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California Energy Commission

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# MEMORANDUM

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## MULTIFAMILY ANALYSIS FOR RESIDENTIAL ENVELOPE CASE PROPOSALS

The California Energy Commission requested that the Statewide CASE Teams provide multifamily prototype energy savings and cost-effectiveness for measures proposed in the High Performance Attics / Ducts in Conditioned Space CASE proposal and Residential High Performance Walls CASE proposal. This memo presents results in formats similar to those presented in the respective CASE reports, and when appropriate, uses the same assumptions and methodologies as those used in the respective CASE reports.

### Prototype

Our analysis used the multifamily prototype described in the Residential ACM. Some of the key attributes of the multifamily model, as compared to the weighted single family prototype (which weighs 45% of the single-story prototype and 55% of the two-story prototype), are presented below.

*Table 1: Prototype attribute comparison*

Prototype Attribute	Weighted Single Family	Multifamily	MF/SF
Number of Dwelling Units	1	8	
Floor Area (ft <sup>2</sup> )	2,430	6,960	286%
Slab Area (ft <sup>2</sup> )	1,633	3,480	213%
Ceiling Area (ft <sup>2</sup> )	1,743	3,480	200%
Roof Area (ft <sup>2</sup> )	2,091	4,176	200%
Wall Area (ft <sup>2</sup> )	1,639	3,760	229%
Window Area (ft <sup>2</sup> )	486	1,044	215%
Net Wall Area (ft <sup>2</sup> )	1,268	2,720	236%
Number of HVAC Systems	1	8	
Default Duct Location	1-story: 100% attic 2-story: 65% attic, 35% conditioned space	100% conditioned space	

## High Performance Attics

The CEC specifically requested that the Statewide CASE team provide results for a high performance attics package including R-13 below-deck insulation, R-38 ceiling insulation, R-8 duct insulation, and 5% duct leakage. The following tables provide the per unit and statewide energy impacts and the cost-effectiveness results of the proposed package. Note that the R-8 duct insulation by itself does not save energy in the models due to the assumptions that all ducts are in conditioned space. Duct leakage however, does have an energy impact by itself.

Table 2 presents the energy savings for the package of measures including R-13 below-deck insulation.

*Table 2: Energy impacts per multifamily prototype with R-13 below-deck insulation package*

Climate Zone	Per Unit First Year Savings <sup>2</sup>			
	Electricity Savings <sup>3</sup> (kWh/yr)	Demand Savings (kW)	Natural Gas Savings (Therms/yr)	Total TDV Savings <sup>5</sup> (kBTU)
Climate Zone 1	36	0.0	37	7,586
Climate Zone 2	231	0.4	29	23,455
Climate Zone 3	67	0.1	18	7,934
Climate Zone 4	260	0.5	23	22,202
Climate Zone 5	56	0.1	13	6,403
Climate Zone 6	139	0.3	6	10,788
Climate Zone 7	65	0.2	1	7,169
Climate Zone 8	357	0.6	6	21,576
Climate Zone 9	485	0.8	9	32,294
Climate Zone 10	487	0.7	12	29,162
Climate Zone 11	614	0.7	24	37,584
Climate Zone 12	429	0.6	25	31,111
Climate Zone 13	715	0.9	21	41,482
Climate Zone 14	547	0.7	21	32,573
Climate Zone 15	1398	1.2	2	59,508
Climate Zone 16	226	0.3	64	25,613

1. Unit refers to the multifamily building as a whole, which contains 8 dwelling units.
2. Savings from one unit (weighted prototype building), for the first year the building is in operation.
3. Site electricity savings. Does not include TDV of electricity savings.
4. Calculated using CEC's 2016 TDV factors and methodology. Includes savings from electricity and natural gas.

Table 3 shows the potential statewide energy savings from this package of measures. As described in the CASE report, the CEC provided low, middle, and high forecasts for Residential New Construction starts, and the Statewide CASE Team used the middle forecast. Note that the multifamily forecast includes both high-rise and low-rise multifamily buildings, though this proposal will only affect low-rise multifamily. The CEC does not provide information on the breakdown of high-rise and low-rise construction and thus the statewide savings here are likely inflated.

*Table 3: Statewide multifamily energy impacts of high performance attic package with R-13 below-deck*

Climate Zone	First Year Statewide Savings <sup>1</sup>			
	Electricity Savings <sup>3</sup> (GWh)	Power Demand Reduction (MW)	Natural Gas Savings (MMtherms)	Total TDV Energy Savings <sup>4</sup> (Million kBTU)
Climate Zone 1	0.00	0.00	0.00	0.36
Climate Zone 2	0.12	0.22	0.01	11.90
Climate Zone 3	0.23	0.31	0.06	27.14
Climate Zone 4	0.27	0.52	0.02	23.38
Climate Zone 5	0.01	0.02	0.00	1.31
Climate Zone 6	0.30	0.57	0.01	23.21
Climate Zone 7	0.17	0.51	0.00	19.26
Climate Zone 8	1.39	2.37	0.02	84.22
Climate Zone 9	3.89	6.52	0.07	259.11
Climate Zone 10	0.91	1.32	0.02	54.49
Climate Zone 11	0.13	0.15	0.01	8.15
Climate Zone 12	0.64	0.89	0.04	46.62
Climate Zone 13	0.55	0.66	0.02	31.94
Climate Zone 14	0.27	0.34	0.01	16.03
Climate Zone 15	0.61	0.54	0.00	25.78
Climate Zone 16	0.11	0.17	0.03	13.02
<b>TOTAL</b>	<b>9.6</b>	<b>15.1</b>	<b>0.3</b>	<b>645.9</b>

1. First year savings from all multifamily buildings built statewide during the first year the 2016 Standards are in effect.
2. First year TDV savings from all multifamily buildings built statewide during the first year the 2016 Standards are in effect.
3. Site electricity savings.
4. Calculated using CEC's 2016 TDV factors and methodology.

Table 4 provides the cost-effectiveness results for the HPA package with R-13 below deck insulation at a unit level (a 'unit' for this analysis is the building).

*Table 4: Cost-effectiveness summary for multifamily high performance attic package with R-13 below*

Climate Zone	Benefit: TDV Energy Cost Savings <sup>2</sup> (2016 PV\$)	Cost: Total Incremental Cost <sup>3</sup> (2016 PV\$)	Change in Lifecycle Cost <sup>4</sup> (2016 PV\$)	Benefit to Cost Ratio <sup>5</sup>
Climate Zone 1	\$1,312	\$1,753	\$441	0.7
Climate Zone 2	\$4,058	\$1,651	\$(2,407)	2.5
Climate Zone 3	\$1,373	\$1,651	\$278	0.8
Climate Zone 4	\$3,841	\$1,651	\$(2,190)	2.3
Climate Zone 5	\$1,108	\$1,651	\$543	0.7
Climate Zone 6	\$1,866	\$1,651	\$(215)	1.1
Climate Zone 7	\$1,240	\$1,651	\$411	0.8
Climate Zone 8	\$3,733	\$1,651	\$(2,082)	2.3
Climate Zone 9	\$5,587	\$1,651	\$(3,936)	3.4
Climate Zone 10	\$5,045	\$1,651	\$(3,394)	3.1
Climate Zone 11	\$6,502	\$1,168	\$(5,334)	5.6
Climate Zone 12	\$5,382	\$1,168	\$(4,214)	4.6
Climate Zone 13	\$7,176	\$1,168	\$(6,008)	6.1
Climate Zone 14	\$5,635	\$1,329	\$(4,306)	4.2
Climate Zone 15	\$10,295	\$1,168	\$(9,127)	8.8
Climate Zone 16	\$4,431	\$1,914	\$(2,517)	2.3

1. Relative to existing conditions. All cost values presented in 2016 dollars.
2. Present value of TDV cost savings equals TDV electricity savings plus TDV natural gas savings;  $\Delta TDV\$ = \Delta TDV\$_E + \Delta TDV\$_G$ .
3. Total incremental cost equals incremental construction cost (post adoption) plus present value of incremental maintenance cost;  $\Delta C = \Delta C_{I_{PA}} + \Delta C_M$ .
4. Negative values indicate the measure is cost-effective. Change in lifecycle cost equals cost premium minus TDV energy cost savings;  $\Delta LCC = \Delta C - \Delta TDV\$$
5. The benefit to cost ratio is the TDV energy cost savings divided by the total incremental costs;  $B/C = \Delta TDV\$ \div \Delta C$ . The measure is cost effective if the B/C ratio is 1.0 or greater.

The results for the low-rise multifamily analysis show that this package is cost-effective in most of the same climate zones as the single family results with two exceptions: measure is not cost-effective for multifamily in climate zone 1, whereas it is cost-effective for single family; measure is cost-effective for multifamily in climate zone 6, where it was not cost-effective for single family. The kTDV savings per square foot for multifamily are lower than for single family analysis due to the lower ratio of building envelope area to conditioned square footage in the multifamily prototype (roof-to-floor area percentage is 60% for the multifamily prototype and 86% for the single family prototype). However, the overall savings are higher due to the larger overall square footage of the multifamily prototype as compared to the single family prototypes.

## Alternative High Performance Attic and Ducts in Conditioned Space Scenario Results

There are alternative packages to the proposed high performance attic package, which includes R-13 below deck insulation, that achieve similar savings. Table 5 to Table 9 provide the analysis results for four additional constructions: one for a high performance attic package and three for ducts in conditioned space options.

The multifamily prototype has ducts located in conditioned space, so there are no energy savings or first costs for the ‘Ducts located entirely in conditioned space’ scenario, as it is seen as standard practice. However, there are savings that can be achieved for verifying low duct leakage to the outside and verifying low leakage ducts. The cost for verifying low duct leakage to the outside assumes that the individual unit and the five surrounding units would need to be simultaneously tested. For now, the CASE team has taken the HERS costs per unit from single family and multiplied it by five to get the HERS test cost for multifamily. Likewise, to achieve 3% duct leakage, it is assumed that an HVAC contractor would need to install a low leakage air handler for each unit. The cost estimate from the single family analysis is applied to all eight units.

*Table 5 Energy impacts per multifamily unit for alternative options*

Climate Zone	Per Unit First Year Savings (kTDV/sf) <sup>1</sup>				
	R6 above deck + 5% duct leakage + R38	R13 below deck - RB + 5% duct leakage + R38	Ducts located entirely in conditioned space <sup>2</sup>	Verified low-leakage ducts entirely in conditioned space	Ducts located entirely in conditioned space + 3% Duct Leakage
Climate Zone 1	1.1	1.1	0.0	1.4	0.7
Climate Zone 2	3.6	3.4	0.0	1.6	0.9
Climate Zone 3	1.2	1.1	0.0	0.6	0.3
Climate Zone 4	3.4	3.2	0.0	1.4	0.8
Climate Zone 5	1.0	0.9	0.0	0.5	0.2
Climate Zone 6	1.7	1.6	0.0	0.5	0.3
Climate Zone 7	1.2	1.0	0.0	0.3	0.3
Climate Zone 8	3.3	3.1	0.0	1.4	0.9
Climate Zone 9	5.0	4.6	0.0	2.9	1.8
Climate Zone 10	4.5	4.2	0.0	2.7	1.6
Climate Zone 11	5.8	5.4	0.0	4.9	2.9
Climate Zone 12	4.8	4.5	0.0	3.3	2.0
Climate Zone 13	6.3	6.0	0.0	5.1	3.1
Climate Zone 14	5.1	4.7	0.0	4.7	2.7
Climate Zone 15	9.0	8.5	0.0	10.0	6.3
Climate Zone 16	3.7	3.7	0.0	3.5	1.8

<sup>1</sup> Unit refers to the multifamily building as a whole, which contains 8 dwelling units.

<sup>2</sup> All MF ducts default to conditioned space

Table 6. Percent savings of kTDV/sf for alternative options

Climate Zone	Percent kTDV/sf Savings				
	R6 above deck + 5% duct leakage + R38	R13 below deck - RB + 5% duct leakage + R38	Ducts located entirely in conditioned space <sup>1</sup>	Verified low-leakage ducts entirely in conditioned space	Ducts located entirely in conditioned space + 3% Duct Leakage
Climate Zone 1	2.3%	2.4%	0.0%	3.0%	1.5%
Climate Zone 2	7.4%	6.9%	0.0%	3.4%	1.8%
Climate Zone 3	3.4%	3.2%	0.0%	1.6%	0.8%
Climate Zone 4	7.1%	6.7%	0.0%	2.9%	1.7%
Climate Zone 5	2.9%	2.7%	0.0%	1.4%	0.6%
Climate Zone 6	4.6%	4.2%	0.0%	1.4%	0.9%
Climate Zone 7	3.4%	3.0%	0.0%	1.0%	0.7%
Climate Zone 8	6.8%	6.3%	0.0%	2.9%	1.9%
Climate Zone 9	8.1%	7.6%	0.0%	4.7%	2.9%
Climate Zone 10	7.2%	6.8%	0.0%	4.3%	2.6%
Climate Zone 11	6.5%	6.1%	0.0%	5.5%	3.3%
Climate Zone 12	6.7%	6.3%	0.0%	4.7%	2.8%
Climate Zone 13	7.0%	6.6%	0.0%	5.7%	3.4%
Climate Zone 14	6.0%	5.6%	0.0%	5.5%	3.1%
Climate Zone 15	7.2%	6.8%	0.0%	8.0%	5.0%
Climate Zone 16	5.0%	5.1%	0.0%	4.8%	2.5%

<sup>1</sup>. All MF ducts default to conditioned space

Table 7. Present value (2016\$) of energy cost savings for alternative approaches

Climate Zone	Present Value of Energy Cost Savings (\$)¹				
	R6 above deck + 5% duct leakage + R38	R13 below deck - RB + 5% duct leakage + R38	Ducts located entirely in conditioned space²	Verified low-leakage ducts entirely in conditioned space	Ducts located entirely in conditioned space + 3% Duct Leakage
Climate Zone 1	\$1,264	\$1,312	\$0	\$1,650	\$807
Climate Zone 2	\$4,323	\$4,058	\$0	\$1,975	\$1,060
Climate Zone 3	\$1,493	\$1,373	\$0	\$674	\$349
Climate Zone 4	\$4,094	\$3,841	\$0	\$1,686	\$975
Climate Zone 5	\$1,192	\$1,108	\$0	\$578	\$253
Climate Zone 6	\$2,059	\$1,866	\$0	\$626	\$409
Climate Zone 7	\$1,409	\$1,240	\$0	\$397	\$301
Climate Zone 8	\$3,986	\$3,733	\$0	\$1,686	\$1,096
Climate Zone 9	\$5,984	\$5,587	\$0	\$3,456	\$2,155
Climate Zone 10	\$5,370	\$5,045	\$0	\$3,191	\$1,951
Climate Zone 11	\$6,984	\$6,502	\$0	\$5,900	\$3,528
Climate Zone 12	\$5,731	\$5,382	\$0	\$3,973	\$2,408
Climate Zone 13	\$7,634	\$7,176	\$0	\$6,189	\$3,745
Climate Zone 14	\$6,081	\$5,635	\$0	\$5,611	\$3,191
Climate Zone 15	\$10,861	\$10,295	\$0	\$12,089	\$7,634
Climate Zone 16	\$4,395	\$4,431	\$0	\$4,202	\$2,216

1. Present value of TDV cost savings equals TDV electricity savings plus TDV natural gas savings;  $\Delta TDV\$ = \Delta TDV\$\text{E} + \Delta TDV\$\text{G}$ .

2. All MF ducts default to conditioned space

*Table 8. First costs for alternative approaches in a multifamily unit*

Climate Zone	Measure First Cost (\$)				
	R6 above deck + 5% duct leakage + R38	R13 below deck - RB + 5% duct leakage + R38	Ducts located entirely in conditioned space <sup>1</sup>	Verified low-leakage ducts entirely in conditioned space	Ducts located entirely in conditioned space + 3% Duct Leakage
Climate Zone 1	\$2,512	\$1,753	\$0	\$625	\$612
Climate Zone 2	\$2,995	\$1,651	\$0	\$625	\$612
Climate Zone 3	\$2,995	\$1,651	\$0	\$625	\$612
Climate Zone 4	\$2,995	\$1,651	\$0	\$625	\$612
Climate Zone 5	\$2,995	\$1,651	\$0	\$625	\$612
Climate Zone 6	\$2,995	\$1,651	\$0	\$625	\$612
Climate Zone 7	\$2,995	\$1,651	\$0	\$625	\$612
Climate Zone 8	\$2,995	\$1,651	\$0	\$625	\$612
Climate Zone 9	\$2,995	\$1,651	\$0	\$625	\$612
Climate Zone 10	\$2,995	\$1,651	\$0	\$625	\$612
Climate Zone 11	\$2,512	\$1,168	\$0	\$625	\$612
Climate Zone 12	\$2,512	\$1,168	\$0	\$625	\$612
Climate Zone 13	\$2,512	\$1,168	\$0	\$625	\$612
Climate Zone 14	\$2,512	\$1,329	\$0	\$625	\$612
Climate Zone 15	\$2,512	\$1,168	\$0	\$625	\$612
Climate Zone 16	\$2,512	\$1,914	\$0	\$625	\$612

<sup>1</sup>. All MF ducts default to conditioned space



Table 9. Life Cycle Cost for alternative approaches in a multifamily unit

Climate Zone	Life Cycle Cost (\$)¹				
	R6 above deck + 5% duct leakage + R38	R13 below deck - RB + 5% duct leakage + R38	Ducts located entirely in conditioned space²	Verified low-leakage ducts entirely in conditioned space	Ducts located entirely in conditioned space + 3% Duct Leakage
Climate Zone 1	\$1,248	\$441	\$0	\$(1,025)	\$(194)
Climate Zone 2	\$(1,328)	\$(2,407)	\$0	\$(1,350)	\$(447)
Climate Zone 3	\$1,502	\$278	\$0	\$(49)	\$263
Climate Zone 4	\$(1,099)	\$(2,190)	\$0	\$(1,061)	\$(363)
Climate Zone 5	\$1,803	\$543	\$0	\$47	\$360
Climate Zone 6	\$936	\$(215)	\$0	\$(1)	\$203
Climate Zone 7	\$1,586	\$411	\$0	\$228	\$311
Climate Zone 8	\$(991)	\$(2,082)	\$0	\$(1,061)	\$(483)
Climate Zone 9	\$(2,989)	\$(3,936)	\$0	\$(2,831)	\$(1,543)
Climate Zone 10	\$(2,375)	\$(3,394)	\$0	\$(2,566)	\$(1,338)
Climate Zone 11	\$(4,472)	\$(5,334)	\$0	\$(5,275)	\$(2,915)
Climate Zone 12	\$(3,219)	\$(4,214)	\$0	\$(3,348)	\$(1,796)
Climate Zone 13	\$(5,122)	\$(6,008)	\$0	\$(5,564)	\$(3,132)
Climate Zone 14	\$(3,569)	\$(4,306)	\$0	\$(4,986)	\$(2,578)
Climate Zone 15	\$(8,349)	\$(9,127)	\$0	\$(11,464)	\$(7,021)
Climate Zone 16	\$(1,883)	\$(2,517)	\$0	\$(3,577)	\$(1,603)

¹. Negative values indicate the measure is cost-effective. Change in lifecycle cost equals cost premium minus TDV energy cost savings;  $\Delta LCC = \Delta C - \Delta TDV\$$

². All MF ducts default to conditioned space

Note that in Table 9, a negative value indicates that the measure is cost-effective.

## High Performance Walls Results

The CEC specifically requested that the Statewide CASE team provide results for high performance walls with a U-factor of 0.049. The construction assembly used to estimate savings and cost for this U-factor, as described in the CASE report, is 2x6 studs at 16" on-center, with R-19 cavity insulation and R-6 exterior insulation, though other combinations of cavity and exterior insulation can achieve a similar U-factor for compliance purposes.

*Table 10: Energy impacts per multifamily prototype with exterior walls U-factor = 0.049*

Climate Zone	Per Unit First Year Savings <sup>2</sup>			
	Electricity Savings <sup>3</sup> (kWh/yr)	Demand Savings (kW)	Natural Gas Savings (Therms/yr)	Total TDV Savings <sup>5</sup> (kBTU)
Climate Zone 1	55	0.0	69	14,268
Climate Zone 2	56	0.0	45	11,762
Climate Zone 3	21	0.0	30	6,890
Climate Zone 4	49	0.1	37	9,744
Climate Zone 5	1	0.0	28	4,733
Climate Zone 6	9	0.0	12	3,341
Climate Zone 7	-2	0.0	1	557
Climate Zone 8	19	0.1	9	5,081
Climate Zone 9	63	0.2	15	10,022
Climate Zone 10	94	0.2	19	11,414
Climate Zone 11	217	0.3	45	22,759
Climate Zone 12	116	0.2	44	17,191
Climate Zone 13	226	0.3	39	22,272
Climate Zone 14	205	0.3	45	21,158
Climate Zone 15	532	0.5	3	25,961
Climate Zone 16	81	0.0	90	21,158

- <sup>3.</sup> Unit refers to the multifamily building as a whole, which contains 8 dwelling units.
- <sup>4.</sup> Savings from one unit (weighted prototype building), for the first year the building is in operation.
- <sup>5.</sup> Site electricity savings. Does not include TDV of electricity savings.
- <sup>6.</sup> Calculated using CEC's 2016 TDV factors and methodology. Includes savings from electricity and natural gas.

As described in the CASE report, the CEC provided low, middle, and high forecasts for Residential New Construction, and the Statewide CASE Team used the middle forecast for the statewide savings estimates.

*Table 11: Statewide energy impacts of exterior walls U-factor = 0.049*

Climate Zone	First Year Statewide Savings <sup>1</sup>			
	Electricity Savings <sup>3</sup> (GWh)	Power Demand Reduction (MW)	Natural Gas Savings (MMtherms)	Total TDV Energy Savings <sup>4</sup> (Million kBTU)
Climate Zone 1	0.00	0.00	0.00	0.7
Climate Zone 2	0.03	0.02	0.02	6.0
Climate Zone 3	0.07	0.03	0.10	23.6
Climate Zone 4	0.05	0.06	0.04	10.3
Climate Zone 5	0.00	-0.01	0.01	1.0
Climate Zone 6	0.02	0.05	0.03	7.2
Climate Zone 7	-0.01	0.06	0.00	1.5
Climate Zone 8	0.07	0.52	0.03	19.8
Climate Zone 9	0.51	1.76	0.12	80.4
Climate Zone 10	0.18	0.46	0.03	21.3
Climate Zone 11	0.05	0.06	0.01	4.9
Climate Zone 12	0.17	0.27	0.07	25.8
Climate Zone 13	0.17	0.26	0.03	17.1
Climate Zone 14	0.10	0.14	0.02	10.4
Climate Zone 15	0.23	0.23	0.00	11.2
Climate Zone 16	0.04	0.02	0.05	10.8
<b>TOTAL</b>	<b>1.7</b>	<b>3.9</b>	<b>0.6</b>	<b>252</b>

7. First year savings from all buildings built statewide during the first year the 2016 Standards are in effect.
8. First year TDV savings from all buildings built statewide during the first year the 2016 Standards are in effect.
9. Site electricity savings.
10. Calculated using CEC's 2016 TDV factors and methodology.

*Table 12: Cost-effectiveness summary for exterior walls U-factor = 0.049*

Climate Zone	Benefit: TDV Energy Cost Savings <sup>2</sup> (2016 PV\$)	Cost: Total Incremental Cost <sup>3</sup> (2016 PV\$)	Change in Lifecycle Cost <sup>4</sup> (2016 PV\$)	Benefit to Cost Ratio <sup>5</sup>
Climate Zone 1	\$2,468	\$818	(\$1,650)	3.0
Climate Zone 2	\$2,035	\$818	(\$1,217)	2.5
Climate Zone 3	\$1,192	\$818	(\$374)	1.5
Climate Zone 4	\$1,686	\$818	(\$868)	2.1
Climate Zone 5	\$819	\$818	(\$1)	1.0
Climate Zone 6	\$578	\$818	\$240	0.7
Climate Zone 7	\$96	\$818	\$722	0.1
Climate Zone 8	\$879	\$818	(\$61)	1.1
Climate Zone 9	\$1,734	\$818	(\$916)	2.1
Climate Zone 10	\$1,975	\$818	(\$1,157)	2.4
Climate Zone 11	\$3,937	\$818	(\$3,119)	4.8
Climate Zone 12	\$2,974	\$818	(\$2,156)	3.6
Climate Zone 13	\$3,853	\$818	(\$3,035)	4.7
Climate Zone 14	\$3,660	\$818	(\$2,842)	4.5
Climate Zone 15	\$4,491	\$818	(\$3,673)	5.5
Climate Zone 16	\$3,660	\$818	(\$2,842)	4.5

11. Relative to existing conditions. All cost values presented in 2016 dollars.
12. Present value of TDV cost savings equals TDV electricity savings plus TDV natural gas savings;  $\Delta\text{TDV}\$ = \Delta\text{TDV}\$\text{E} + \Delta\text{TDV}\$\text{G}$ .
13. Total incremental cost equals incremental construction cost (post adoption) plus present value of incremental maintenance cost;  $\Delta\text{C} = \Delta\text{C}_{\text{PA}} + \Delta\text{C}_{\text{M}}$ .
14. Negative values indicate the measure is cost-effective. Change in lifecycle cost equals cost premium minus TDV energy cost savings;  $\Delta\text{LCC} = \Delta\text{C} - \Delta\text{TDV}\$$
15. The benefit to cost ratio is the TDV energy cost savings divided by the total incremental costs;  $\text{B/C} = \Delta\text{TDV}\$ \div \Delta\text{C}$ . The measure is cost effective if the B/C ratio is 1.0 or greater.

As in the single family cost-effectiveness results, the High Performance Walls proposal is not cost effective for the multifamily prototype in Climate Zone 7. Additionally, the measure is also not cost-effective in Climate Zone 6. This may be due to the fact that the net-wall-to-floor ratio is 52% in the weighted single-family prototype, while it is 39% in the multifamily prototype. Thus, for each square foot of floor area, high performance walls will have less of an impact in the multifamily prototype. This supports the fact that, averaged across all climate zones, the modeled kTDV/s.f. savings due to high performance walls in multifamily prototypes (3.1%) is approximately half the savings in single family prototypes (5.7%).