Energy & Environmental Solutions

Energy Analysis for Window Films Applications in New and Existing Homes and Offices – Revised July 19, 2013

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Overview of this Study

The purpose of this study is to demonstrate the cost-effectiveness of external and internal energy control window film in homes and offices, in order to make a case for inclusion in energy and green codes, programs, and incentives in the state of California and expand opportunities for window film in the California market. The internal window film portions of this study have been released previously (February 10, 2012) and are now combined with similar analyses for external window film. The study is organized into two sections: energy impacts of external and internal window film on new and existing buildings.

Energy Analysis for Internal Window Films Applications in New and Existing Homes and Offices

Purpose of This Study/ Scope

The purpose of this study is to demonstrate the cost-effectiveness of internally applied energy control window film in homes and offices, in order to make a case for inclusion in energy and green codes, programs, and incentives in the state of California and expand opportunities for window film in the California market.

Energy Analysis

Description of New and Existing Baselines

The home modeled in the study is a 2,123 ft^2, two-story, single family detached unit, with a glazing percentage of 20% of the conditioned floor area. This house is representative of the new construction housing in California. In the new home model, the energy features of the building was specified as meeting Title 24 Building Energy Efficiency Standards, Part 6 (Title 24) for 2008, the requirements for buildings built at the time of this report. The baseline glass type, however, was not code-compliant glass (0.40 U-factor, 0.40 SHGC), but clear, dual pane glass (0.71 U-factor, 0.63 SHGC). NFRC data for window film is benchmarked against clear glass, and the impact of window film is determined by NFRC ratings, which are recognized by the California Energy Commission (CEC) for code compliance. All residential analysis was done using MICROPAS, which is the most frequently used residential compliance software certified for Title 24.

The existing home baseline was the same model as the new homes, but modified to reflect decreased efficiencies, insulation levels and other features according to TABLE R3-50: Vintage Table Values in

appendix B of the of the 2008 Residential Compliance Manual. The energy features of the existing building represented those features used for a house built in the 1990s.

The office building modeled in the study is the Energy Plus Commercial Building Benchmark Model developed by the U.S. Department of Energy (DOE), titled large office building. A version of Energy Plus, modified to comply with the 2008 version of Title 24, rather than with ASHRAE 90.1 Standards, was obtained from the California Energy Commission (CEC) to model the new office building in this study. The office building is 12 stories, and 498,588 ft^2 in conditioned floor area.

The existing large office building is based off of the same model, with energy features modified to comply with the Standards for 1990.

Both residential and office simulations were run in each of the four cardinal directions and the energy usage was averaged over the four orientations.

Description of Variables

The homes were simulated in four key climate zones of the sixteen climate zones recognized in California for the purposes of code requirements. The climate zones were chosen in order to get a range of conditions and represent areas with greater building numbers. These were the mild climate of the Northern California Bay Area (CZ4), the coastal climate zone of San Diego (CZ7), the inland climate zone of Riverside (CZ10) and the Central Valley climate zone of Sacramento (CZ12). These climate zones are representative of the areas where most homes are built in the state. Climate Zones 10 and 12 represent locations with high cooling loads where window film should have a substantial impact on energy use.

The office buildings were simulated in a different set of climate zones, based off of volume of existing and new commercial construction. The representative cities for these climate zones are Oakland (CZ3), San Diego (CZ7), Pasadena (CZ9), and Fresno (CZ13).

Using data from manufacturers and the National Fenestration Rating Council (NFRC) Certified Products Directory, the Directory, the internal window films on the market were characterized into three groups, “good”, “better” and “best” “better” and “best” options, and a rounded median value chosen for solar heat gain coefficient (SHGC) and U-factor. The and U-factor. The values used for residential energy use are detailed in

Table 1 and the office building values are detailed in Table 2 (shown below). For the office building model, the visible transmittance is also modeled for the purposes of evaluating daylighting design, which is not modeled in the residential software. The films were also evaluated with and without an impact on U-factor to account for the variations in different manufacturers’ products, as some do not achieve significant U-factor differences, yet still achieve significant savings through limiting solar heat gain. The good, better, and best categories in the large office model represent these basic technology films which limit primarily solar heat gain. The better (u) and best (u) categories represent spectrally selective and low-e technology films, respectively.

Table 1: Properties of Windows Studied for the Residential Model

	without	good	better	best
SHGC				
Single	0.71	0.45	0.35	0.20
Double	0.63	0.50	0.45	0.25
U-factor				
Single	1.09	1.09	0.90	0.70
Double	0.71	0.71	0.65	0.55
Cost/ft^2		$4.00	$7.00	$9.00

Table 2: Properties of Windows Studied for the Large Office Model

	without	good	better	best	better(u)	best(u)
SHGC						
Single	0.71	0.45	0.35	0.20	0.35	0.20
Double	0.63	0.50	0.45	0.25	0.45	0.25
U-factor						
Single	1.09	1.09	1.09	1.09	0.90	0.70
Double	0.71	0.71	0.71	0.71	0.65	0.55
VT						
Single	0.74	0.5	0.30	0.18	0.30	0.18
Double	0.67	0.5	0.30	0.18	0.30	0.18
Cost/ft^2		$4.00	$4.00	$4.00	$5.50	$7.00

Simulation Software

The simulation software used for the residential models is MICROPAS v8.1 (r03), which is the CEC certified software for demonstrating compliance with Title 24. The simulation runs an annual, hourly calculation for each of the 8,760 hours throughout the year, accounting for interactions between the heating and cooling systems, lighting and envelope features including the fenestration. This performance software is typically used to give builders the flexibility to trade off energy measures with those that would be required if one follows the prescriptive package of Title 24 approach to compliance. The performance method is the least expensive path to compliance and used by the vast majority of builders to obtain compliance with Title 24.

Table 1 above represents the variables use in the residential simulation. Note it does not include the visible transmittance, because MICROPAS does not use this variable, nor does it have the capability to model daylighting controls. Daylighting controls are not common in residential spaces, and any dimming

or shutting off of lights in homes is performed by occupants who determine if there is adequate light in the space.

The simulation software used for the commercial model is Energy Plus v6.0, which is the most recent generation of modeling software from the Department of Energy. This simulation was also run as an 8760 hour annual simulation. Energy Plus also takes into account building system interactions with each other and with building envelope features, but has additional capabilities to model many non-residential features not available in MICROPAS. The simulations were run with daylighting controls active, since window film can lower the visible light transmittance which interacts with that feature of energy conscious design in large office buildings.

Results

The results in this internal window film study are presented differently for the residential and commercial office buildings. For residential applications, the most important information is how the measure compares to other energy efficiency measures that might be taken when considering a new home or a home retrofit. The energy unit used in Title 24 compliance software is a measurement used by the CEC known as "Time Dependent Valuation" of energy or TDV. The MICROPAS software automatically calculates energy savings in TDV, which is the compliance standard measure for energy use. Energy used during peak usage hours (approximately noon – 7 PM in the summer) is weighted more heavily than energy used at night (off peak). TDV energy emphasizes the impact of energy features that reduce peak load (primarily air conditioning load). This is beneficial for window film savings, since the energy saved by applying window film is typically space cooling energy which occurs during the peak period.

For commercial applications, the return on investment (ROI) is the deciding factor in implementing an energy measure. The results presented here are the return on investment for the application of the window film alone. Utility incentives or other rebate programs represent additional financial incentives to make the investment in energy efficiency and will be discussed in a separate section of this report.

Results in New Homes

The window film in the new home application has a simple payback of 10 to 43 years depending on climate zone. Figure 1 through Figure 4 show internal window films (red bars) in relation to other energy efficiency measures (blue bars) considered for new homes. Only the application of the window film to double pane glass is included in the results for new homes, since new homes would not be code compliant with single pane glass. The energy efficiency features used in new construction are:

- 0.92 AFUE furnace – higher efficiency heating equipment
- 0.30/0.30 glazing – windows with 0.30 U-factor and 0.30 SHGC (code requires 0.40/0.40)
- 13, 14, or 15 SEER – choose more efficent AC equipment
- Buried ducts – ducts buried in ceiling insulation to reduce energy losses
- Concrete roof/ cool concrete roof/ clay roof/ cool clay roof/ cool asphalt roof – roof with higher reflectance value than standard asphalt roof letting less heat into space
- Efficent air conditioniong (AC) motor

- One coat stucco – wrap house in R-4 foam and exterior thin coat stucco
- Low air infiltration – seal leaks in envelope
- Quality Insulation – proceses and testing to ensure insulation is installed to be most effective
- R-6 HVAC ducts – increased insulation on air ducts
- R-7 slab edge insulation –insulating edge of slab
- R-15 or R-21 walls – increased insulation level in walls
- Radiant barrier – reflective material on underside of roof deck; reduces heat gain in attic
- Right Sizing AC – analysing heating and cooling loads; choosing apropriate equipment size for load of house
- Tankless water heater – water heated as needed; reduces heat loss from standing hot water
- Tight ducts – diagnostically test ducts to ensure low leakage rates from HVAC ductwork

Figures 1 through 4 demonstrate internal window film in residential new construction is not a competitive choice to meet the energy code (Title 24). More wall insulation (one coat sutto), low air infiltration, radiant barrier, and tight HVAC ducts produce more TDV energy savings in the various climate zones than internal window films. In the hotter Central Valley and Riverside climate zones (Figures 3 and 4) where air conditioning is a significant portion of energy high efficinecy air conditioning equipment was also more TDV energy efficient than internal window films. This result is anticipated as windows in new construction are required to have excellent u-values and low SHGCs. The 2008 Title 24 requirement for new homes assumes windows with a solar heat gain coefficient of no more than 0.4 which already surpasses the performance of the first level of product in this study when applied to clear glass. There is little room for energy savings through the window when the base window installed in new construction is very efficient.

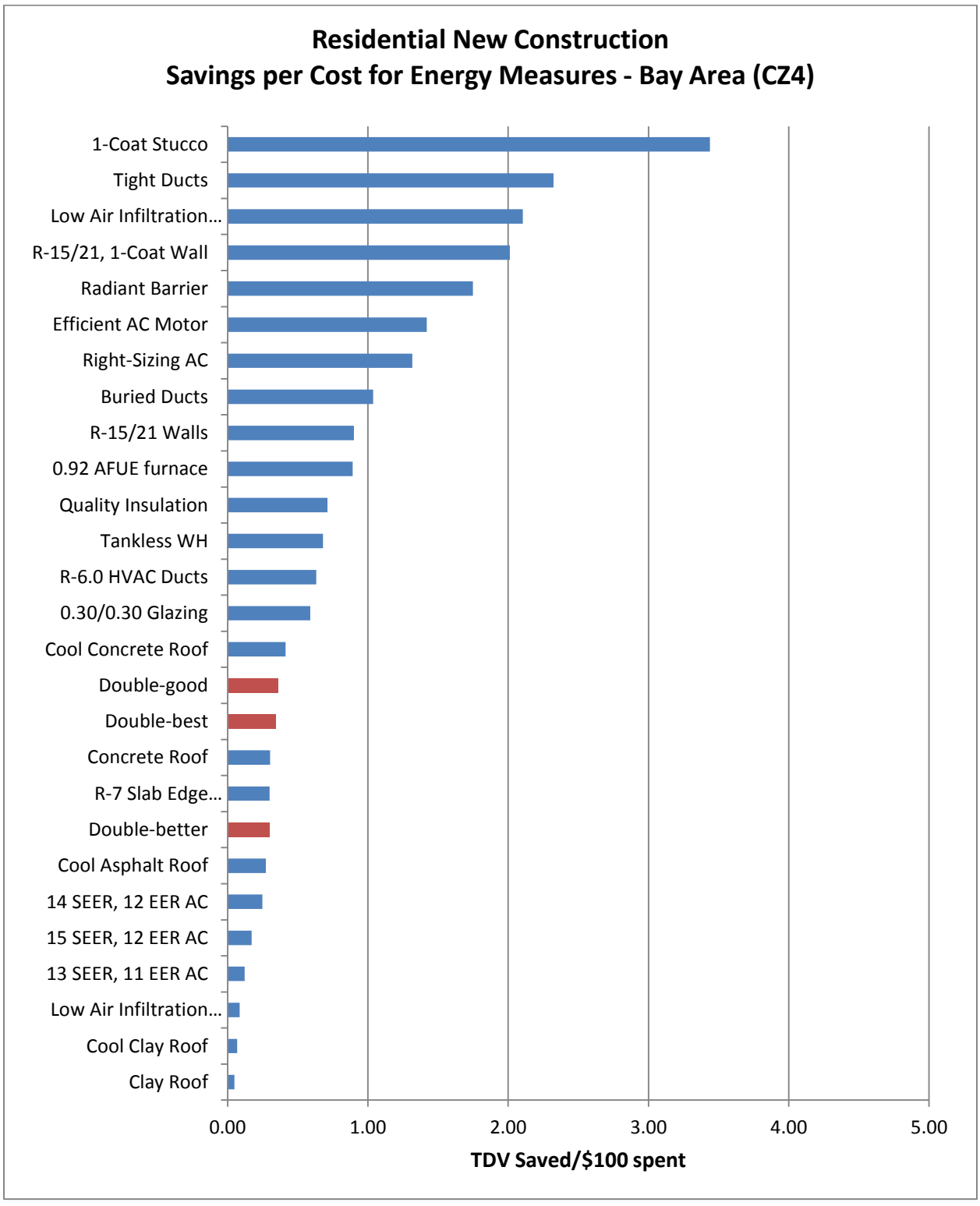


Figure 1: Residential New Construction: Savings per Cost for Energy Measures - Bay Area (CZ4)

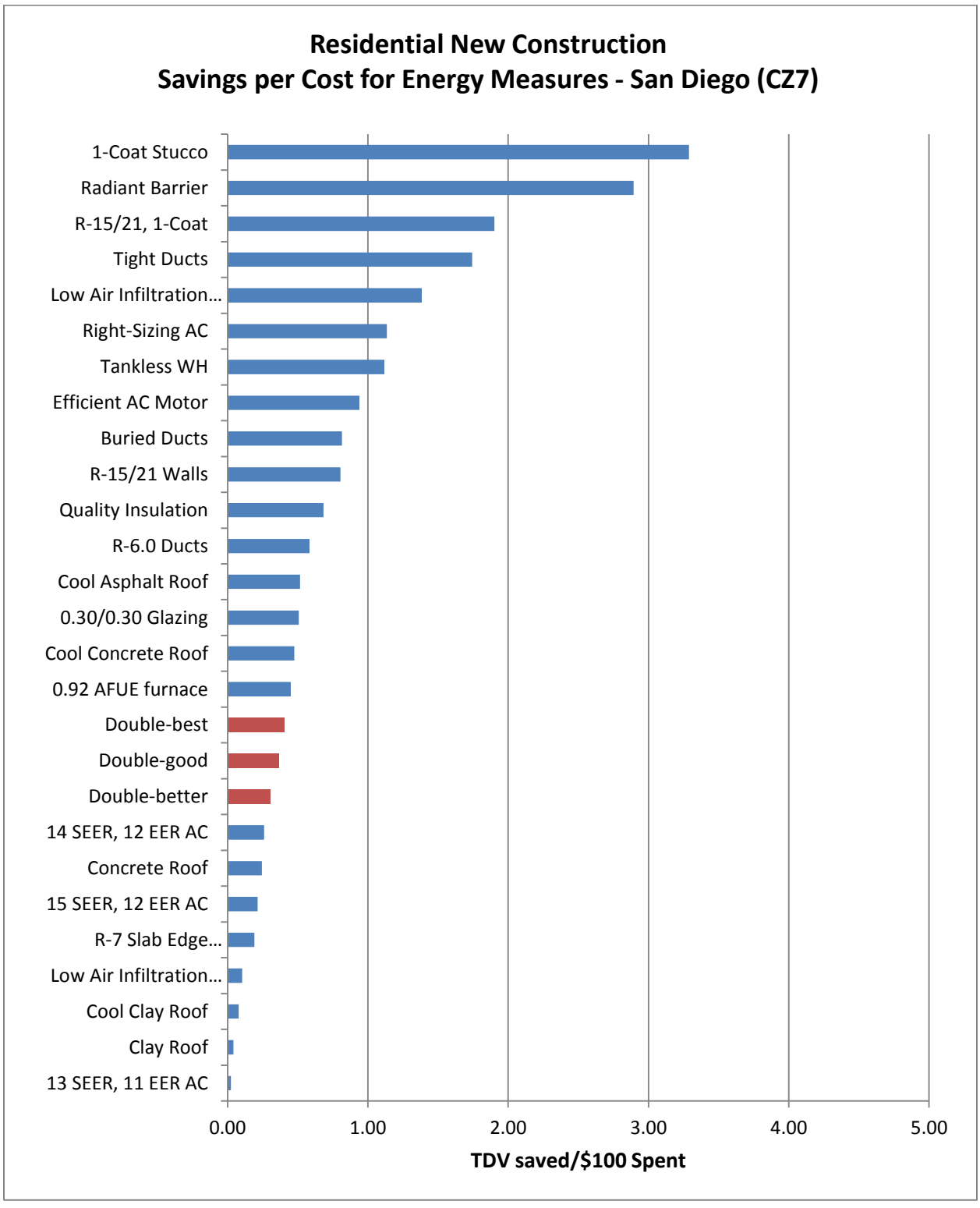


Figure 2: Residential New Construction: Savings per Cost for Energy Measures - San Diego (CZ7)

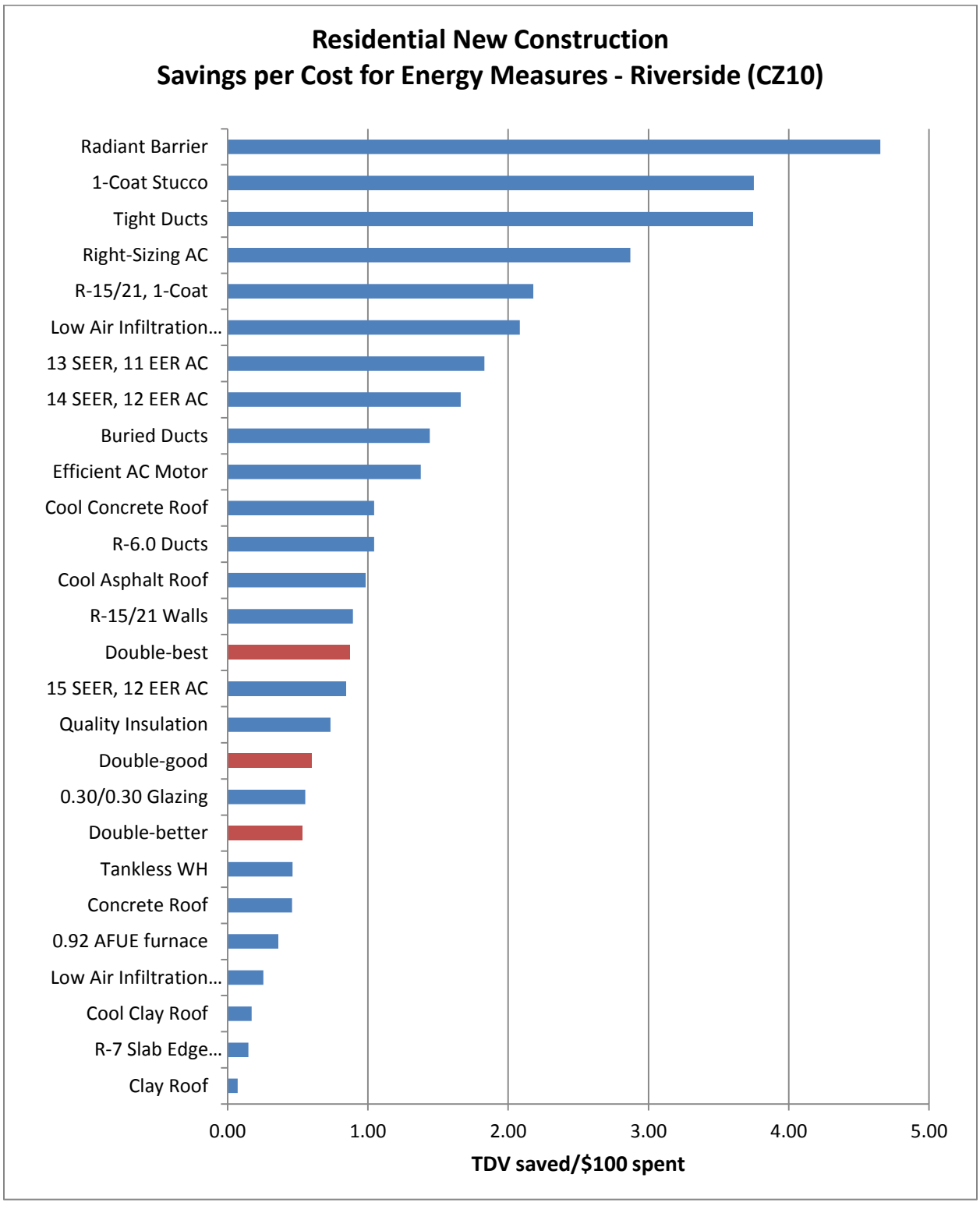


Figure 3: Residential New Construction: Savings per Cost for Energy Measures - Riverside (CZ10)

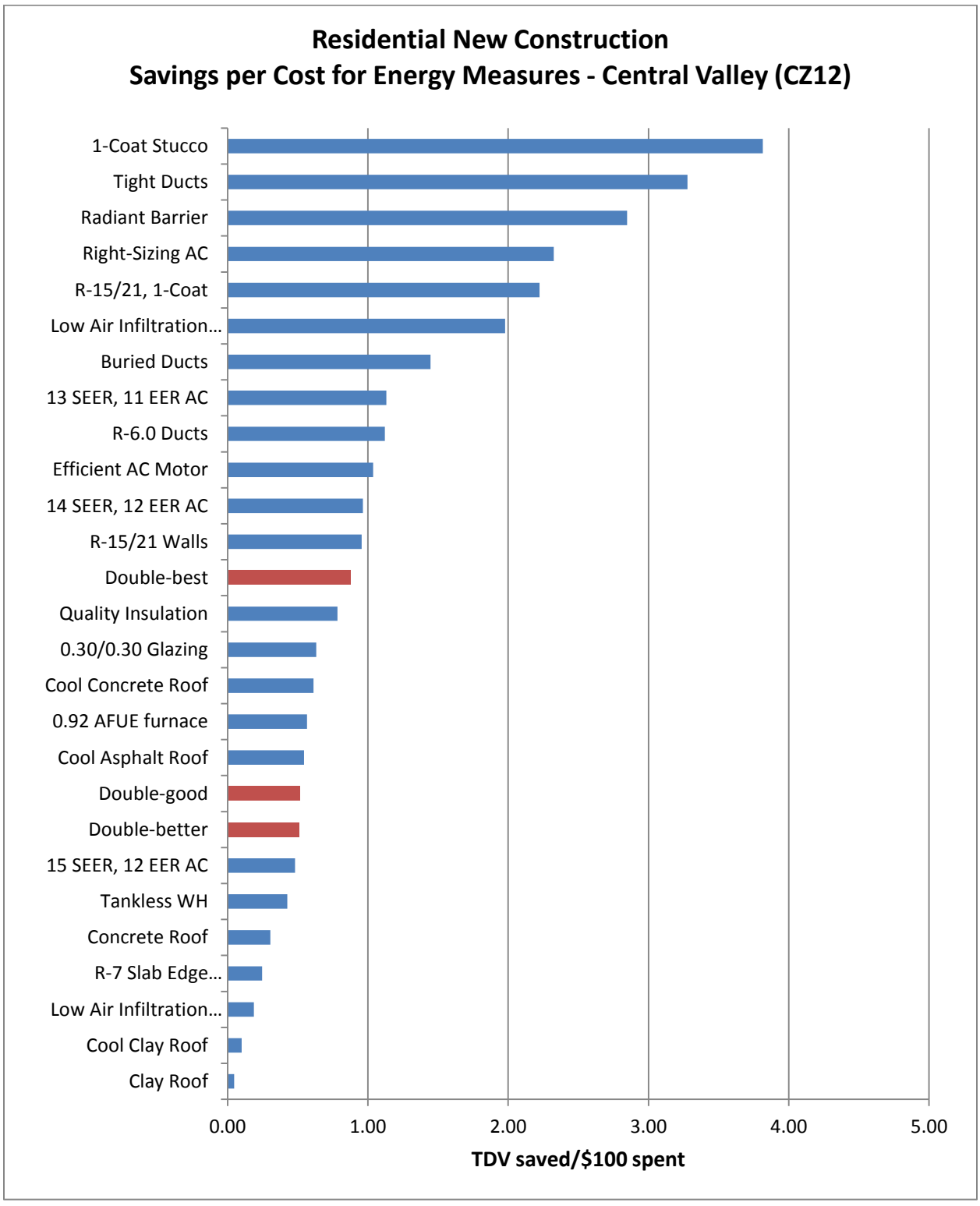


Figure 4: Residential New Construction: Savings per Cost for Energy Measures - Central Valley (CZ12)

Results in Existing Homes:

In Figure 5 through Figure 8, the orange bars represent the effect of internal window film on single pane existing glass, and the red bars represent the effect of film on existing double pane glass. The blue bars as before are the other common energy efficiency measures used during retrofits. Typically, there are fewer energy efficient features considered for retrofitting a home compared to the energy features considered for new construction.

The energy efficiency features that window film was compared to for existing homes are:

- R-38 ceiling insulation – adding insulation to the attic
- 0.80 AFUE furnace – replacing furnace with more efficient new unit
- 13 SEER, 11 EER AC – replacing AC equipment with more efficient new unit
- Air Sealing – sealing gaps in building envelope (walls, doors, around windows, etc.)

Figures 5 through 8 demonstrate installing internal window films are the most cost effective energy efficiency feature that can be added to an existing California home. Window films are more energy efficient to install than new furnaces, new air conditioning, more ceiling insulation and caulking and sealing the existing home. In the warmer climate zones of Riverside and the Central Valley, the savings from internal window film are twice that of the moderate climates of the coast (San Diego) and mild inland (Bay Area).

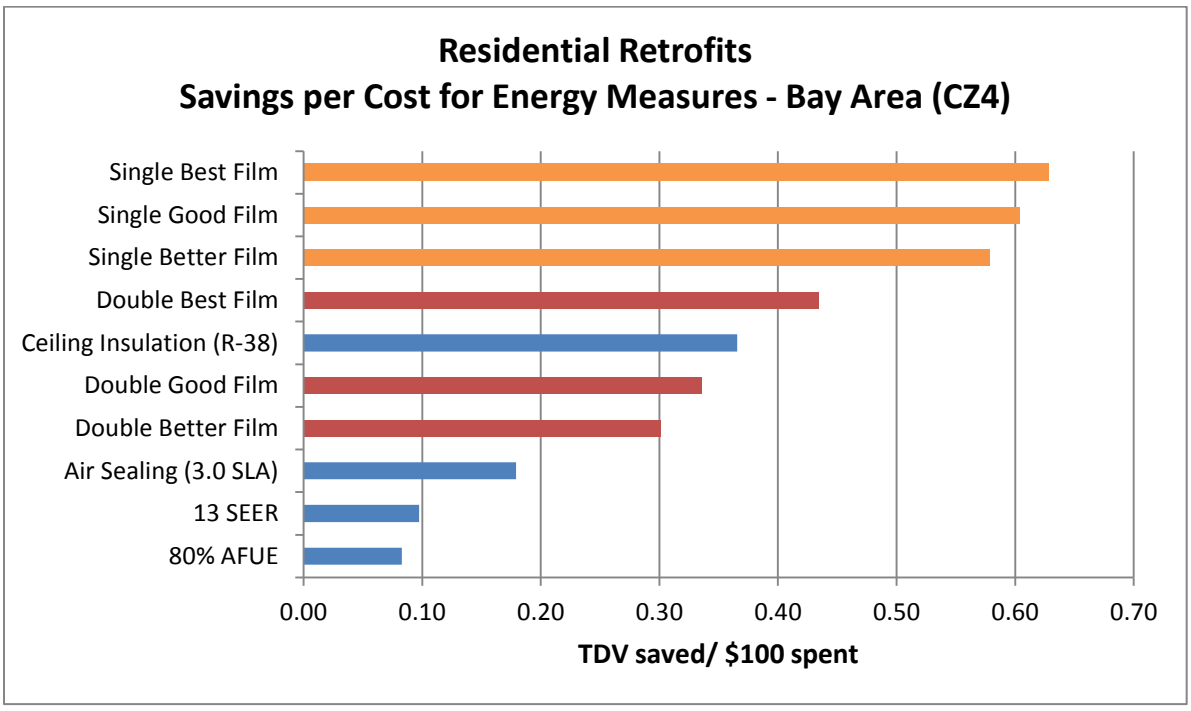


Figure 5: Residential Retrofits: Savings per Cost for Energy Measures - Bay Area (CZ4)

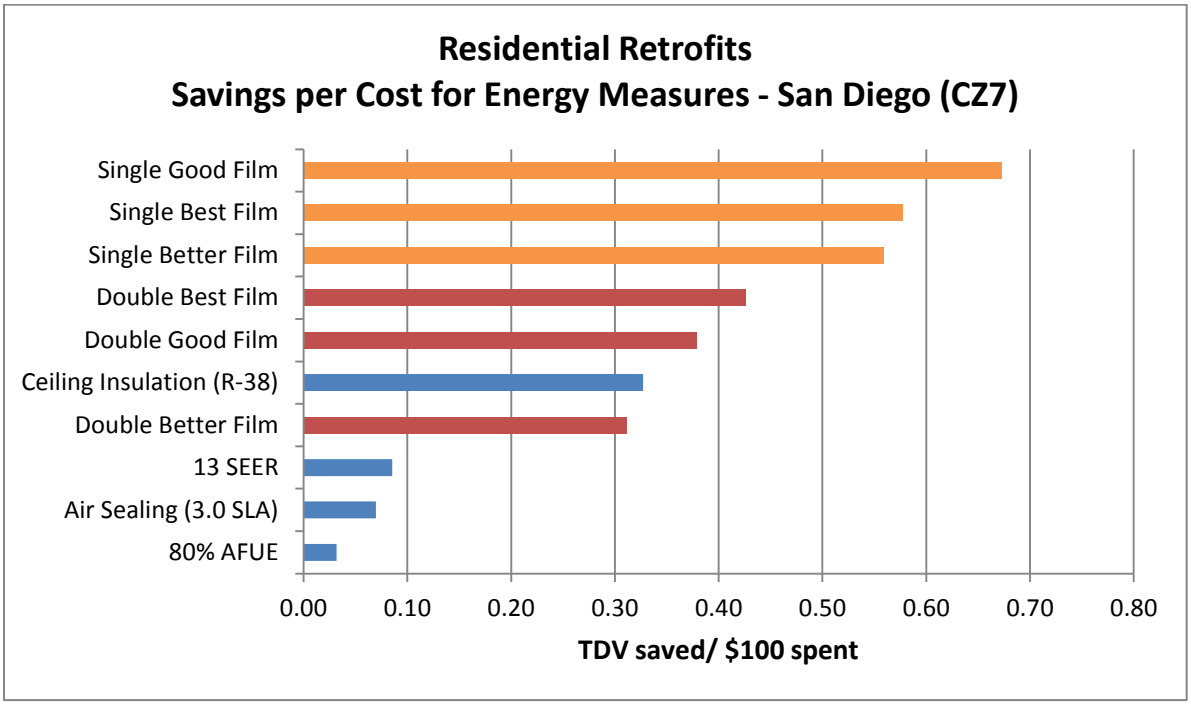


Figure 6: Residential Retrofits: Savings per Cost for Energy Measures - San Diego (CZ7)

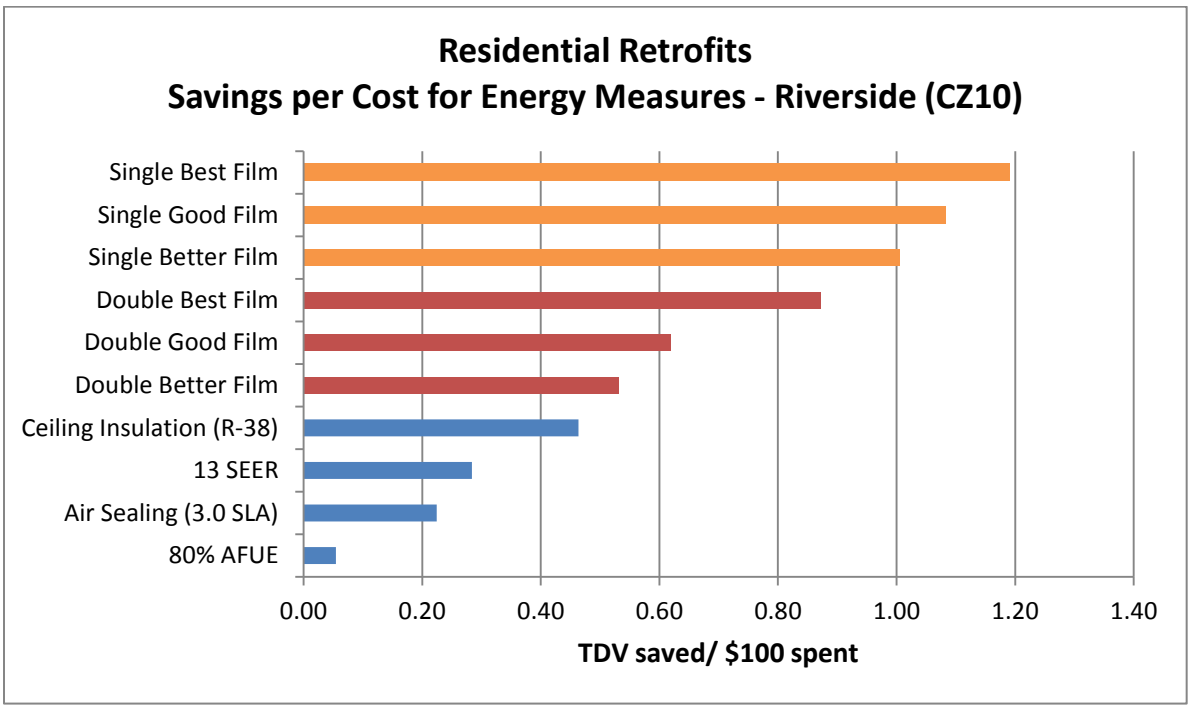


Figure 7: Residential Retrofits: Savings per Cost for Energy Measures - Riverside (CZ10)

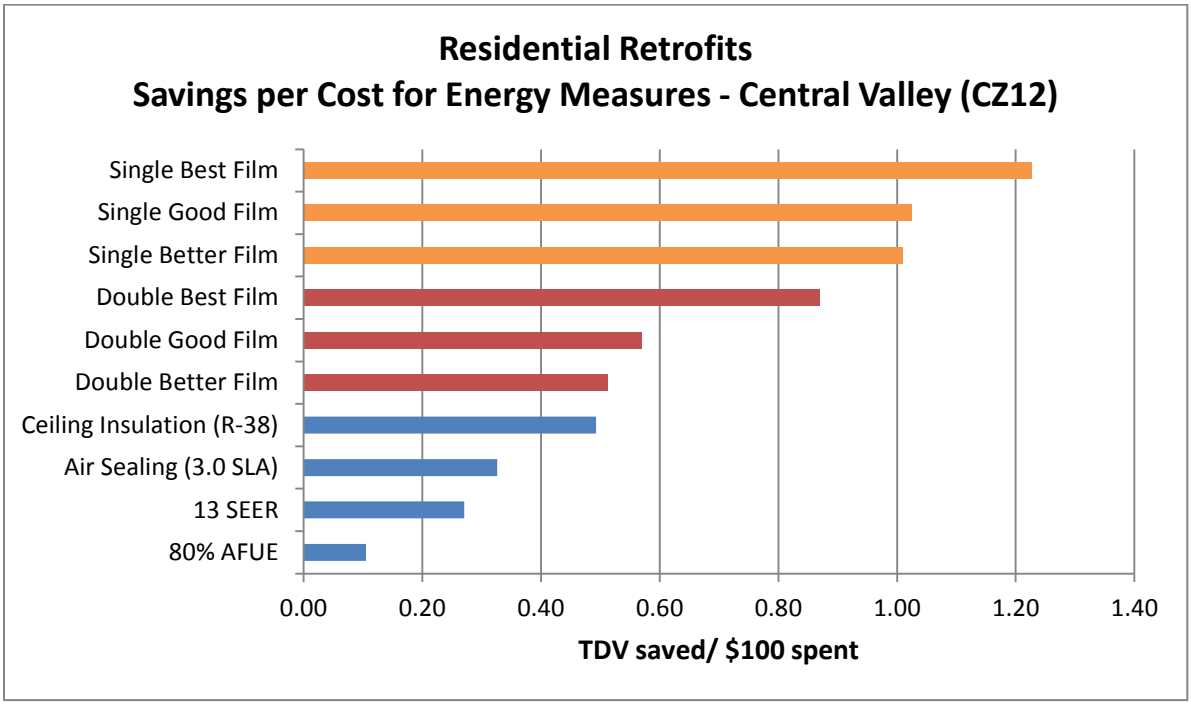


Figure 8: Residential Retrofits: Savings per Cost for Energy Measures - Central Valley (CZ12)

Results in New Offices:

In new construction, the return–on-investments (ROIs) for offices are around 1-3% annually, due to the fact that code compliant windows are already using high performance glazing (0.47U/0.31SHGC). Building owners want energy features to have between a 3 to 5 year payback, and a 20% to 33% ROI. Window films are not an attractive energy efficiency option for new office buildings.

Results in Existing Offices:

In existing offices, window film represents a significant opportunity for cost effective energy savings. Figure 9 shows the typical electricity breakdown in the large office building by end use. The cooling electricity is isolated from this data in Figure 10, to demonstrate the effect that window film has on space cooling, which is the majority of the savings (along with reduced fan energy which is the other end use involved in cooling the building). Return on investment ranges from 10% to 77% annually depending on climate zone and product as detailed in Table 3 through Table 10

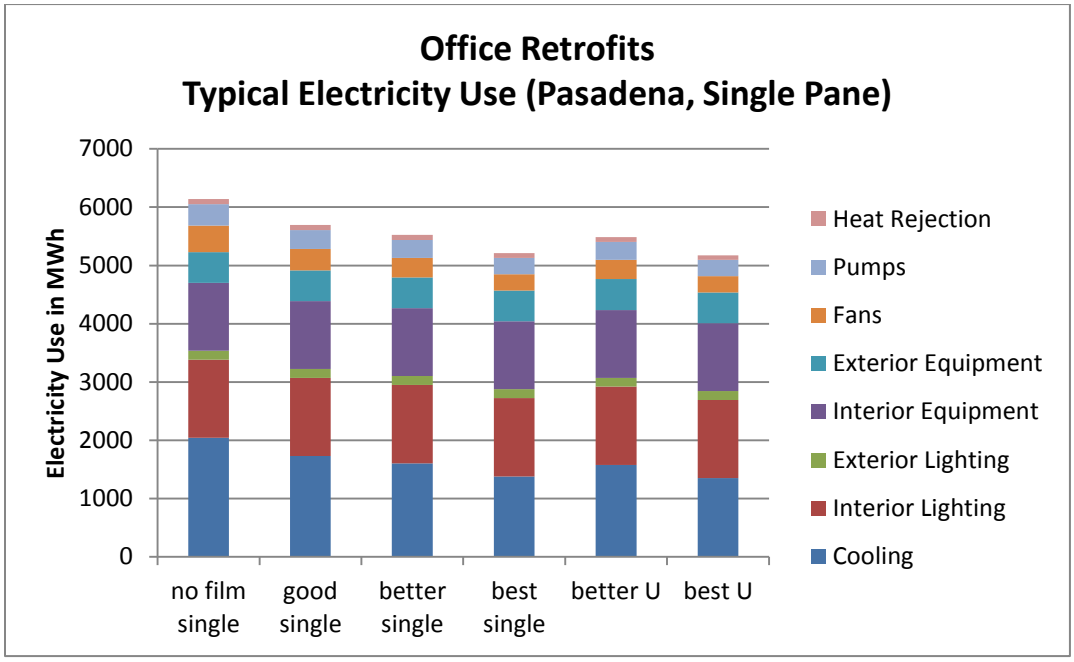


Figure 9: Office Retrofits: Typical Electricity Use (Pasadena, Single Pane)

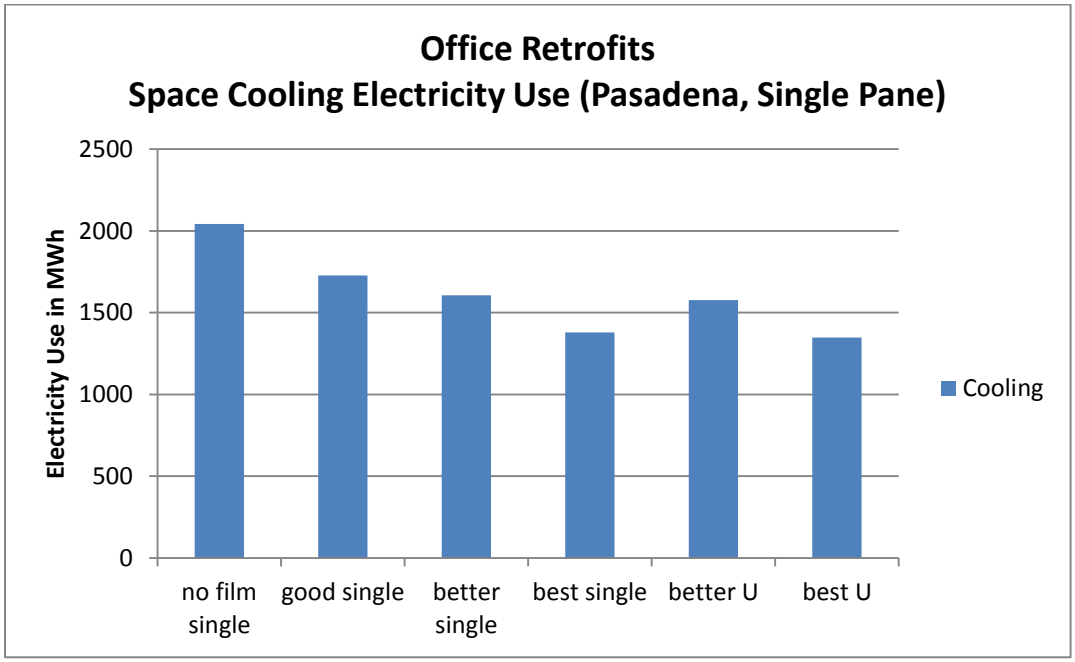


Figure 10: Office Retrofits: Cooling Electricity Use (Pasadena, Single Pane)

Existing Offices in Oakland

Table 3: Oakland (CZ3) ROI for Existing Offices with Single Pane Glass

SINGLE PANE	good	better	better U	best	best U
Total Electricity (MWh)	4,315	4,222	4,214	4,053	4,055
Total Gas (Therms)	20,609	19,685	17,962	16,885	12,893
Energy Cost	$667,770	$653,011	$650,109	$624,850	$621,089
Annual Savings	$39,286	$54,046	$56,948	$82,206	$85,968
Cost of Film	$199,612	$199,612	$274,467	$199,612	$349,321
Annual ROI	20%	27%	21%	41%	25%
Simple Payback	5.08	3.69	4.82	2.43	4.06

Table 4: Oakland (CZ3) ROI for Existing Offices with Double Pane Glass

DOUBLE PANE	good	better	better U	best	best U
Total Electricity (MWh)	4,335	4,279	4,263	4,111	4,106
Total Gas (Therms)	16,873	16,312	15,341	13,932	11,789
Energy Cost	$667,125	$658,131	$654,728	$630,617	$627,698
Annual Savings	$20,721	$29,715	$33,118	$57,229	$60,148
Cost of Film	199,612	199,612.22	274,466.80	199,612.22	349,321.38
Annual ROI	10%	15%	12%	29%	17%

Simple Payback	9.63	6.72	8.29	3.49	5.81

In mild Oakland-like climates the ROI ranges from 10%-41%. Single pane existing windows provide an opportunity for up to a 41% ROI, while adding film to double pane windows will pay back at 10%-29% annually.

Existing Offices in San Diego

Table 5: San Diego (CZ7) ROI for Existing Offices with Single Pane Glass

SINGLE PANE	good	better	better U	best	best U
Total Electricity (MWh)	5,528	5,362	5,340	5,065	5,044
Total Gas (Therms)	10,256	9,469	8,605	8,085	6,220
Energy Cost	$839,516	$813,765	$809,644	$767,860	$762,879
Annual Savings	$67,908	$93,660	$97,781	$139,565	$144,546
Cost of Film	$199,612	$199,612	$274,467	$199,612	$349,321
Annual ROI	34%	47%	36%	70%	41%
Simple Payback	2.94	2.13	2.81	1.43	2.42

Table 6: San Diego (CZ7) ROI for Existing Offices with Double Pane Glass

DOUBLE PANE	good	better	better U	best	best U
Total Electricity (MWh)	5,537	5,436	5,400	5,147	5,124
Total Gas (Therms)	8,236	7,836	7,255	6,662	5,715
Energy Cost	$838,764	$823,204	$817,291	$778,712	$774,372
Annual Savings	$35,693	$51,253	$57,166	$95,745	$100,084
Cost of Film	199,612	199,612.22	274,466.80	199,612.22	349,321.38
Annual ROI	18%	26%	21%	48%	29%
Simple Payback	5.59	3.89	4.80	2.08	3.49

In coastal, San Diego -like climates the ROI ranges from 18%-70%. Single pane existing windows provide an opportunity for 34%-70% ROI, while adding film to double pane windows will pay back at 18%-48% annually.

Existing Offices in Pasadena

Table 7: Pasadena (CZ9) ROI for Existing Offices with Single Pane Glass

SINGLE PANE	good	better	better U	best	best U
Total Electricity (MWh)	5,695	5,523	5,486	5,210	5,175
Total Gas (Therms)	15,273	14,281	12,888	12,469	9,275
Energy Cost	$869,531	$842,752	$835,794	$793,886	$785,529

Annual Savings	$69,056	$95,834	$102,793	$144,700	$153,057
Cost of Film	$199,612	$199,612	$274,467	$199,612	$349,321
Annual ROI	35%	48%	37%	72%	44%
Simple Payback	2.89	2.08	2.67	1.38	2.28

Table 8: Pasadena (CZ9) ROI for Existing Offices with Double Pane Glass

DOUBLE PANE	good	better	better U	best	best U
Total Electricity (MWh)	5,670	5,566	5,518	5,266	5,228
Total Gas (Therms)	11,915	11,356	10,682	9,875	8,114
Energy Cost	$862,332	$846,305	$838,323	$799,718	$792,249
Annual Savings	$37,588	$53,615	$61,596	$100,202	$107,671
Cost of Film	199,612	199,612.22	274,466.80	199,612.22	349,321.38
Annual ROI	19%	27%	22%	50%	31%
Simple Payback	5.31	3.72	4.46	1.99	3.24

In Pasadena -like climates the ROI ranges from 19%-72%. Single pane existing windows provide an opportunity for 35%-72% ROI, while adding film to double pane windows will pay back at 19%-50% annually.

Existing Offices in Fresno

Table 9: Fresno (CZ13) ROI for Existing Offices with Single Pane Glass

SINGLE PANE	good	better	better U	best	best U
Total Electricity (MWh)	5,815	5,637	5,589	5,300	5,227
Total Gas (Therms)	28,820	27,795	25,291	25,473	19,299
Energy Cost	$901,002	$873,312	$863,652	$820,406	$803,269
Annual Savings	$73,539	$101,228	$110,889	$154,135	$171,272
Cost of Film	$199,612	$199,612	$274,467	$199,612	$349,321
Annual ROI	37%	51%	40%	77%	49%
Simple Payback	2.71	1.97	2.48	1.30	2.04

Table 10: Fresno (CZ13) ROI for Existing Offices with Double Pane Glass

DOUBLE PANE	good	better	better U	best	best U
Total Electricity (MWh)	5,754	5,648	5,600	5,341	5,289
Total Gas (Therms)	22,721	21,712	20,534	20,175	17,101
Energy Cost	$885,785	$868,849	$860,530	$821,270	$810,381
Annual Savings	$39,137	$56,074	$64,393	$103,653	$114,541
Cost of Film	199,612	199,612.22	274,466.80	199,612.22	349,321.38

Annual ROI	20%	28%	23%	52%	33%
Simple Payback	5.10	3.56	4.26	1.93	3.05

In hot, Fresno -like climates the ROI ranges from 20%-77% annually. Single pane existing windows provide an opportunity for 37%-77% ROI, while adding film to double pane windows will pay back at 20%-52% annually.

In general, standard improved SHGC film gives as good or better return on investment than the more expensive options of spectrally selective or low-e films. The energy saved by these low U-factor options is outweighed in office buildings by the higher cost for these technologies. This is most likely because offices are dominated by cooling loads, rather than the mixture of cooling and heating loads seen in residential buildings. The monetary cost to improve SHGC from one film to the next is negligible, but the loss of visible transmittance can determine the choice of film between these options, balancing energy savings with such concerns as occupant comfort and views. Again the hotter climate zones, in this case Pasadena and Fresno, benefit most from window film. But even the mildest climate zone, Oakland, finds around a 20% annual return on investment with the various window films. In existing offices with single pane windows, anywhere other than the mildest zones, window film is an energy efficiency measure that can pay back in less than 2 years.

Results summary

New homes are not a particularly attractive market for internal window films in California, since there are many more cost effective ways to reduce energy in new homes, and the windows that go into new homes already perform well in the areas that window film addresses. There may be an opportunity in the high desert, an area that was not studied due to a low concentration of homes built there, but typically, new homes are not a good market for window film. On the other hand, existing homes are a market in which window films perform very favorably against other typical energy retrofit options, particularly in the hotter climate zones of California.

New office buildings likewise show little opportunity for this technology to thrive. Again the Standards already require that windows have a high degree of performance. Existing office buildings, however, are a very attractive market for window film products. High ROIs (paybacks less than five years) can attract building managers to invest in this energy efficiency technology. Only a small percentage of buildings are added to the building stock each year, while existing buildings represent a large market for efficiency measures, consuming more energy due to a less advanced design.

Global Warming Implications

AB 32 Global Warming Solutions Act Background

AB32 requires greenhouse gas emissions to be reduced to 1990 levels by 2020, which constitutes approximately a 30% reduction over business-as-usual projections for 2020.

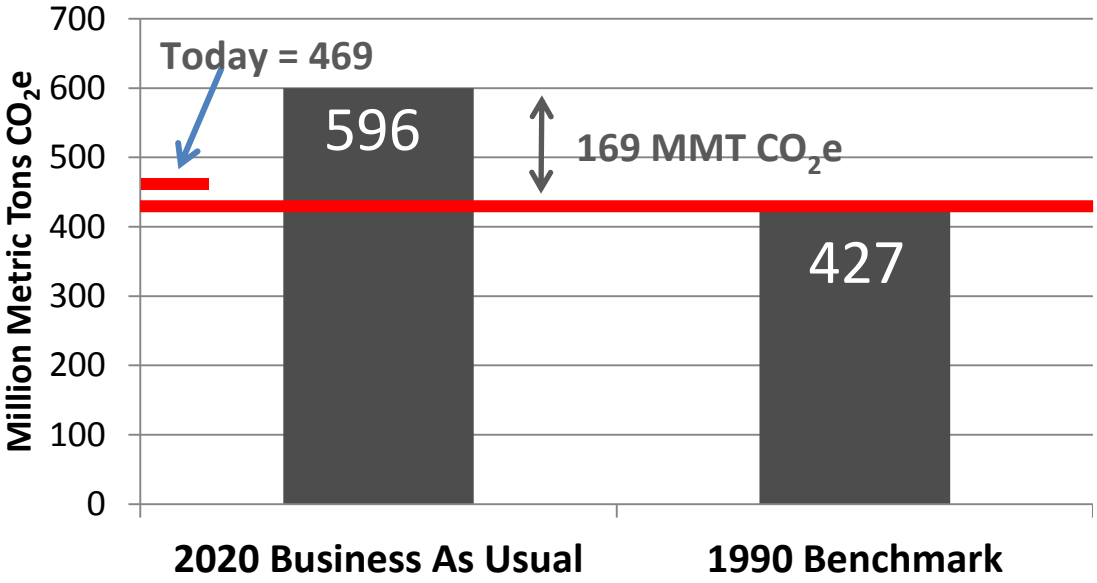
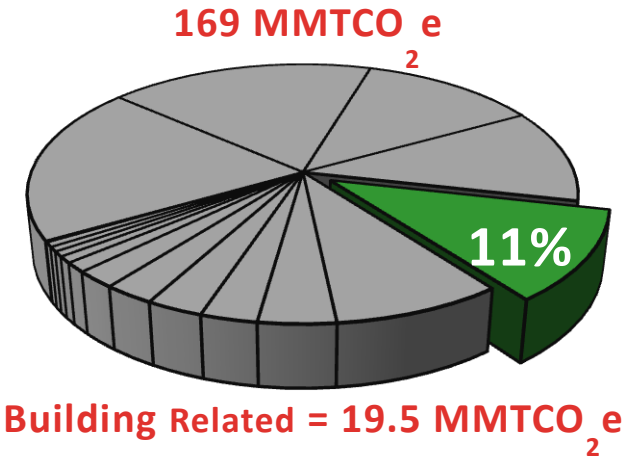


Figure 11 Greenhouse Gas Emission Goals

Within the AB 32 Scoping Plan to reduce the total greenhouse gas emissions for California by 169 Million Metric Tons of CO_2 equivalent ($MMTCO_2e$), the Air Resources Board (ARB) has outlined 16 greenhouse gas reduction strategies, one of which is implementing energy efficiency in California's buildings. The recommendation is that 11% or 19.5 $MMTCO_2e$ of the total savings goal will come from reduction in energy in residential and commercial buildings.



This is equivalent to the emissions from 3.5 million cars or from 1.8 million homes. It is also equivalent to a 14% reduction in energy use in every building in the state. ARB recommendations outline that part of that savings come from more stringent new buildings standards, but that 75% come from retrofits to existing buildings. The Scoping Plan suggests that there will be substantial pressure on voluntary (utility) programs as well as legislative requirements to improve the energy efficiency of existing buildings.

New construction has minimal impact on the GHG reduction goal. There are approximately 13,460,000 residential dwelling units in California. In 2011, 46,000 new residential units were constructed. If all residential units emitted the same amount of GHG, new construction would amount to only 0.34% (approximately one third of one percent) of annual GHG emissions in 2011 for California homes. In fact, new homes emit far less GHG than existing homes, meaning that new homes are an even smaller part of the equation. 2011, like the preceding few years, has been abnormally slow for the home building sector; yet, this trend is not expected to change for at least the next five years. The California Legislative Analyst Office predicts residential new construction will not recover until after 2017[1]. To effectively reduce residential sector GHG emissions, existing homes must be made more energy efficient.

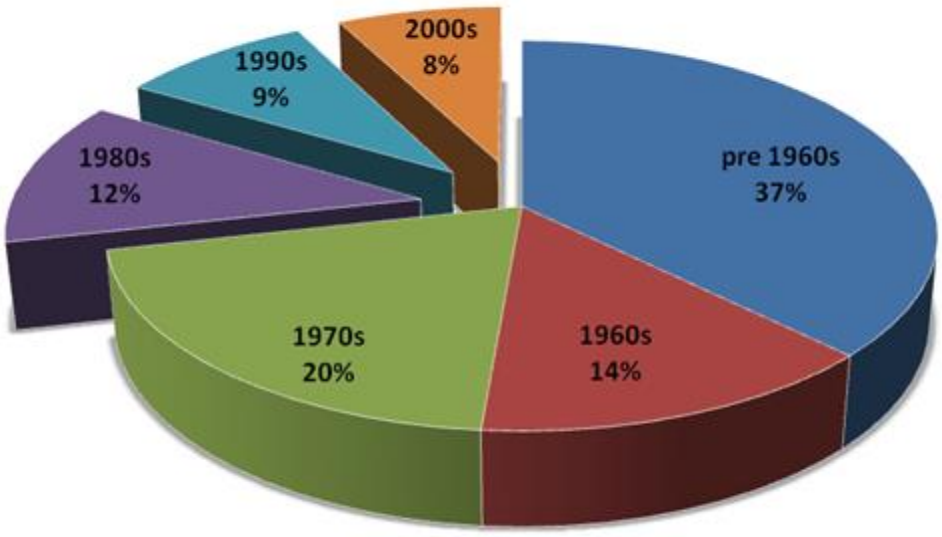


Figure 12: Single Family Home Emissions by Decade Built[2]

Over 70% of GHG related to single-family envelope energy consumption can be attributed to homes built before 1980; homes built before any energy codes were adopted in California (see Figure 12). Since most GHG comes from older homes and increasing energy codes on new homes has such a minimal impact, retrofitting existing homes with cost effective energy upgrades is essential to meeting AB 32 GHG reduction goals. Window films are among the most cost effective energy retrofits for existing residential and commercial buildings. Window films should be recognized as a viable solution to cost effectively reduce GHGs.

[1] http://www.lao.ca.gov/reports/2011/bud/fiscal_outlook/fiscal_outlook_2011.aspx

[2] From " Meeting AB 32 – Cost Effective Green House Gas Reductions in the Residential Sector" ConSol, August, 2008

Window Film GHG Impact

To demonstrate window film impact on GHG Figure 13 shows a theoretical situation in which all existing homes in the state of California are retrofitted with a given energy efficiency measure over the course of 7 years, by retrofitting one seventh of the existing homes each year. The measures examined are replacing the AC with a 13 SEER unit, adding the "better" window film as analyzed in this study, adding R-30 insulation in the attic, and replacing the furnace with a 92% efficient furnace. These measures are compared against business as usual, updated Title 24 standards, and net zero new construction.

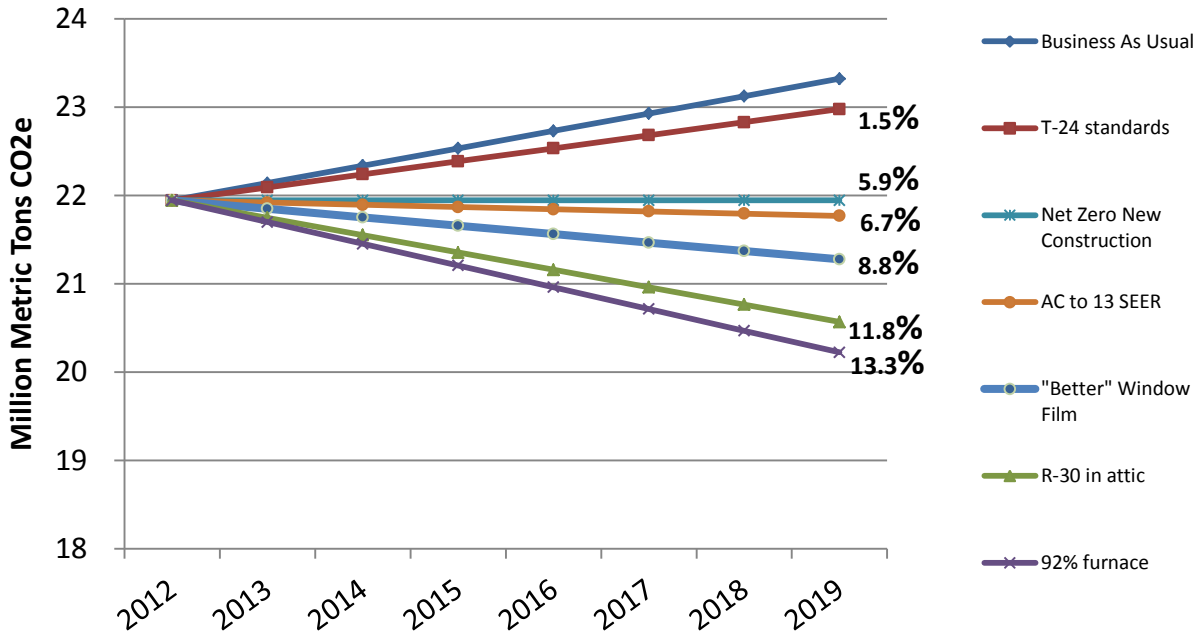


Figure 13: Theoretical Reduction in GHG over Time in California

This comparison demonstrates two things. First, that targeting only new homes, as in the case of Title 24, has a limited potential (1.5%) for reducing GHG emissions compared to targeting existing homes. And second, that window films have a relatively good potential (8.8%) to impact GHG emissions when compared to other retrofit measures. When cost is taken into account as in the previous sections, it is one of the most effective measures that can be considered.

Conclusions for Internal Window Film

The best opportunities for saving energy with internal window films in California are in existing buildings, especially in existing residential homes and high-rise office buildings. New homes are not an attractive opportunity because of the high energy standards for windows already in place. New non-residential buildings have the same problem. Window films are a more cost effective retrofit

opportunity for homes than other measures, especially in homes with single pane glass. Existing office buildings are an ideal opportunity for window film retrofits. They contain a large amount of glazing and cooling loads typically dominate. Rates of return on investment are high, even before utility incentives. Window films are an effective means of reducing GHG emissions when used in retrofitting existing buildings.

Energy Analysis for External Window Films Applications in Existing Homes and Offices

Purpose/ Scope

The purpose of this study is to demonstrate the cost-effectiveness of externally applied energy control window film when applied in homes and offices. The results from this study will be used to encourage the use of external window films within energy and green codes and incentive based California utility programs, and, to determine opportunities within the California market. This study is a supplement to, and now included in, the report, "Energy Analysis for Window Films Applications in New and Existing Homes and Offices." External window film results have been added to the initial internal window film study.

Externally applied window films are weatherproof films which are applied to the external surface of the fenestration. The composition, technology and product types are similar to internal window films. The external films are commonly used on office buildings, and less commonly on homes. The primary advantage of external window films is that the solar heat is reflected before entering the fenestration product, eliminating the problems experienced when window products or seals overheat.

Energy Analysis

Description of New and Existing Baselines

The home modeled in this study is a 2,123 ft^2, two-story, single family detached unit, with a glazing percentage of 20% of the conditioned floor area. This house is an existing home , modified to reflect the mechanical efficiencies, insulation levels and other features according to TABLE R3-50: Vintage Table Values in Appendix B of the of the 2008 Residential Compliance Manual published by the California Energy Commission (CEC). The energy features represented are those used for a house built in the early 1990s.

The baseline glass type is clear, dual pane glass (0.71 U-factor, 0.63 SHGC). The National Fenestration Rating Council (NFRC) data for window film is benchmarked against clear glass, and the impact of window film is determined by NFRC ratings, which are recognized by the CEC for code compliance. All residential analysis was done using MICROPAS, which is the most frequently used California residential compliance software certified for Title 24 code compliance.

The office building modeled in the study is the EnergyPlus Commercial Building Benchmark Model developed by the U.S. Department of Energy (DOE) for large office buildings. The office building is 12 stories, and 498,588 ft^2 in conditioned floor area, with energy features modified to comply with the California Title 24 Standards for 1990 to represent existing offices.

Both residential and office simulations were run in each of the four cardinal directions and the energy usage was averaged over the four orientations.

Description of Variables

The homes were simulated for the purposes of code requirements in four key climate zones of the sixteen climate zones recognized in California. The climate zones were chosen in order to get a range of conditions and represent areas with greater building numbers. They included the mild climate of the Northern California Bay Area (CZ4), the coastal climate zone of San Diego (CZ7), the inland climate zone of Riverside (CZ10) and the Central Valley climate zone of Sacramento (CZ12). These climate zones are representative of the areas where most homes are built in the State. Climate Zones 10 and 12 represent locations with high cooling loads where window film should have a substantial impact on energy use.

The office buildings were simulated in a different set of climate zones, based off of volume of existing and new commercial construction. The representative cities for these climate zones are Oakland (CZ3 – Bay Area no cooling load), San Diego (CZ7 - coastal), Pasadena (CZ9 – mild inland), and Fresno (CZ13 – Central Valley).

Using data from manufacturers and the NFRC Certified Products Directory, the exterior window films products currently in the market were characterized into three groups, “good”, “better” and “best” options with a rounded median value chosen for solar heat gain coefficient (SHGC). The values used are detailed in Table 11 residential and Table 12 large office, shown below. In the office building model, the visible transmittance (VT) is also modeled for the purpose of evaluating daylighting design, which is not modeled in the residential software. The good, better, and best categories in the large office model represent the basic technology films which limit solar heat gain.

Table 11: Properties and Cost Range of External Window Films Studied for the Residential Model

	without	good	better	best
SHGC				
Single	0.71	0.49	0.35	0.19
Double	0.63	0.41	0.29	0.15
Cost/ft^2		$5.00	$5.00	$5.00
		$8.50	$8.50	$8.50
		$12.00	$12.00	$12.00

Table 12: Properties and Cost Range of External Window Films Studied for the Large Office Model

	without	good	better	best
SHGC				
Single	0.71	0.51	0.36	0.19
Double	0.63	0.40	0.28	0.15
VT				
Single	0.74	0.42	0.30	0.16
Double	0.67	0.37	0.27	0.14
Cost/ft^2		$5.00 $8.50 $12.00	$5.00 $8.50 $12.00	$5.00 $8.50 $12.00

Installed window film prices include the window film itself, installation supplies needed, and installation labor and setup costs (ladders, scaffolding, etc.) to do the job properly. For that reason, any of these window films if installed in three different scenarios could have three different installed prices. For example, "better" window film installed on the outside of a first floor residence versus on the outside of the 14th floor of an apartment building could result in a very different installation cost per square foot. The same film and the same installers might be used, but the cost of getting to the outside of the windows on the 14th floor far exceeds the cost of getting to the outside of the windows on the first floor. The same is true for commercial installations. For that reason, this report analyzes three average price levels which should give potential users of exterior window films an understanding of how installed price may affect choices of energy saving alternatives.

Simulation Software

The simulation software used for the residential models is MICROPAS v8.1 (r.03), which is the CEC certified software for demonstrating compliance with Title 24, Part 6 (CA Energy Code). The simulation runs an annual, hourly calculation for each of the 8,760 hours throughout the year, accounting for interactions between the heating and cooling systems, lighting and envelope features including the fenestration. This performance software is typically used to give builders the flexibility to trade off energy measures with those that would be required if one follows the prescriptive package of Title 24 approach to compliance. The performance method is the least expensive path to compliance and used by the vast majority (95%+) of builders to obtain compliance with Title 24. Table 11 above represents the variables used in the residential simulation. Note it does not include the visible transmittance, because MICROPAS does not use this variable, nor does it have the capability to model daylighting controls. Daylighting controls are not common in residential spaces. Any dimming or shutting off of lights in homes is performed by the occupants who determine whether there is adequate light in the space.

The simulation software used for the commercial model is EnergyPlus v6.0, which is the newest generation of modeling software from the DOE. This simulation was also run as an 8760 hour annual simulation, but EnergyPlus can also take into account building system interactions with each other and with building envelope features. In addition it has capabilities to model many non-residential features

which are not available in MICROPAS. The simulations were run without daylighting controls active, since existing office buildings are unlikely to have such controls without a separate retrofit.

Results

The results in this study are presented differently for the residential and commercial office buildings. For residential applications, the most important information is how the measure compares to other energy efficiency measures that might be taken when considering a home retrofit. The energy unit used in Title 24 compliance software is a measurement used by the CEC known as Time Dependent Valuation of energy or TDV. The MICROPAS software automatically calculates energy savings in TDV, which is the compliance standard measure for energy use. Energy used during peak usage hours (summer afternoons) is weighted more heavily than energy used off peak (at night). TDV energy emphasizes the impact of energy features that reduce peak load (primarily air conditioning load). This is beneficial for window film savings, since the energy saved is typically space cooling energy which occurs during the peak period.

For commercial applications, the return on investment (ROI) is the deciding factor in implementing an energy measure. The results presented here are the ROI for the application of window film alone. Utility incentives or other rebate programs represent additional financial incentives that help make the investment in energy efficiency and were discussed in the primary report "Energy Analysis for Window Films Applications in New and Existing Homes and Offices".

Results in Existing Homes

In Figure 14 through Figure 19, the orange bars represent the effect of film on single pane existing glass, and the red bars represent the effect of film on existing double pane glass. The blue bars are the other common energy efficiency measures used during retrofits.

The energy efficiency features that window film was compared to for existing homes are:

- R-38 ceiling insulation – adding insulation to the attic
- 0.80 AFUE furnace – replacing furnace with more efficient new unit
- 13 SEER, 11 EER AC – replacing AC equipment with more efficient new unit
- Air Sealing – sealing gaps in building envelope (walls, doors, around windows, etc.)

All figures below outline the data using TDV cost effectiveness. The use of TDV cost effectiveness does not directly relate to utility costs. TDV is used by the CEC to determine which energy feature will reduce peak load most cost effectively. TDV is used to set the residential loading order (which energy efficiency improvement is most cost-effective) for energy improvements in California residential retrofits. This process is known in California as HERS II. It is the HERS II process that will eventually be required for all California homes (possibly at time of sale) and will inform the homeowner what energy improvements are cost effective.

The $5.00 installed cost for external window films on single pane windows was determined to be the top energy efficiency improvement when determined by TDV cost effectiveness (see Figures 14, 17, 18, and

19). In fact, in homes with single pane glass, there is little that one could do to improve energy performance more cost effectively.

The cost effectiveness of the external window film was greatly influenced by cost. External window film at the lowest installation cost ($5.00 per square foot) was more cost effective than typical retrofit installations of ceiling insulation, air sealing and new HVAC equipment (furnace or air conditioner) in mild climate zones. The lowest cost installation window film was in the top three choices determined by TDV cost effectiveness in all climate zones studied which covers most of California. As the costs increased to $8.50 per square foot and $12.00 per square foot external window films became less cost effective than air sealing or ceiling insulation (see Figures 15 and 16). When compared to the most expensive window film ($12.00 per square foot), ceiling insulation was more cost effective in a mild climate zone (Bay Area CZ4 – see Figure 16). External window films at the three levels of installed costs were more cost effective than changing out HVAC equipment (furnace or air conditioner) in all climate zones studied. These results were similar for all climates zones. The figures that follow charts the results for all price points for climate zone 4. Since the results are similar only the chart for $5.00 per square foot are shown for climate zones 7, 10 and 12.

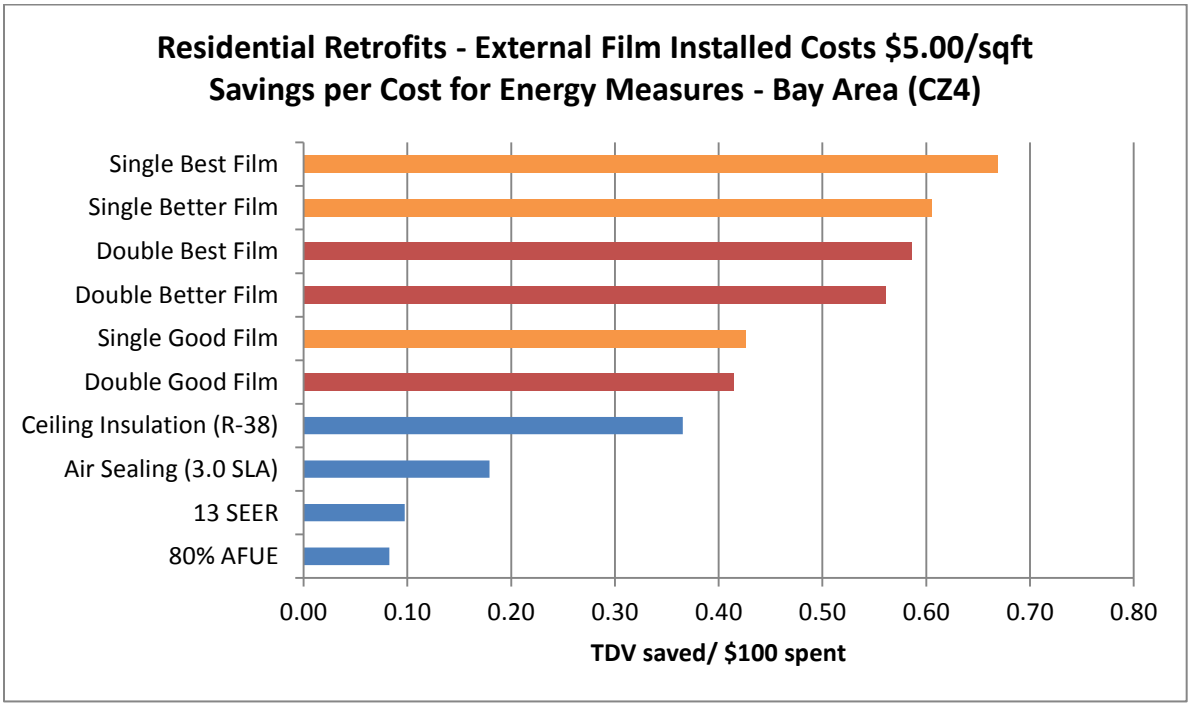


Figure 14: Residential Retrofits: Savings per Cost for Energy Measures - Bay Area (CZ4) $5.00/sqft Installed Costs

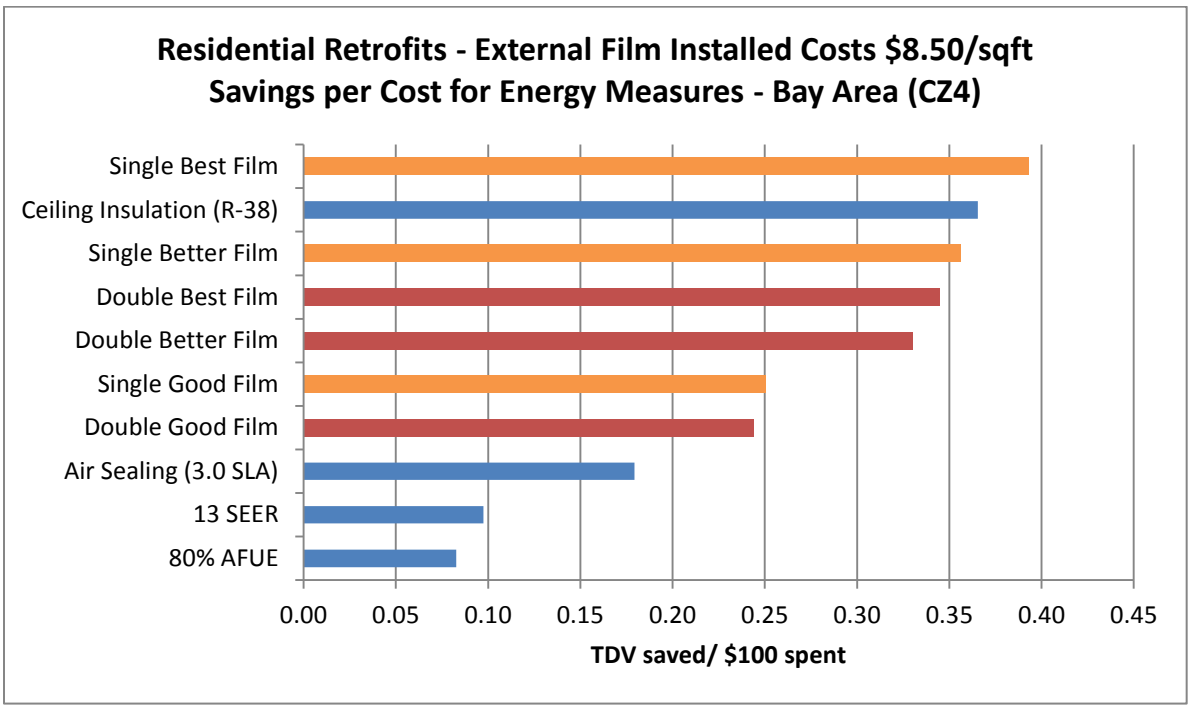


Figure 15: Residential Retrofits: Savings per Cost for Energy Measures - Bay Area (CZ4) $8.50/sqft Installed Costs

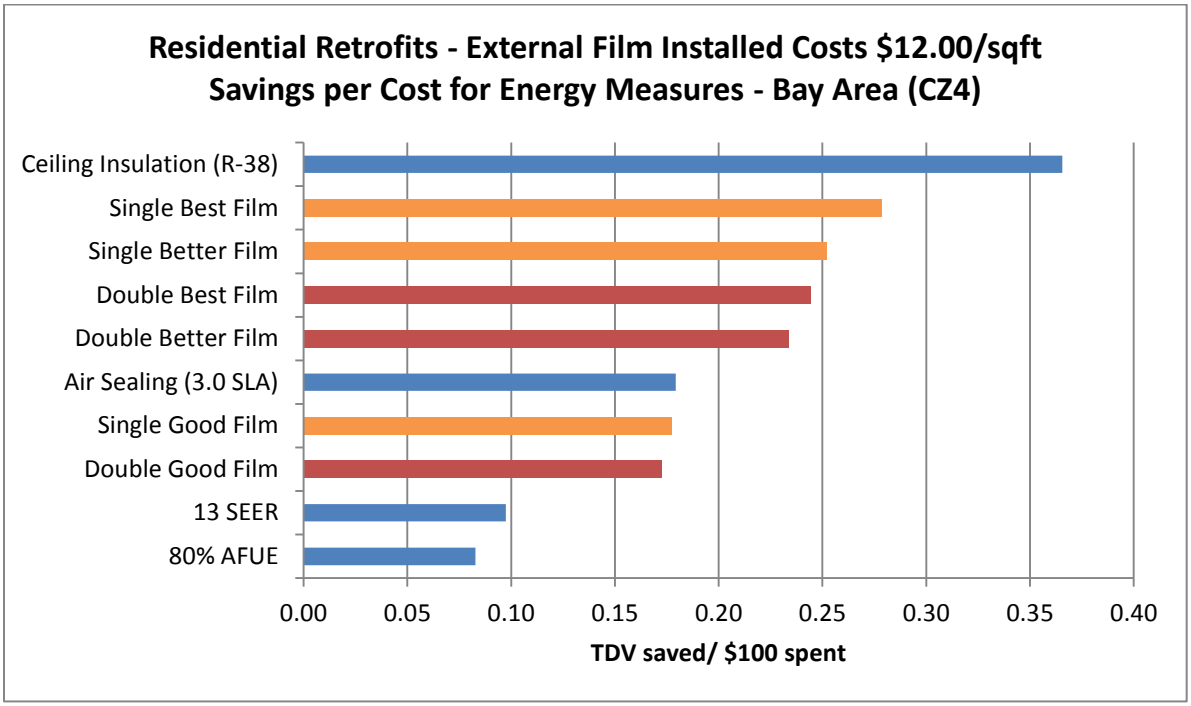


Figure 16: Residential Retrofits: Savings per Cost for Energy Measures - Bay Area (CZ4) $12.00/sqft Installed Costs

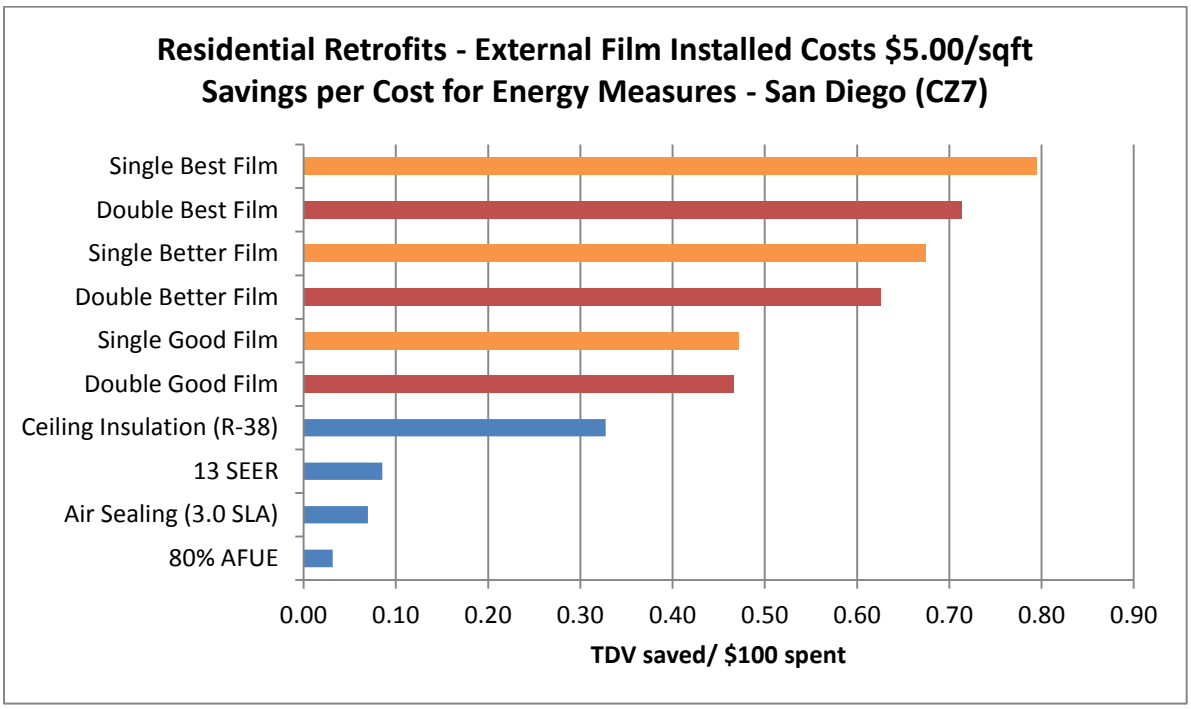


Figure 17: Residential Retrofits: Savings per Cost for Energy Measures - San Diego (CZ7) $5.00/sqft Installed Costs

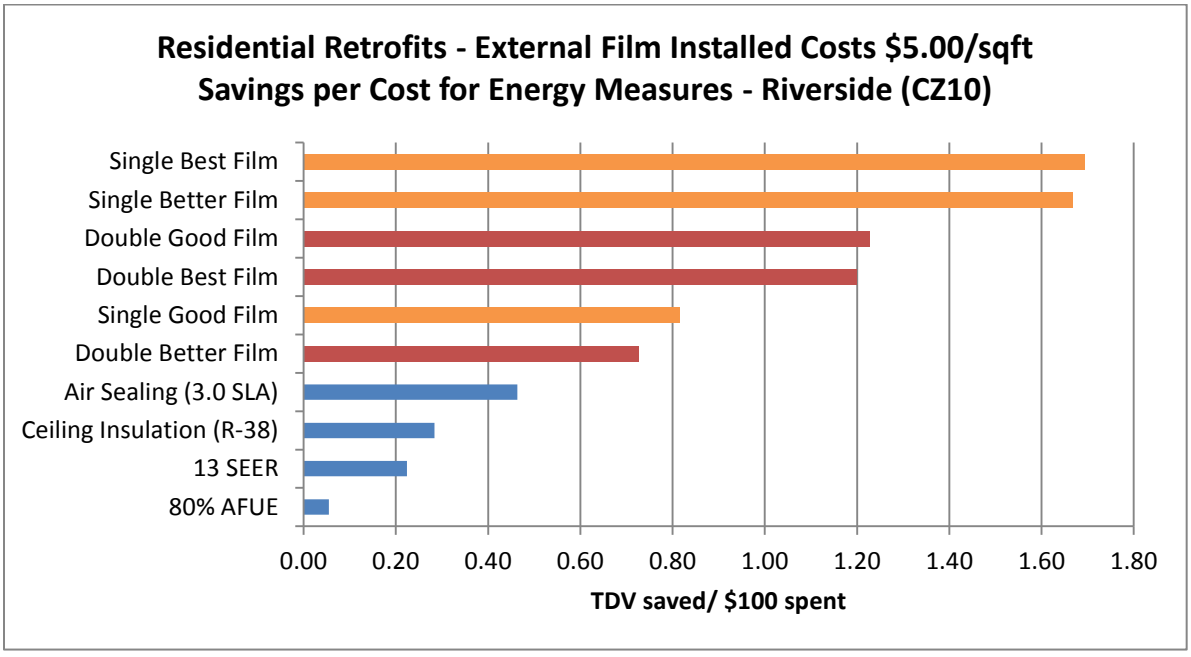


Figure 18: Residential Retrofits: Savings per Cost for Energy Measures - Riverside (CZ10) $5.00/sqft Installed Costs

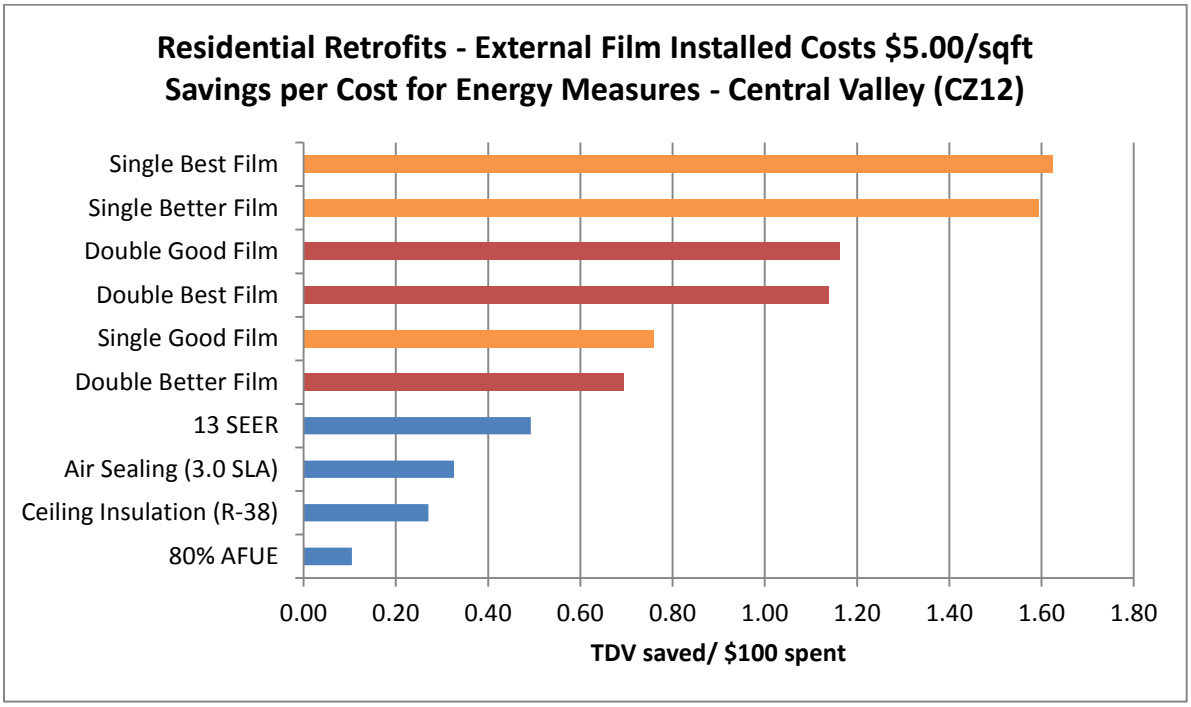


Figure 19: Residential Retrofits: Savings per Cost for Energy Measures - Central Valley (CZ12) $5.00/sqft Installed Costs

Results in Existing Offices

Figure 20 shows the typical electricity breakdown in the large office building by end use. Window films primarily impact the cooling portion of the electricity in these buildings. In existing offices, window film represents a significant opportunity for cost effective energy savings. The majority of the savings are from the effect that window film has on cooling loads (along with reduced fan energy which is the other end use involved in cooling the building). ROI ranges from 6% - 58% annually depending on climate zone and product as detailed in Table 13 through Table 20. For building owners to add energy efficiency improvements they typically want a ROI of 33% or greater which translates into a payback of 3 years or less.

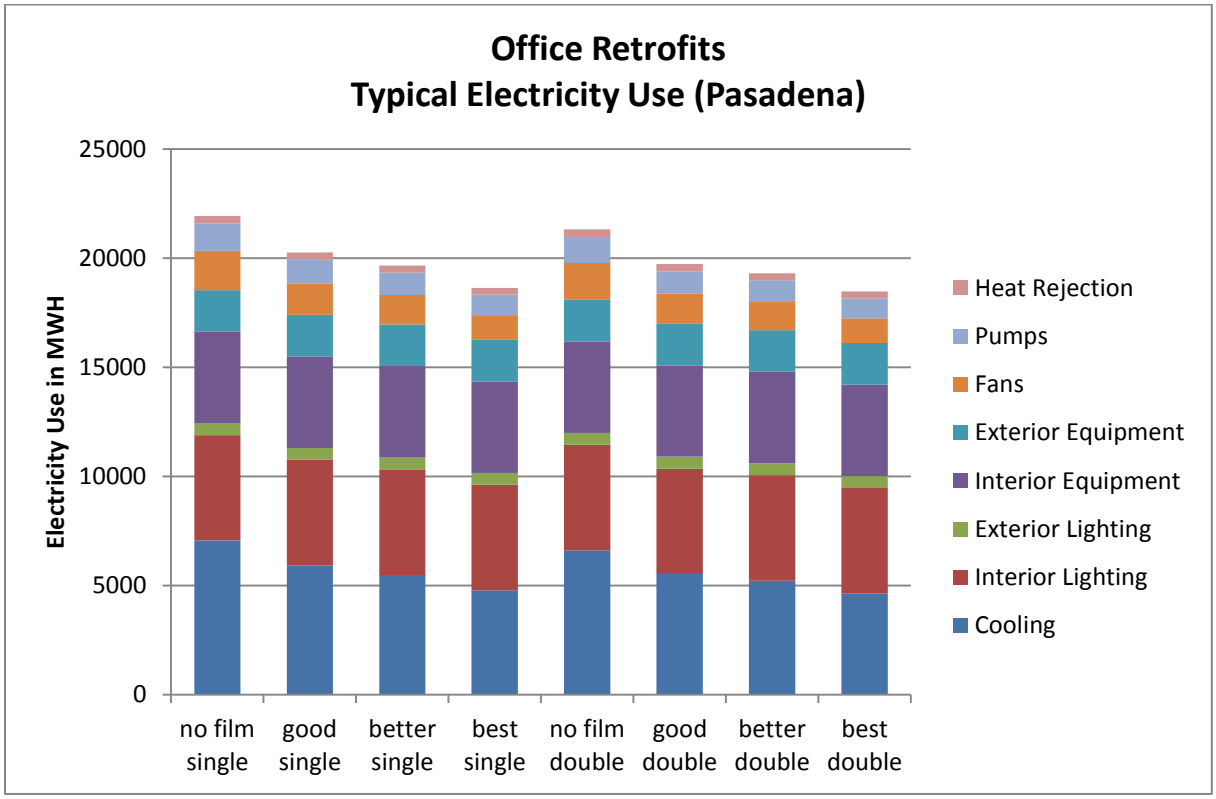


Figure 20: Office Retrofits: Typical Electricity Use (Pasadena)

The following tables outline the energy savings, return on investment (ROI or simple payback) on single pane and dual pane glass for the prototypical office building in the four climate zones. Each table has the ROI for each type of exterior window film at the three price points ($5.00, $8.50 and $12.00 per square foot).

Existing Offices in Oakland

Table 13: Oakland (CZ3) ROI for Existing Offices with Single Pane Glass

SINGLE PANE	no film	good	better	best
Total Electricity (MWh)	4,556	4,382	4,230	4,041
Total Gas (Therms)	23,641	21,528	19,534	16,624
Energy Cost	$707,056	$678,850	$653,985	$622,721
Annual Savings	-	$28,206	$53,071	$84,335
Cost of Film	-	$249,515 $424,176 $598,837	$249,515 $424,176 $598,837	$249,515 $424,176 $598,837
Annual ROI $5 film	-	11%	21%	34%
Annual ROI $8.50 film	-	7%	13%	20%
Annual ROI $12 film	-	5%	9%	14%
Simple Payback $5 film	-	8.85	4.70	2.96
Simple Payback $8.50 film	-	15.04	7.99	5.03
Simple Payback $12 film	-	21.23	11.28	7.10

Table 14: Oakland (CZ3) ROI for Existing Offices with Double Pane Glass

DOUBLE PANE	no film	good	better	best
Total Electricity (MWh)	4,464	4,230	4,127	4,013
Total Gas (Therms)	18,206	15,836	14,195	12,535
Energy Cost	$687,846	$650,374	$633,309	$614,470
Annual Savings	-	$37,472	$54,537	$73,376
Cost of Film	-	$249,515 $424,176 $598,837	$249,515 $424,176 $598,837	$249,515 $424,176 $598,837
Annual ROI $5 film	-	15%	22%	29%
Annual ROI $8.50 film	-	9%	13%	17%
Annual ROI $12 film	-	6%	9%	12%
Simple Payback $5 film	-	6.66	4.58	3.40
Simple Payback $8.50 film	-	11.32	7.78	5.78
Simple Payback $12 film	-	15.98	10.98	8.16

In mild Oakland-like climates the ROI ranges from 5%-34%. Single pane existing windows provide an opportunity for up to a 34% ROI, while external adding film to double pane windows will pay back at up to 29% annually.

Existing Offices in San Diego

Table 15: San Diego (CZ7) ROI for Existing Offices with Single Pane Glass

SINGLE PANE	no film	good	better	best
Total Electricity (MWh)	5,969	5,655	5,366	5,030
Total Gas (Therms)	12,036	10,790	9,577	7,982
Energy Cost	$907,425	$859,045	$814,443	$762,529
Annual Savings	-	$48,380	$92,981	$144,896
Cost of Film	-	$249,515 $424,176 $598,837	$249,515 $424,176 $598,837	$249,515 $424,176 $598,837
Annual ROI $5 film	-	19%	37%	58%
Annual ROI $8.50 film	-	11%	22%	34%
Annual ROI $12 film	-	8%	16%	24%
Simple Payback $5 film	-	5.16	2.68	1.72
Simple Payback $8.50 film	-	8.77	4.56	2.93
Simple Payback $12 film	-	12.38	6.44	4.13

Table 16: San Diego (CZ7) ROI for Existing Offices with Double Pane Glass

DOUBLE PANE	no film	good	better	best
Total Electricity (MWh)	5,755	5,357	5,174	4,949
Total Gas (Therms)	9,203	7,498	6,788	5,917
Energy Cost	$872,403	$811,057	$782,845	$748,312
Annual Savings	-	$61,346	$89,558	$124,091
Cost of Film	-	$249,515 $424,176 $598,837	$249,515 $424,176 $598,837	$249,515 $424,176 $598,837
Annual ROI $5 film	-	25%	36%	50%
Annual ROI $8.50 film	-	14%	21%	29%
Annual ROI $12 film	-	10%	15%	21%
Simple Payback $5 film	-	4.07	2.79	2.01
Simple Payback $8.50 film	-	6.91	4.74	3.42
Simple Payback $12 film	-	9.76	6.69	4.83

In coastal, San Diego -like climates the ROI ranges from 8%-58%. Single pane existing windows provide an opportunity for 8%-58% ROI, while adding external film to double pane windows will pay back at 10%-50% annually.

Existing Offices in Pasadena

Table 17: Pasadena (CZ9) ROI for Existing Offices with Single Pane Glass

SINGLE PANE	no film	good	better	best
Total Electricity (MWh)	6,141	5,821	5,534	5,181
Total Gas (Therms)	17,448	15,858	14,139	12,340
Energy Cost	$938,586	$889,011	$844,259	$789,518
Annual Savings	-	$49,575	$94,327	$149,068
Cost of Film	-	$249,515 $424,176 $598,837	$249,515 $424,176 $598,837	$249,515 $424,176 $598,837
Annual ROI $5 film	-	20%	38%	60%
Annual ROI $8.50 film	-	12%	22%	35%
Annual ROI $12 film	-	8%	16%	25%
Simple Payback $5 film	-	5.03	2.65	1.67
Simple Payback $8.50 film	-	8.56	4.50	2.85
Simple Payback $12 film	-	12.08	6.35	4.02

Table 18: Pasadena (CZ9) ROI for Existing Offices with Double Pane Glass

DOUBLE PANE	no film	good	better	best
Total Electricity (MWh)	5,913	5,479	5,295	5,061
Total Gas (Therms)	13,039	10,905	9,938	8,774
Energy Cost	$899,920	$832,776	$804,192	$767,899
Annual Savings	-	$67,144	$95,728	$132,021
Cost of Film	-	$249,515 $424,176 $598,837	$249,515 $424,176 $598,837	$249,515 $424,176 $598,837
Annual ROI $5 film	-	27%	38%	53%
Annual ROI $8.50 film	-	16%	23%	31%
Annual ROI $12 film	-	11%	16%	22%
Simple Payback $5 film	-	3.72	2.61	1.89
Simple Payback $8.50 film	-	6.32	4.43	3.21
Simple Payback $12 film	-	8.92	6.26	4.54

In Pasadena -like climates the ROI ranges from 8%-60%. Single pane existing windows provide an opportunity for 8%-60% ROI, while adding external film to double pane windows will pay back at 11%-53% annually.

Existing Offices in Fresno

Table 19: Fresno (CZ13) ROI for Existing Offices with Single Pane Glass

SINGLE PANE	no film	good	better	best
Total Electricity (MWh)	6,288	5,962	5,654	5,272
Total Gas (Therms)	31,295	29,724	27,893	25,279
Energy Cost	$974,540	$924,026	$876,037	$816,035
Annual Savings	-	$50,515	$98,504	$158,506
Cost of Film	-	$249,515 $424,176 $598,837	$249,515 $424,176 $598,837	$249,515 $424,176 $598,837
Annual ROI $5 film	-	20%	39%	64%
Annual ROI $8.50 film	-	12%	23%	37%
Annual ROI $12 film	-	8%	16%	26%
Simple Payback $5 film	-	4.94	2.53	1.57
Simple Payback $8.50 film	-	8.40	4.31	2.68
Simple Payback $12 film	-	11.85	6.08	3.78

Table 20: Fresno (CZ13) ROI for Existing Offices with Double Pane Glass

DOUBLE PANE	no film	good	better	best
Total Electricity (MWh)	6,005	5,561	5,373	5,123
Total Gas (Therms)	24,138	21,711	20,234	18,950
Energy Cost	$924,922	$855,833	$826,106	$787,437
Annual Savings	-	$69,089	$98,816	$137,486
Cost of Film	-	$249,515 $424,176 $598,837	$249,515 $424,176 $598,837	$249,515 $424,176 $598,837
Annual ROI $5 film	-	28%	40%	55%
Annual ROI $8.50 film	-	16%	23%	32%
Annual ROI $12 film	-	12%	17%	23%
Simple Payback $5 film	-	3.61	2.53	1.81
Simple Payback $8.50 film	-	6.14	4.29	3.09
Simple Payback $12 film	-	8.67	6.06	4.36

In hot, Central Valley (Fresno) climates the ROI ranges from 8%-64% annually. Single pane existing windows provide an opportunity for 8%-64% ROI, while adding external film to double pane windows will pay back at 12%-55% annually.

In existing offices with single pane windows, anywhere other than the mildest zones (Oakland, CZ3), there is an external window film product that can pay back in less than 2 years. In all climate zones there are better and/or best external window films on dual and single pane windows at $5.00 or $8.50 per square foot that produced less than a three year payback (ROI). For existing office buildings external window films are an attractive energy conservation measure to reduce annual energy costs.

Conclusions for External Window Film

Window film applied to the exterior of existing windows in housing is, if not the most, one of the most cost effective energy efficiency improvements one can make to existing housing. In a previous study on energy improvements to existing housing similar results were determined for internal window films. The external film installed in existing residential housing ranked number one at the lower price point ($5.00 per square foot installed) in mild, inland and hot California climate zones. At the highest price point ($12.00 per square foot installed) only ceiling insulation outperformed external window film.

Existing office buildings may be a very attractive market for external window film products. Best external window films in the hotter climate zones produced paybacks from 1.6 to 4.5 years. High ROIs are found with externally applied films just as they were with internally applied films on clear, single-pane glazing. Exterior film may also create lower thermal stress risk to glazing, making it an attractive energy conservation option for many commercial and public building retrofits. .