat core 2.5" EPS each side	0.046	8.23	22.48	3.68	8.93	43.32	3411	377	7	478	59	73
	C10	8" flat core 2.5" XPS each side	0.036	7.53	21.77	3.55	8.93	41.78	3289	499	7	459	78	72
	D18	10" flat core 4.5" polyurethane each side	0.022	6.47	20.69	3.34	8.93	39.43	3102	686	6	430	107	70
	Base Case	Climate Zone 14 Prototype D	0.074	13.87	26.13	4.51	10.1	54.61	3569		7	637		81
	A1	4" flat core 2" EPS each side	0.058	12.83	25.17	4.32	10.1	52.42	3414	155	7	608	29	79
14	C3	8" flat core 2.5" EPS each side	0.046	11.63	24.07	4.1	10.1	49.9	3239	330	7	576	61	77
	C10	8" flat core 2.5" XPS each side	0.036	10.75	23.26	3.93	10.1	48.04	3110	459	6	552	85	76
	D18	10" flat core 4.5" polyurethane each side	0.022	9.42	21.99	3.68	10.1	45.19	2909	660	6	516	121	73
	Base Case	Climate Zone 16 Prototype D	0.074	29.53	8.13	2.79	10.06	50.51	1389		6	1106		94
	A1	4" flat core 2" EPS each side	0.058	27.38	7.81	2.64	10.06	47.89	1324	65	6	1046	60	92
16	C3	8" flat core 2.5" EPS each side	0.046	24.89	7.45	2.46	10.06	44.86	1254	135	6	977	129	90
	C10	8" flat core 2.5" XPS each side	0.036	23.09	7.19	2.33	10.06	42.67	1204	185	6	926	180	88
	D18	10" flat core 4.5" polyurethane each side	0.022	20.3	6.81	2.13	10.06	39.3	1130	259	5	848	258	85

Figure 24: Insulating Concrete Forms Energy Analysis Outputs