CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

# Nonresidential & High-Rise Residential Fenestration Requirements

*2013 California Building Energy Efficiency Standards*

California Utilities Statewide Codes and Standards Team September 2011

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# Nonresidential & High-Rise Residential Fenestration Requirements

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**CONTENTS**

## FIGURES

# 1. Purpose

Fenestration requirements in Title 24 were last updated in the 2001 Standards. Significant changes in pricing and technology have occurred since then allowing for an update to the Standards. In addition, updated TDV[1] and weather files provided the revised future expected worth of energy and more complete and current weather data. The effect of solar angle of incidence was also considered for accuracy. This document presents the work performed towards incorporating these criteria and proposed updates to the Standard.

[1] See section 3.1 for a definition of this term.

# 2. Overview

The following is a summary of the proposed measures, their impacts and enforcement.

| | |
|---|---|
| a. Measure Title | Nonresidential and High-Rise Residential Fenestration Requirements |
| b. Description | The proposed update would change the required NFRC[2] performance ratings for nonresidential and high-rise residential buildings. |

[2] See section 3.1 for a definition of this term.

| | |
|---|---|
| c. Type of Change | The update will change the Prescriptive Envelope Component Approach of the Standards. The NFRC rated U-factor and SHGC will change, and a new VT[3] requirement will be enforced. The Standards will no longer have different NFRC ratings for every climate zone, fenestration ratio and façade orientation. There will instead be a single required NFRC rating for the whole state, but divided into the following window type categories: fixed, operable, curtain wall/storefront and glazed doors. The skylight categories remain the same. |
| d. Energy Benefits | The energy benefits below reflect savings based on the prototype building as described in the section 4.6. Briefly, the prototype building was a 130' X 130', single-floor energy model, with Title 24-2008 office occupancy loads, Title 24-2008 minimally-compliant walls, roof and HVAC. Internal loads and schedules were taken from the Title 24-2008 ACM for nonresidential and high-rise residential occupancies. Daylighting was applied to capture lighting savings and to account for the externality of occupant view benefit. The window-to-wall ratios were modeled at 10%, 20%, 30% and 40% and skylight-to-roof ratios were modeled at 2% and 5%. The model used updated weather and TDV files. |

| **Nonresidential Window Prototype** | Electricity Savings (kwh/yr) | Demand Savings (kw) | Natural Gas Savings (Therms/yr) | TDV Savings (kBTU/yr) |
|---|---|---|---|---|
| Per Window | 69.40 | 0.0164 | -0.0043 | 1,769 |
| Per Prototype Building | 4,295 | 1.01 | -0.27 | 109,511 |
| Savings per square foot | 0.254 | 0.00006 | -0.00002 | 6.48 |

| **High-Rise Residential Window Prototype** | Electricity Savings (kwh/yr) | Demand Savings (kw) | Natural Gas Savings (Therms/yr) | TDV Savings (kBTU/yr) |
|---|---|---|---|---|
| Per Window | 49.86 | 0.0150 | -1.4562 | 1,103 |
| Per Prototype Building | 2,974 | 0.90 | -86.87 | 65,798 |
| Savings per square foot | 0.176 | 0.00005 | -0.00514 | 3.89 |

[3] See section 3.1 for definitions of U-factor, SHGC and VT.

| **Nonresidential Glass Skylight Prototype** | Electricity Savings (kwh/yr) | Demand Savings (kw) | Natural Gas Savings (Therms/yr) | TDV Savings (kBTU/yr) |
|---|---|---|---|---|
| Per Skylight | 317.27 | 0.1275 | -0.1741 | 9,788 |
| Per Prototype Building | 7,606 | 3.06 | -4.17 | 234,646 |
| Savings per square foot | 0.450 | 0.00018 | -0.00025 | 13.88 |

| **High-Rise Residential Glass Skylight Prototype** | Electricity Savings (kwh/yr) | Demand Savings (kw) | Natural Gas Savings (Therms/yr) | TDV Savings (kBTU/yr) |
|---|---|---|---|---|
| Per Skylight | 157.55 | 0.0637 | -1.8974 | 4,497 |
| Per Prototype Building | 1,891 | 0.76 | -22.77 | 53,964 |
| Savings per square foot | 0.112 | 0.00005 | -0.00135 | 3.19 |

| **Nonresidential Plastic Skylight Prototype** | Electricity Savings (kwh/yr) | Demand Savings (kw) | Natural Gas Savings (Therms/yr) | TDV Savings (kBTU/yr) |
|---|---|---|---|---|
| Per Skylight | 234.20 | 0.0729 | -0.2991 | 6,569 |
| Per Prototype Building | 6,255 | 1.95 | -7.99 | 175,447 |
| Savings per square foot | 0.370 | 0.00012 | -0.00047 | 10.38 |

| **High-Rise Residential Plastic Skylight Prototype** | Electricity Savings (kwh/yr) | Demand Savings (kw) | Natural Gas Savings (Therms/yr) | TDV Savings (kBTU/yr) |
|---|---|---|---|---|
| Per Skylight | 99.48 | 0.0400 | -1.4398 | 2,772 |
| Per Prototype Building | 1,194 | 0.48 | -17.28 | 33,264 |
| Savings per square foot | 0.071 | 0.00003 | -0.00102 | 1.97 |

TDV as a metric captures this measure's significant effect on source energy reduction.

<table>
<tr><td></td><td>The lowering of the required SHGC reduces the HVAC energy required during peak periods. The inclusion of a VT requirement also reduces the lighting energy during peak periods which affects both the lighting load and the cooling load.<br><br>Recall that the values given on a "Per Prototype Building" basis represent only a single-floor and therefore, with the exception of skylights, will be additive if more floors are considered.<br><br>The savings from this/these measures results in the following statewide first year savings:<br><table><tr><td>Total Electric Energy Savings (GWh)</td><td>Total Gas Energy Savings (ktherms)</td><td>Total TDV Cost Savings ($)</td></tr><tr><td>77.87</td><td>-117.90</td><td>M$ 319.53</td></tr></table></td></tr>
<tr><td>e. Non-Energy Benefits</td><td>The new VT requirement is predicted to give occupants a better connection to the outdoors, which has been shown to improve occupant comfort and productivity.</td></tr>
</table>

### f. Environmental Impact

The proposed measure does not affect the installation, operation, or maintenance of the fenestration at the site. Therefore there is no additional environmental impact at the site. The environmental impact associated with the manufacture of the products is documented below.

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

| | Mercury | Lead | Copper | Steel | Plastic | Others (Indentify) |
|---|---|---|---|---|---|---|
| Per Window | NC | NC | NC | NC | NC | |
| Per Skylight | NC | NC | NC | NC | NC | |
| Per Prototype Building | NC | NC | NC | NC | NC | |

**Water Consumption:**

| | On-Site (Not at the Powerplant) Water Savings (or Increase) (Gallons/Year) |
|---|---|
| Per Window | NC |
| Per Skylight | NC |
| Per Prototype Building[2] | NC |

**Water Quality Impacts:**

Comment on the potential increase (I), decrease (D), or no change (NC) in contamination compared to the basecase assumption, including but not limited to: mineralization (calcium, boron, and salts), algae or bacterial buildup, and corrosives as a result of PH change.

| | Mineralization (calcium, boron, and salts) | Algae or Bacterial Buildup | Corrosives as a Result of PH Change | Others |
|---|---|---|---|---|
| Impact (I, D, or NC) | NC | NC | NC | |

| | |
|---|---|
| g. Technology Measures | **Measure Availability:**<br>Triple-silver coated glazing which forms the basis for most of the updates to the Standard, is proprietary to Cardinal, PPG and Guardian, but is also available from Viracon. It is predicted that that other companies will follow as well.<br>In addition, through certain adjustments to the code, the proposed measure accommodates double-silver, single-silver and pyrolytic coatings, and encourages other existing energy-saving window strategies that have so far been in limited use in projects. These include: overhangs, fins and window recesses, low VT view windows with high VT clerestory windows, triple-pane windows, room-side low-e surface coatings and suspended film glazing.<br>**Useful Life, Persistence, and Maintenance:**<br>The performance of the fenestration is typically due to properties of components internal to the fenestration (e.g. low-e coatings, gas fills). Due to their protected position within the product there is little or no expected degradation of the performance with time of the proposed update's fenestration. Exposed features of the fenestration have been designed to withstand exterior exposure. Certainly the proposed fenestration is not expected to degrade any more than fenestration installed under the current code. Therefore:<br>◆ The measure is expected to last at least through the 30 year life span of the study and more likely, through the life span of the building which can be much longer.<br>◆ The persistence of the energy savings should last through the installed life of the fenestration.<br>◆ Maintenance is not increased from the use of this fenestration. |
| h. Performance Verification of the Proposed Measure | An additional step of identifying fenestration type (e.g. fixed, operable) and verifying the fenestration VT along with the other performance ratings will be needed. However, verification of VT is simply another number to check that is listed along with U-factor and SHGC. The verification of window-to-wall ratio, skylight-to-roof ratio, and climate zone will no longer be required. |

i. **Cost Effectiveness**

The table below documents the statewide cost-effectiveness of the proposed measures. The data represents area-weighted average costs using the forecated construction of all climate zones, all window-to-wall and skylight-to-roof ratios, and all fenestration types. An area-weighted average form for the data was chosen in order that the information be communicated in a succinct way.

| a | b | c | | d | | e | | f | g | |
|---|---|---|---|---|---|---|---|---|---|---|
| Measure Name | Measure Life (Years) | Additional Costs[1]– Current Measure Costs (Relative to Basecase) ($) | | Additional Cost[2]– Post-Adoption Measure Costs (Relative to Basecase) ($) | | PV of Additional[3] Maintenance Costs (Savings) (Relative to Basecase) (PV$) | | PV of[4] Energy Cost Savings – Per Proto Building (PV$) | LCC Per Prototype Building[6] ($) | |
| | | Per Unit | Per Proto Building | Per Unit | Per Proto Building | Per Unit | Per Proto Building | | (c+e)-f Based on Current Costs | (d+e)-f Based on Post-Adoption Costs |
| Non-residential Window Update | 30 | 101 | 6,225 | NC | NC | 0 | 0 | 16,864 | -10,639 | -10,639 |
| High-Rise Residential Window Update | 30 | 50 | 2,967 | NC | NC | 0 | 0 | 10,132 | -7,165 | -7,165 |
| Non-residential Glass Skylight Update | 30 | 232 | 5.557 | NC | NC | 0 | 0 | 36,133 | -30,576 | -30,576 |
| High-Rise Glass Skylight Update | 30 | 345 | 4,144 | NC | NC | 0 | 0 | 8,310 | -4,166 | -4,166 |
| Non-residential Plastic Skylight Update | 30 | 89 | 2,364 | NC | NC | 0 | 0 | 27,017 | -24,653 | -24,653 |
| High-Rise Plastic Skylight Update | 30 | 0[5] | 0 | NC | NC | 0 | 0 | 5,122 | -5,122 | -5,122 |

1. **Current Measure Costs** - Represents the current cost above the Basecase to implement the measure.
2. **Post Adoption Measure Costs** - NC = No assumed changes in cost were assumed after the adoption of the measure. Reduction in cost will most likely occur but the conservative assumption of no change was used in all calculations.
3. **Maintenance Costs** - The technology of the new measures requires no additional maintenance in comparison to the Basecase.
4. **Energy Cost Savings** - the PV of the energy savings are calculated using the method described in the 2013 LCC Methodology report.
5. Both T24-2008 and the proposed T24-2013 were based on double-pane, aluminum frames with thermal break and pigmented plastic lites. Therefore, there was no cost difference.
6. Recall that the Prototype Building consisted of only a single floor. If more floors are considered in a building, the savings would increase.

| | |
|---|---|
| j. Analysis Tools | All previous Title 24 code-compliance tools are sufficient to quantify the energy savings and peak electricity demand reductions resulting from this proposed measure. The only required inputs are U-factor, SHGC and VT.<br><br>Although EnergyPlus, CMAST, Window6 and Therm6 were used in this analysis to optimize the life-cycle cost and statewide savings of proposed fenestration updates, they are not required to determine performance tradeoffs. |
| k. Relationship to Other Measures | The new VT requirement affects the daylighting measures. With a new required VT, daylighting can be required deeper into spaces. |

# 3. Methodology

This section describes the research performed, tools used and steps taken to determine the fenestration requirements. The basic approach was to determine the life-cycle cost of all fenestration alternatives applicable to California nonresidential construction, then to use the NFRC performance ratings of cost-effective fenestration as the fenestration requirements for the 2013 Standard.

Notable goals within this structure were the use of:

- Angle of incidence in fenestration performance
- EnergyPlus for improved simulation accuracy and to begin the move towards using this software as a basis for the Standards
- The Component Modeling Approach Software Tool (CMAST) to attain consistency between the Standard and NFRC ratings
- Window6 data files to improve the accuracy of the analysis

## *3.1 Definitions*

The following are terms and abbreviations that will be used throughout this document.

- *COG* – Center of glass
- *fenestration alternative* – A unique, complete fenestration assembly including frame, lites, gas and spacers as applicable.
- *fenestration category* – The set of nonresidential or high-rise residential windows or skylights as applicable.
- *fenestration ratio* – The ratio of window area to gross exterior wall area or skylight area to gross roof area as applicable.
- *LCC* – Life-cycle cost.
- *N/A* – Not applicable
- *performance rating* – the U-factor, SHGC and VT for fenestration.
- *previous code update* – the 2001 update to the fenestration requirements in Title 24, Part 6.
- *component category* – A generic title for components of similar purpose and characteristic (e.g. the component category of spacers covered aluminum spacers, steel spacers, etc.).
- *SHGC* – Solar Heat Gain Coefficient as tested by NFRC 200. It is a metric of the heat gain from solar radiation through fenestration.
- *SRR* – Skylight-to-roof ratio. The ratio of skylight area to gross roof area.
- *T24-20XX* – Title 24, Part 6 where XX represents the two-digit vintage for the standard.
- *TDV* – Time-Dependent Valuation of energy. It is an hourly multiplier on site energy that is intended to reflect the energy required at the energy production source.

- *U-factor* – U-factor as tested by NFRC 100.  It is a metric of the conductance of heat through fenestration.
- *VT* – Visible Transmittance as tested by NFRC 200 or ASTM E972 as applicable. It is a metric of the visible light through fenestration from solar radiation.
- *WWR* – Window-to-wall ratio. The ratio of window area to gross wall area.

### *3.2 Research*

Interviews and literature reviews were performed to develop a methodology, to gather data including component information and typical practices, and to find stakeholders.  A summary of the research follows:

- Interviews – Codes and Standards developers, fenestration manufacturers and fabricators, fenestration component manufacturers, fenestration trade organizations and energy and environmental technical experts were interviewed to determine:
    - Developments in the fenestration industry since the previous code update
    - Market studies, research reports or other pertinent resources that they recommend
    - Their opinion on important considerations for this study
    - Whether they would like to be considered a stakeholder in the process or whether they recommend another resource for this role
    - Who are the major companies in the industry
- Literature review – T24-2001 and its associated reports, other fenestration codes and online resources of current technology were reviewed.  Technical documents were also consulted to understand the underlying physics of different components on window performance and typical production, specification and installation practices.
- Market studies – Reports on the nonresidential fenestration market and on the market share of various fenestration characteristics were studied.
- A list of these resources is given in the Bibliography and Other Research section.

### *3.3 Component selection*

To select applicable components, the below criteria were considered.  Note that although a component may not have been considered in the analysis to determine cost-effectiveness that does not imply that the component cannot be used to meet the Standard. It only means that it was not used in this analysis to determine cost-effective fenestration. For example, xenon filled air gaps were not considered in the analysis.  However, a window that incorporates a xenon filled air gap would be able seek compliance, as always, under any of the existing methods in the Standard (i.e. Prescriptive or Performance).

Component selection criteria were:

- Marketplace availability

- Reliability
- Verifiability of performance data
- State and local building code compliance
- Applicability to all nonresidential construction
- Comparison of performance versus cost – If a component was more expensive and lower performing than another component in the same component category, it was not selected. For example, thermally broken spacers were more expensive than hybrid stainless steel spacers. However, they had a higher conductivity. Therefore, they were not selected for use in the analysis.
- Visibility: Fenestration must be transparent and have a visible transmittance (VT) greater than 30%.
- Extreme conditions test – LCCs of certain components were determined in climate zones 1, 7, 15 or 16 at the minimum or maximum fenestration ratio in the nonresidential model only. The choice of climate zone and fenestration ratio depended on the property being evaluated. For example, gas fills were compared in climate zones 15 and 16 since those climate zones represented the extremes of cooling and heating load, respectively. Components were compared to the next, lower costing component in the same component category (e.g. Krypton compared to Argon). If the LCC was higher, no further analysis was performed.

### *3.4 Component combination research*

Research was conducted to determine which components were not compatible with other components and therefore should not be included in combinations together to form a fenestration alternative.

### *3.5 Fenestration alternative generation*

Using an indexing algorithm a list of all possible fenestration alternatives was generated using the considerations determined from the methodology of sections 3.3 and 3.4.

### *3.6 Fenestration alternative properties*

To create consistency between T24-2013 and NFRC ratings, CMAST was used to generate the performance ratings for fenestration alternatives. CMAST contains a database of fenestration components that are combined to form a complete fenestration assembly.

However, not all components needed for the analysis exist in the database. Therm6 was used to create these needed components and then imported into CMAST.

Plastic skylights were the only set of fenestration alternatives that could not be generated using this method. For these alternatives, the previous code update's performance ratings were used.

In addition, skylight curbs do not currently exist in CMAST therefore a correlation was developed from the previous code update to calculate curb-mounted U-factors. The details of the correlation are given in the Appendices.

### *3.7 Component cost collection*

A survey was used to collect cost data. The survey was structured such that a complete baseline fenestration alternative was presented to the surveyee. The surveyee was then requested to provide the cost premium for simple swaps of one component for another, for example, swapping the baseline aluminum frame for a poured and debridged thermally broken aluminum frame.

85% of the data was obtained from window manufacturers. The remaining data was collected from component manufacturers and glazing contractors. Note that initially an online survey of over 300 glazing contractors was conducted but the response was less than 1%.

Surveys were able to obtain at least three cost data points per component category for 90% of the components. The remaining components were of low cost consequence to the cost of the overall fenestration alternative. For example, many spacers are proprietary to particular companies and therefore two cost data points were available. However, the costs of spacers were typically only between 2%-6% of the total cost of the fenestration.

A combination of manufacturer’s surveys and the 90.1 Skylighting Requirements Code Change Proposal determined plastic skylight cost data.

### *3.8 Component cost synthesis*

The cost of fenestration to the owner was the cost considered in the analysis. To this end costs were adjusted according to the following schedule:

- 35% profit: component manufacturer to glazing contractor
- 20% markup: glazing contractor to general contractor
- 10% markup: general contractor to owner
- Non-California data adjusted for California using R.S. Means’ City Index.

Median costs were calculated for each component category for the LCC analysis. Median costs typically represent a real price and are better with outliers (e.g. special pricing structures). The median costs did not differ significantly from the average cost.

### *3.9 Fenestration alternative cost*

A simple cost model was used. The fenestration alternative cost was calculated as the sum of the components’ costs used in that alternative.

### *3.10 Fenestration alternative modeling subset*

From section 3.6 the minimum and maximum performance ratings of all fenestration alternatives were calculated. Then, for each performance parameter, 10 even intervals were calculated within the range. Fenestration alternatives were selected for the modeling subset if one of their performance ratings was the closest to one of the intervals. For example, if an SHGC interval were to be at 0.30, then the fenestration alternative that's SHGC fell closest to 0.30 would be selected.

CMAST was then used on these modeling subset alternatives to create Window6 files.

Window6 files were not created for skylights as domed skylights are not accurately represented in Window6. Instead, performance ratings were used in the energy model.

Note that for plastic skylights, there were few enough alternatives such that modeling alone could be used to find the optimum alternative and therefore no modeling subset was determined.

### *3.11 Modeling parameter generation*

Using an indexing algorithm a list was generated that was comprised of all fenestration alternatives in all climate zones at fenestration ratios of 10%, 20%, 30% and 40% for windows and at 2% and 5% for skylights.

Parameter generation also varied other non-fenestration items including, but not limited to: TDV, weather and design day data by climate zone, envelope properties by climate zone, daylighting controls by fenestration ratio and lighting and equipment loads by occupancy type.

### *3.12 Energy model*

An attempt was made to be consistent with the previous code update's energy model characteristics. However the current analysis incorporated EnergyPlus, CMAST NFRC ratings, Window6 data files and other pertinent changes in the code since the previous code update. The output of the model was annual TDV energy use.

Building characteristics for the model were guided by:

- Forecasted California construction by building type, developed by the California Energy Commission Forecasting Office
- The U.S. Department of Energy Commercial Reference Building Models of the National Building Stock
- Title 24-2008
- The California Commercial End-Use Survey (CEUS)
- Engineering judgment

### *3.13 Curve fit research*

Once the results from the energy model were assembled, curve fit research was conducted to determine a way to predict energy use outside the time-consuming task of energy modeling. Note that if every alternative had been analyzed via the energy model it is estimated that computer run time would be on the order of 6 months for nonresidential windows only.

The research for determining the structure of the curve fit included the following:

- Previous code update – The curve fit used in the previous code update was applied to the results with some success, but agreement metrics were outside preferred tolerances.
- Data inspection – The data was inspected to look for patterns that corresponded to changes in fenestration performance ratings.
- Physical laws – The physics of the changes in the fenestration performance ratings was analyzed to gain insight as to possible forms for the curve fit. This included a study of physical analogies such as decay phenomenon.

Note that for plastic skylights, there were few enough alternatives such that modeling alone could be used to find the optimum alternative and therefore no curve-fitting was performed.

To restate and clarify, the curve fit allowed the analysis to predict the TDV energy use of the remaining fenestration alternatives generated by the methodology of section 3.5. The curve fit methodology did not eliminate any of these fenestration alternatives.

### *3.14 Curve fit trials*

Using the results from section 3.13, several curve fit structures were tested and optimized using an iterative procedure on the parameters of the curve fits, maximizing the agreement metrics with the energy model.

### *3.15 Minimum life-cycle cost*

The LCC of a particular fenestration alternative was calculated as the sum of the fenestration alternative cost and annual energy cost as follows:

- Fenestration alternative cost – As described in section 3.9.
- Annual energy cost – The annual TDV energy use multiplied by the 30-year nonresidential cost per TDV as determined outside this analysis.
- A correlation of fenestration alternative cost versus performance ratings was developed using the cost data collected for this update. This correlation was used to calculate cost information for the cost-effectiveness baseline (i.e. Title 24-2008 fenestration). The formula and agreement metrics for this correlation are given in the Appendices.

### 3.16 Code simplification

In addition to the cost-effectiveness consideration there is a move towards simplification of the Standards. In the interest of code simplification, a reduced set of requirements was considered for the code. This code simplification included:

- A single SHGC and VT for all fenestration ratios up to the maximum fenestration ratio
- A single U-factor, SHGC and VT for all climate zones
- A single SHGC and VT for all orientations

The method for determining these single value performance ratings was to find the most cost-effective fenestration alternative for the State. The most cost-effective fenestration alternative for the State was the one that, when used in all climate zones at all fenestration ratios, would have the lowest LCC statewide when compared to all other fenestration alternatives.

This minimum statewide LCC fenestration alternative was calculated by taking each of the minimum life-cycle fenestration alternatives found in section 3.15 and analyzing them in every climate zone at every fenestration ratio. Then each was weighted according to the forecasted construction within each climate zone.

Weighting was guided by:

- Forecasted California construction by building type, developed by the California Energy Commission Forecasting Office
- The U.S. Department of Energy Commercial Reference Building Models of the National Building Stock
- The California Commercial End-Use Survey
- Engineering judgment

Details of the forecasted construction and building characteristics are given in the Appendices.

Also, no performance rating was allowed that was lower-performing than the requirements of T24-2008. In these cases, the next lowest LCC which met this criterion was chosen.

### 3.17 Performance rating bounds

The effect of upper and lower limits on performance ratings was analyzed to determine the optimum energy savings.

### 3.18 Stakeholder feedback

Feedback from stakeholders in the process was considered in the analysis. Three meetings were held to keep the stakeholders apprised of the progress of, and to allow them to comment on, the analysis. Details of stakeholder comments and project team responses are included in section 4.11.

### *3.19 Final performance rating selection*

The final choice for the code considered the minimum LCC, code simplification and stakeholder feedback.

### *3.20 Statewide Savings Estimates*

The statewide energy savings associated with the proposed measures will be calculated by multiplying the energy savings per square foot with the statewide estimate of new construction in 2014. Details on the method and data source of the nonresidential construction forecast are in the Appendices.

# 4. Analysis and Results

This section presents the analysis and results from the work performed per the Methodology section.

### *4.1 Methodology research*

Research provided information on the methodology, analysis and results of the previous code update and the ASHRAE 90.1-2010 fenestration update. A similar approach to these code updates was used to determine the cost-effective fenestration performance ratings for the proposed update. This approach used an energy model with representative fenestration to produce annual energy use data points. These data points were then used to determine a curve of annual energy use versus fenestration performance ratings. From the results of this curve the CEC cost-effectiveness calculation was performed. Then the statewide impact was calculated from a construction forecast provided to the CASE team by the California Energy Commission Forecasting Office.

### *4.2 Component selection and cost research*

Research also resulted in a comprehensive list of fenestration components. Figure 4-1 lists these, their cost premiums over baseline and any rationale for elimination from the analysis. Note that green, standard and high-performance tints had the highest VT of all other tints and were therefore chosen for the analysis.

The "IDs" are used throughout this document to identify the components that make up a fenestration assembly. The order of components in a fenestration assembly is given as:

*Layers-Frame-Substrate-Coating-Spacer-Gas-Coating-Substrate-Coating…*

The *Spacer-Gas-Coating-Substrate-Coating* pattern repeats itself for additional layers.

| | Component Category | Cost Premium | ID | Elimination rationale |
|---|---|---|---|---|
| **Glass Fenestration (Windows and& Skylights)** | | | | |
| **Coatings** | Uncoated (Baseline) | $- | NC | |
| | Low-e with a low SHGC (triple silver coating) | $6.78/sf | eL | |
| | Low-e with a medium SHGC (double silver coating) | $4.12/sf | eM | |
| | Low-e with a high SHGC (single silver coating) | $2.75/sf | eH | |
| | Low-reflectance reflective coating (2nd surface reflective) | $2.56/sf | Rf | Visibility |
| | Pyrolytic | $4.24/sf | eP | |
| **Substrates** | Clear (Baseline) | $- | C | |
| | Suspended film | $8.42/sf | SF | |
| | Standard tint (Green) | $1.27/sf | Gr | |
| | High-performance tint (Green) | $5.53/sf | HP | |
| | Building-integrated photovoltaics | | N/A | Non-verifiable performance |
| | Diffusive (Kalwall, nano-gel) | | N/A | Visibility |
| | Angularly dependent diffusivity | | N/A | Non-verifiable performance |
| | Light redirective | | N/A | Non-verifiable performance |
| **Frames** | Standard Aluminum (Baseline) | $- | Al | |
| | Poured and debridged thermal break | $1.79/lf | DB | |
| | Polyamide thermal break | $3.53/lf | PA | More expensive, lower performing than Poured and debridged thermal break |
| | Vinyl frames | | Vn | Building code (Windows) |
| | Fiberglass frames | | N/A | Building code |
| | Low-e painted | | N/A | Market availability |
| **Spacers** | Standard Aluminum (Baseline) | $- | Al | |
| | Mild Steel | $0.02/lf | MS | |
| | SST | $0.21/lf | SS | More expensive, lower performing than Mild Steel |

| | | | | |
|---|---|---|---|---|
| | Hybrid Steel | $0.11/lf | US | |
| | Hybrid SST | $0.21/lf | UT | |
| | Thermal break | $0.42/lf | TB | More expensive, lower performing than Hybrid SST |
| | Non-metal | $0.48/lf | NM | |
| **Gases** | Air (Baseline) | $- | Ai | |
| | Argon | $0.03/sf | Ar | |
| | Krypton | $2.12/sf | Kr | Extreme conditions test versus Argon, Reliability[2] |
| | Xenon | $7.23/sf | Xe | Extreme conditions test versus Argon, Market Availability[3], Relability[4] |
| **Layers** | Single-pane (Baseline) | $- | S | |
| | Double-pane | $3.83/sf | D | |
| | Triple-pane | $11.18/sf | T | |
| **<u>Plastic/Acrylic Fenestration (Skylights)</u>** | | | | |
| **Substrates** | Clear (Baseline) | $- | C | |
| | Bronze tint acrylic | $2.66/sf | Bz | |
| | High white pigment acrylic | $2.66/sf | HW | |
| | Medium white pigment acrylic | $2.66/sf | MW | |
| | Low white pigment acrylic | $2.66/sf | LW | |
| | Diffuser | $7.20/sf | Df | Extreme conditions test versus without Diffuser: Diffusers always proved to be cost-effective on skylights with non-diffusing materials and therefore skylights without either a diffuser or diffusing materials were eliminated. |
| **Frames** | Standard Aluminum (Baseline) | $- | Al | |
| | Poured and debridged thermal break | $0.44/lf | DB | |
| | Vinyl frame | $2.52/lf | Vn | |
| **Layers** | Single-pane (Baseline) | $- | S | |
| | An additional pane of clear acrylic (Double-pane) | $1.63/lf | D | |
| | Two additional panes of clear acrylic (Triple-pane) | $5.22/lf | T | |
| | Three additional panes of clear acrylic (Quadruple-pane) | $6.85/lf | Q | |
| **Mounting** | Curb | $- | Cb | |
| | Deck | $- | Dk | |

**Figure 4-1 Components Considered in the Analysis, Their IDs and Their Costs**

1. Grey cells represent components that were not selected for the minimum LCC analysis.
2. If Krypton gas leaks and is replaced by air, the U-factor drops significantly. In addition, Krypton shows little improvement in U-factor over Argon for triple-pane windows.
3. If Xenon gas leaks and is replaced by air, the U-factor drops significantly.
4. There are studies that show that there may not be enough Xenon in the atmosphere to support widespread use.

### *4.3 Component combination selection*

The following criteria were considered to determine which components were used in combinations with other components:

- Only the outside lite was ever tinted.
- A room-side low-e coating was only ever used if there was already an even-surfaced inner lite coating (e.g. a $4^{th}$ surface indoor coating was used on an alternative only if there was already a $2^{nd}$ surface coating.).
- Room-side low-e coatings were only pyrolytic as sputter coatings are easily damaged.
- For triple-pane fenestration, the assumption was made that the gas fills, spacers, and air gap dimensions were the same for each air gap and that the same coating type and placement (even- or odd-surface number) was used for coatings interior to the fenestration.
- $3^{rd}$ surface coatings were only used for passive solar fenestration
- Only clear substrates were used on passive solar fenestration
- For the sputter coatings, only low-e with a high SHGC was used for passive solar fenestration because the other sputter coatings were more expensive, with comparable U-factors but lower SHGCs.

### *4.4 Fenestration alternative generation*

Using the methodology from section 3.5 the fenestration alternatives generated encompassed all the components mentioned in section 4.3. Note that using this methodology generated not only typical standard strategies (e.g. low solar gain), but also passive solar strategies and room-side (e.g. $4^{th}$ surface) pyrolytic low-e coating strategies. The counts for the fenestration alternatives were as follows:

- 1,393 window alternatives
- 588 glass skylight alternatives (Triple-pane and suspended film were not analyzed.)
- 55 plastic skylight alternatives

### *4.5 Fenestration alternative modeling subset*

The minimum and maximum U-factor, SHGC and VT were used to determine the range of performance ratings. These ranges were then divided into 10 evenly distributed intervals for each rating per the criteria in section 3.10. Figure 4-2 and Figure 4-3 present the performance ratings of the fenestration alternatives that were closest to these intervals and therefore selected for the energy model runs and subsequent curve fitting. The fenestration ID can be translated using Figure 4-1.

Some fenestration alternatives were closest to more than one performance rating interval. For example, a fenestration alternative could be close to both an SHGC and VT interval. Therefore, the total number of modeled fenestration alternatives is less than 30.

Note again that there is no modeling subset for plastic skylights as there were few enough alternatives that modeling alone could be used to determine the optimum alternative.

| Fenestration ID | U-factor | SHGC | VT | COG U-factor | COG SHGC | COG VT |
|---|---|---|---|---|---|---|
| S-Al-C-NC | 1.140 | 0.760 | 0.739 | 0.990 | 0.817 | 0.884 |
| S-DB-C-NC | 0.992 | 0.723 | 0.739 | 0.990 | 0.817 | 0.884 |
| S-DB-Gr-NC | 0.992 | 0.553 | 0.645 | 0.990 | 0.613 | 0.771 |
| S-Al-C-eP | 0.837 | 0.666 | 0.686 | 0.628 | 0.705 | 0.821 |
| S-Al-Gr-eP | 0.817 | 0.490 | 0.599 | 0.604 | 0.496 | 0.717 |
| S-DB-Gr-eP | 0.669 | 0.454 | 0.599 | 0.604 | 0.496 | 0.717 |
| S-DB-C-eP | 0.666 | 0.627 | 0.684 | 0.628 | 0.705 | 0.821 |
| D-Al-HP-NC-Al-Ai-NC-C-NC | 0.649 | 0.347 | 0.501 | 0.473 | 0.394 | 0.607 |
| D-Al-C-NC-Al-Ar-NC-C-NC | 0.628 | 0.604 | 0.648 | 0.445 | 0.705 | 0.786 |
| D-Al-C-eH-Al-Ai-NC-C-NC | 0.526 | 0.473 | 0.624 | 0.309 | 0.545 | 0.757 |
| D-Al-HP-eL-Al-Ai-NC-C-NC | 0.512 | 0.223 | 0.399 | 0.289 | 0.242 | 0.484 |
| D-Al-HP-eH-Al-Ai-NC-C-eP | 0.474 | 0.264 | 0.447 | 0.244 | 0.293 | 0.541 |
| T-Al-C-NC-UT-Ai-NC-C-NC-UT-Ai-NC-C-NC | 0.425 | 0.528 | 0.588 | 0.307 | 0.617 | 0.703 |
| D-DB-C-eH-Al-Ai-NC-C-NC | 0.406 | 0.469 | 0.642 | 0.309 | 0.545 | 0.757 |
| D-DB-HP-eH-Al-Ai-NC-C-NC | 0.406 | 0.276 | 0.496 | 0.309 | 0.318 | 0.584 |
| D-DB-C-eM-Al-Ai-NC-C-NC | 0.392 | 0.331 | 0.595 | 0.290 | 0.382 | 0.701 |
| T-Al-C-NC-Al-Ai-eP-C-NC-Al-Ai-NC-C-NC | 0.382 | 0.507 | 0.546 | 0.238 | 0.592 | 0.653 |
| T-DB-HP-NC-Al-Ar-NC-C-NC-Al-Ar-NC-C-NC | 0.357 | 0.284 | 0.454 | 0.283 | 0.330 | 0.544 |
| T-Al-C-eL-UT-Ai-NC-C-eL-UT-Ai-NC-C-NC | 0.323 | 0.195 | 0.366 | 0.156 | 0.218 | 0.438 |
| T-DB-C-eH-Al-Ai-NC-C-NC-Al-Ai-NC-C-NC | 0.319 | 0.420 | 0.565 | 0.226 | 0.493 | 0.676 |
| T-Al-C-eL-Al-Ai-NC-SF-NC-Al-Ai-NC-C-NC | 0.316 | 0.175 | 0.349 | 0.157 | 0.194 | 0.418 |
| T-Al-Gr-eL-Al-Ai-NC-SF-NC-Al-Ai-NC-C-NC | 0.316 | 0.160 | 0.302 | 0.157 | 0.176 | 0.361 |
| T-DB-HP-eM-Al-Ai-NC-C-NC-Al-Ai-NC-C-NC | 0.312 | 0.216 | 0.403 | 0.216 | 0.247 | 0.482 |
| T-DB-Gr-eL-MS-Ar-NC-SF-NC-MS-Ar-NC-C-NC | 0.231 | 0.148 | 0.302 | 0.12 | 0.167 | 0.361 |
| T-DB-C-eL-UT-Ar-NC-SF-NC-UT-Ar-NC-C-NC | 0.221 | 0.166 | 0.349 | 0.120 | 0.189 | 0.418 |

**Figure 4-2 Modeling Subset for Window Curve Fit**

| Fenestration ID | U-factor | SHGC | VT | COG U-factor | COG SHGC | COG VT |
|---|---|---|---|---|---|---|
| S-Al-Cb-C-NC | 1.513 | 0.758 | 0.723 | 1.172 | 0.822 | 0.884 |
| S-DB-Cb-C-NC | 1.334 | 0.718 | 0.723 | 1.172 | 0.822 | 0.884 |
| S-Al-Cb-Gr-eP | 1.209 | 0.513 | 0.587 | 0.835 | 0.525 | 0.717 |
| S-Al-Cb-C-eP | 1.206 | 0.669 | 0.670 | 0.832 | 0.713 | 0.819 |
| S-Vn-Cb-C-NC | 1.158 | 0.658 | 0.690 | 1.172 | 0.822 | 0.884 |
| S-Vn-Cb-Gr-NC | 1.158 | 0.508 | 0.602 | 1.172 | 0.630 | 0.771 |
| S-DB-Cb-Gr-eP | 1.030 | 0.474 | 0.587 | 0.835 | 0.525 | 0.717 |
| S-DB-Cb-HP-eP | 1.028 | 0.399 | 0.513 | 0.832 | 0.434 | 0.626 |
| S-DB-Cb-C-eP | 1.027 | 0.628 | 0.670 | 0.832 | 0.713 | 0.819 |
| S-Vn-Cb-Gr-eP | 0.867 | 0.426 | 0.560 | 0.835 | 0.525 | 0.717 |
| S-Vn-Cb-C-eP | 0.865 | 0.573 | 0.639 | 0.832 | 0.713 | 0.819 |
| D-Al-Cb-C-eM-Al-Ai-NC-C-eP | 0.720 | 0.320 | 0.524 | 0.351 | 0.365 | 0.650 |
| D-Al-Cb-Gr-eL-Al-Ai-NC-C-eP | 0.719 | 0.236 | 0.400 | 0.350 | 0.260 | 0.496 |
| D-Al-Cb-HP-eL-Al-Ai-NC-C-eP | 0.719 | 0.221 | 0.361 | 0.350 | 0.242 | 0.448 |
| S-Vn-Dk-C-eP | 0.715 | 0.573 | 0.639 | 0.832 | 0.713 | 0.819 |
| D-Al-Cb-C-eH-Al-Ar-NC-C-eP | 0.687 | 0.445 | 0.566 | 0.311 | 0.519 | 0.702 |
| D-DB-Cb-Gr-eL-Al-Ai-NC-C-NC | 0.644 | 0.248 | 0.445 | 0.433 | 0.289 | 0.535 |
| D-DB-Cb-C-eM-Al-Ar-NC-C-NC | 0.577 | 0.329 | 0.584 | 0.361 | 0.386 | 0.701 |
| D-DB-Cb-C-eL-Al-Ai-NC-C-eP | 0.567 | 0.235 | 0.480 | 0.350 | 0.274 | 0.576 |
| D-Al-Dk-C-eH-Al-Ar-NC-C-eP | 0.553 | 0.445 | 0.566 | 0.311 | 0.519 | 0.702 |
| D-DB-Cb-Gr-eM-NM-Ai-NC-C-eP | 0.550 | 0.264 | 0.472 | 0.351 | 0.309 | 0.567 |
| D-DB-Cb-HP-eL-Al-Ar-NC-C-eP | 0.520 | 0.202 | 0.373 | 0.298 | 0.234 | 0.448 |
| D-DB-Dk-C-eM-NM-Ar-NC-C-eP | 0.394 | 0.308 | 0.542 | 0.298 | 0.362 | 0.650 |
| D-Vn-Dk-C-NC-NM-Ar-NC-C-NC | 0.245 | 0.597 | 0.634 | 0.529 | 0.709 | 0.786 |
| D-Vn-Dk-C-eL-NM-Ar-NC-C-eP | 0.076 | 0.246 | 0.465 | 0.298 | 0.273 | 0.576 |

**Figure 4-3 Modeling Subset for Glass Skylight Curve Fit**

### *4.6 Energy model*

The most common building characteristics gleaned from the sources in section 3.12 determined modeling inputs. Additional details are given in the Appendices, but the major modeling inputs were:

- Software: EnergyPlus 5.0.0.031
- Environment
    - Weather and TDV – Updated weather and TDV developed outside this analysis
    - Design days – From the EnergyPlus website for California climate zones: Ann Clg 0.4% Condns DB=>MWB, Ann Htg 99.6% Condns DB.

- Envelope
  - 130’ X 130’, single-story, Title 24-2008 prescriptive minimum steel-frame exterior walls, adiabatic roof and floor for windows[4], Title 24-2008 prescriptive minimum roof for skylights. Orientation: directly facing the cardinal directions.
  - 4’ X 5’ windows per NFRC 100. The model used Window6 data files.
  - 4’ X 4’ skylights per NFRC 100. The model used performance ratings. Skylights were only placed on the core zone.
  - Fenestration parametrics – As defined in section 3.11.
- Zones – 4, 15’ deep perimeter zones and a 100’ X 100’ core zone.
- Nonresidential Occupancy
  - Loads – Title 24-2008 Nonresidential ACM Office Building (Table N2-5) lighting, equipment and outside air. Automatic daylighting controls were included for the primary and secondary daylit zones.
  - Schedules – Title 24-2008 Nonresidential ACM nonresidential occupancy (Table N2-8). Standard US and California holidays.
- High-Rise Residential Occupancy
  - Loads – Title 24-2008 Nonresidential ACM Hotel/Motel Guest Room (Table N2-7) lighting, equipment and outside air. Automatic daylighting controls were included for the primary and secondary daylit zones.
  - Schedules – Title 24-2008 Nonresidential ACM residential occupancy (Table N2-10).
- Systems – Title 24-2008 Nonresidential ACM compliant System 1.

[4] Adiabatic floors and roof were chosen to isolate the effects of the windows. Also, there is relatively little heat flux between ceilings and plenums and between ground floors and the ground in comparison to heat flux between windows and the exterior environment.

### *4.7 Curve fit*

The following curve fit structure proved optimal for agreement with the energy model results.

$$TDV_i = C_u FR^{pfU}\,\mathrm{U\text{-}factor}^{\mathrm{pU}} + C_s FR^{pfS}\,\mathrm{SHGC}^{\mathrm{pS}} + C_V FR^{pfV} VT^{\mathrm{pV}} + TDV_{Base}$$

Where:

$TDV_i$ = The TDV energy use of the $i^{th}$ fenestration alternative

$C_x$, pf*x* and p*x* are constants that vary by climate zone.

*x* is a variable that references a performance rating parameter by the following schedule:

U: U-factor

S: SHGC

V: VT

FR = the fenestration ratio

$TDV_{Base}$ = A base TDV.

The constants were determined by maximizing the agreement metrics between the modeled TDV annual energy use and the TDV energy use calculated by curve fit. The list of constants is given in the Appendices.

This curve fit provided very good agreement with the energy model results. A list of agreement metrics is given in the Appendices. An example of the agreement is given Figure 4-4.

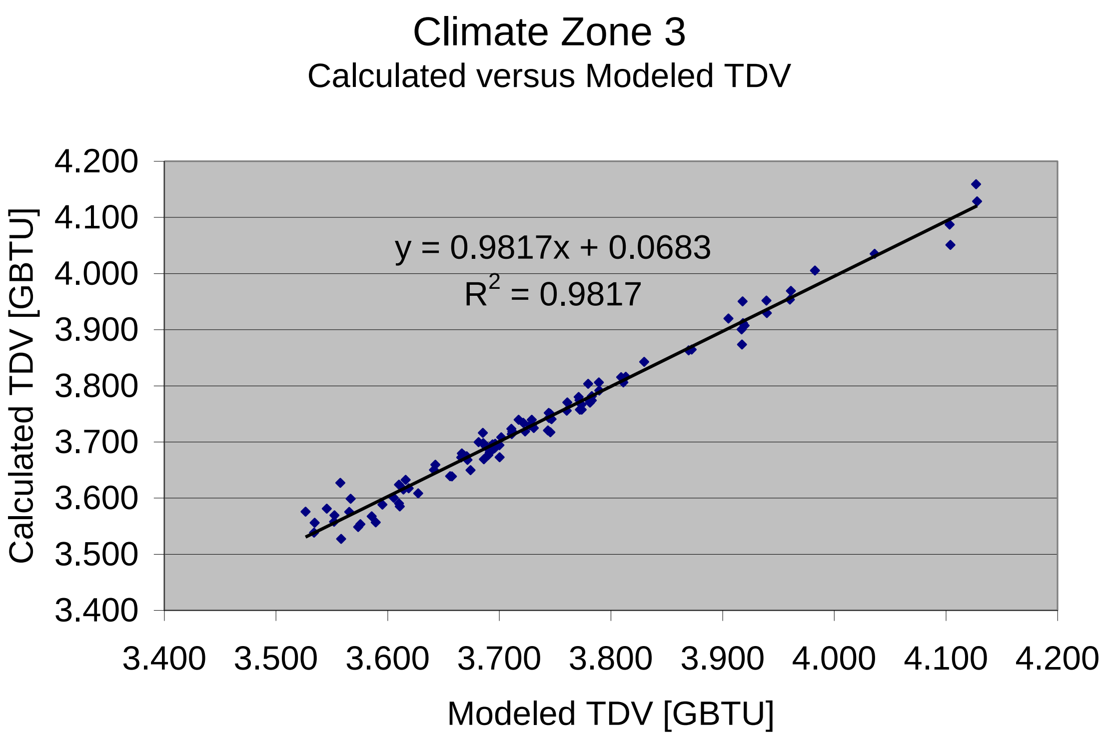



**Figure 4-4 Climate Zone 3 Curve Fit Agreement with Energy Model**

### *4.8 Minimum life-cycle cost*

The curve fits yielded the TDV for each fenestration alternative which yielded the LCC for each fenestration alternative. From these, the minimum LCC fenestration alternative was determined. The nonresidential window minimum LCC performance ratings are presented in Figure 4-5 as an example. The performance ratings for the remaining categories are presented in the Appendices. The theoretical statewide impact results of the minimum LCC fenestration are presented for comparison **Error! Reference source not found.**.

| Climate Zone | Fenestration ID | U-factor | SHGC | VT | COG U-factor | COG SHGC | COG VT |
|---|---|---|---|---|---|---|---|
| 10% WWR | | | | | | | |
| 1 | D-Al-C-eM-Al-Ar-NC-C-NC | 0.474 | 0.335 | 0.578 | 0.239 | 0.377 | 0.701 |
| 2 | D-DB-C-eL-US-Ar-NC-C-NC | 0.340 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 3 | D-DB-C-eL-US-Ar-NC-C-NC | 0.340 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 4 | D-DB-C-eL-US-Ar-NC-C-NC | 0.340 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 5 | D-DB-C-eL-Al-Ar-NC-C-NC | 0.351 | 0.246 | 0.528 | 0.238 | 0.282 | 0.622 |
| 6 | D-DB-C-eL-US-Ar-NC-C-NC | 0.340 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 7 | D-DB-C-eL-US-Ar-NC-C-NC | 0.340 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 8 | D-DB-C-eL-US-Ar-NC-C-NC | 0.340 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 9 | D-DB-C-eL-UT-Ar-NC-C-NC | 0.335 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 10 | D-DB-C-eL-UT-Ar-NC-C-NC | 0.335 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 11 | D-DB-C-eL-UT-Ar-NC-C-NC | 0.335 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 12 | D-DB-C-eL-UT-Ar-NC-C-NC | 0.335 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 13 | D-DB-C-eL-UT-Ar-NC-C-NC | 0.335 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 14 | D-DB-C-eL-UT-Ar-NC-C-NC | 0.335 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 15 | D-DB-C-eL-UT-Ar-NC-C-NC | 0.335 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 16 | D-DB-C-eL-US-Ar-NC-C-NC | 0.340 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 20% WWR | | | | | | | |
| 1 | D-Al-C-eL-Al-Ar-NC-C-NC | 0.473 | 0.256 | 0.513 | 0.238 | 0.282 | 0.622 |
| 2 | D-DB-C-eL-US-Ar-NC-C-NC | 0.340 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 3 | D-DB-C-eL-US-Ar-NC-C-NC | 0.340 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 4 | D-DB-C-eL-US-Ar-NC-C-NC | 0.340 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 5 | D-Al-C-eL-Al-Ar-NC-C-NC | 0.473 | 0.256 | 0.513 | 0.238 | 0.282 | 0.622 |
| 6 | D-DB-C-eL-US-Ar-NC-C-NC | 0.340 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 7 | D-DB-C-eL-US-Ar-NC-C-NC | 0.340 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 8 | D-DB-C-eL-US-Ar-NC-C-NC | 0.340 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 9 | D-DB-C-eL-UT-Ar-NC-C-NC | 0.335 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 10 | D-DB-C-eL-UT-Ar-NC-C-NC | 0.335 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 11 | D-DB-C-eL-UT-Ar-NC-C-NC | 0.335 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 12 | D-DB-C-eL-UT-Ar-NC-C-NC | 0.335 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 13 | D-DB-C-eL-UT-Ar-NC-C-NC | 0.335 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 14 | D-DB-C-eL-UT-Ar-NC-C-NC | 0.335 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 15 | D-DB-C-eL-UT-Ar-NC-C-NC | 0.335 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 16 | D-DB-C-eL-US-Ar-NC-C-NC | 0.340 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 30% WWR | | | | | | | |
| 1 | D-Al-C-eL-Al-Ar-NC-C-NC | 0.473 | 0.256 | 0.513 | 0.238 | 0.282 | 0.622 |
| 2 | D-DB-C-eL-US-Ar-NC-C-NC | 0.340 | 0.245 | 0.528 | 0.238 | 0.282 | 0.622 |
| 3 | D-DB-Gr-eL-US-Ar-NC-C-NC | 0.340 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 4 | D-DB-Gr-eL-US-Ar-NC-C-NC | 0.340 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 5 | D-Al-C-eL-Al-Ar-NC-C-NC | 0.473 | 0.256 | 0.513 | 0.238 | 0.282 | 0.622 |
| 6 | D-DB-Gr-eL-US-Ar-NC-C-NC | 0.340 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 7 | D-DB-Gr-eL-US-Ar-NC-C-NC | 0.340 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 8 | D-DB-Gr-eL-US-Ar-NC-C-NC | 0.340 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |

| Climate Zone | Fenestration ID | U-factor | SHGC | VT | COG U-factor | COG SHGC | COG VT |
|---|---|---|---|---|---|---|---|
| 9 | D-DB-Gr-eL-UT-Ar-NC-C-NC | 0.335 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 10 | D-DB-Gr-eL-UT-Ar-NC-C-NC | 0.335 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 11 | D-DB-Gr-eL-UT-Ar-NC-C-NC | 0.335 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 12 | D-DB-Gr-eL-UT-Ar-NC-C-NC | 0.335 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 13 | D-DB-Gr-eL-UT-Ar-NC-C-NC | 0.335 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 14 | D-DB-Gr-eL-UT-Ar-NC-C-NC | 0.335 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 15 | D-DB-Gr-eL-UT-Ar-NC-C-NC | 0.335 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 16 | D-DB-Gr-eL-US-Ar-NC-C-NC | 0.340 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 40% WWR | | | | | | | |
| 1 | D-Al-C-eL-Al-Ar-NC-C-NC | 0.473 | 0.256 | 0.513 | 0.238 | 0.282 | 0.622 |
| 2 | D-DB-Gr-eL-US-Ar-NC-C-NC | 0.340 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 3 | D-DB-Gr-eL-US-Ar-NC-C-NC | 0.340 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 4 | D-DB-Gr-eL-US-Ar-NC-C-NC | 0.340 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 5 | D-Al-Gr-eL-Al-Ar-NC-C-NC | 0.473 | 0.232 | 0.441 | 0.238 | 0.252 | 0.535 |
| 6 | D-DB-Gr-eL-US-Ar-NC-C-NC | 0.340 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 7 | D-DB-Gr-eL-US-Ar-NC-C-NC | 0.340 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 8 | D-DB-Gr-eL-US-Ar-NC-C-NC | 0.340 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 9 | D-DB-Gr-eL-US-Ar-NC-C-NC | 0.340 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 10 | D-DB-Gr-eL-US-Ar-NC-C-NC | 0.340 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 11 | D-DB-Gr-eL-UT-Ar-NC-C-NC | 0.335 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 12 | D-DB-Gr-eL-US-Ar-NC-C-NC | 0.340 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 13 | D-DB-Gr-eL-UT-Ar-NC-C-NC | 0.335 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 14 | D-DB-Gr-eL-UT-Ar-NC-C-NC | 0.335 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 15 | D-DB-Gr-eL-UT-Ar-NC-C-NC | 0.335 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |
| 16 | D-DB-Gr-eL-US-Ar-NC-C-NC | 0.340 | 0.220 | 0.454 | 0.238 | 0.252 | 0.535 |

**Figure 4-5 Nonresidential Minimum Life-Cycle Cost Performance Ratings**

## *4.9 Code simplification*

After following the procedures in section 3.16, the minimum statewide LCC fenestration alternative was determined for each fenestration category. The results are presented in Figure 4-6. The statewide LCC calculation is given in section 4.13. Briefly, the results of the analysis showed that double-pane triple-silver low-e coated glazing was the most cost-effective choice for a statewide fenestration standard.

| | Nonresidential | | | | High-Rise Residential | | | |
|---|---|---|---|---|---|---|---|---|
| **All Fenestration Ratios**<br>**All Climate Zones** | **Windows** | **Glass Skylights, Curb Mounted** | **Glass Skylights, Deck Mounted** | **Plastic Skylights, Curb Mounted** | **Windows** | **Glass Skylights, Curb Mounted** | **Glass Skylights, Deck Mounted** | **Plastic Skylights, Curb Mounted** |
| **U-factor** | 0.340 | 0.577 | 0.458 | 1.1 | 0.335 | 0.577 | 0.458 | 1.12 |
| **SHGC** | 0.220 | 0.252 | 0.252 | 0.58 | 0.245 | 0.252 | 0.252 | 0.34 |
| **VT** | 0.454 | 0.518 | 0.518 | 0.69 | 0.528 | 0.518 | 0.518 | 0.29 |

**Figure 4-6 Performance Ratings after Code Simplification**

### *4.10 Performance rating bounds*

By inspection of the physics, for all glass fenestration alternatives, if the other two performance ratings are held constant, decreasing the U-factor, decreasing the SHGC or increasing the VT always leads to increased or no change in savings. It is therefore logical to set a maximum U-factor, maximum SHGC and minimum VT for glass fenestration.

However, for plastic fenestration alternatives this is only true for the U-factor and not for the SHGC and VT. For plastic fenestration the pigment determines both the SHGC and the VT. Therefore, setting a maximum SHGC, in effect, sets a maximum VT.

Figure 4-7 shows that for nonresidential occupancies at the maximum U-factor, if VT is increased TDV energy tended to decrease. This is true even though SHGC increases with increased VT.

For the lighting levels used in this study's optimization analysis, there is relatively little change in TDV energy above the minimum VT. The space has been saturated with daylight at this point. However for lighting levels above those used in this analysis the TDV energy would continue to decrease. Therefore, in the case of plastic skylights, it is logical to not have a maximum SHGC requirement as this would in effect set a maximum VT. This maximum VT would negate the possible TDV energy savings that could be realized with VTs that are higher than the proposed minimum.

Due to the low daytime occupancy and correspondingly low lighting levels during daytime hours, daylighting is not as effective in high-rise residential occupancies. Therefore VT did not show the same tendency in these occupancies. In this case, SHGC was the driving factor. Figure 4-8 shows that SHGCs below the code-simplified SHGC had improved TDV energy savings. For these reasons the high-rise residential update is proposed to be bounded by a maximum SHGC with no requirement on VT.

There is also a region where increasing SHGC (corresponding to increasing VT) begins to save energy in high-rise residential buildings due to daylighting effects. However, since this region was not near the cost-effective SHGC, and since daylighting is not as significant in high-rise residential as it is in nonresidential and since creating a second code bound (i.e. "maximum SHGC of 0.34 or minimum VT of 0.62") would complicate the Standard, only the SHGC bound was selected.

The amount of glazing in doors required to be categorized as a glazed door is between 50% and 100% glazing. Therefore, the maximum SHGC was set at 100% glazed and the minimum VT at 50% glazed.

In addition to the above bounding, all ratings were rounded to the nearest 0.01.

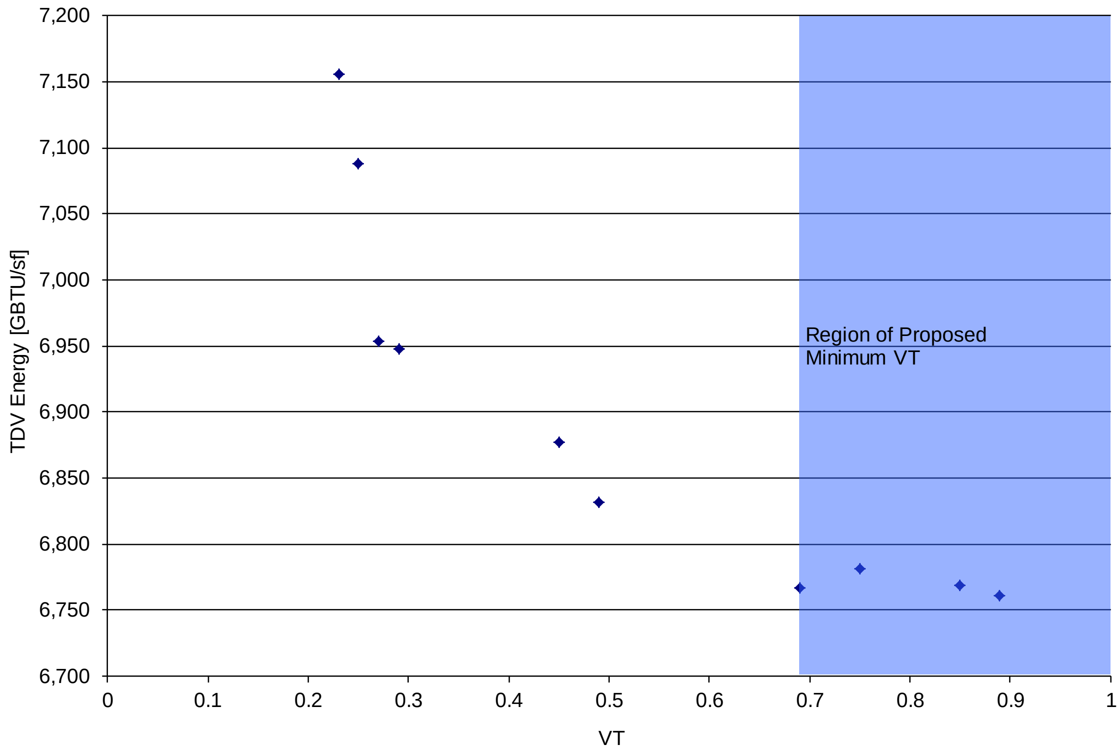



**Figure 4-7 Statewide TDV Energy versus VT for Nonresidential Plastic Skylights**

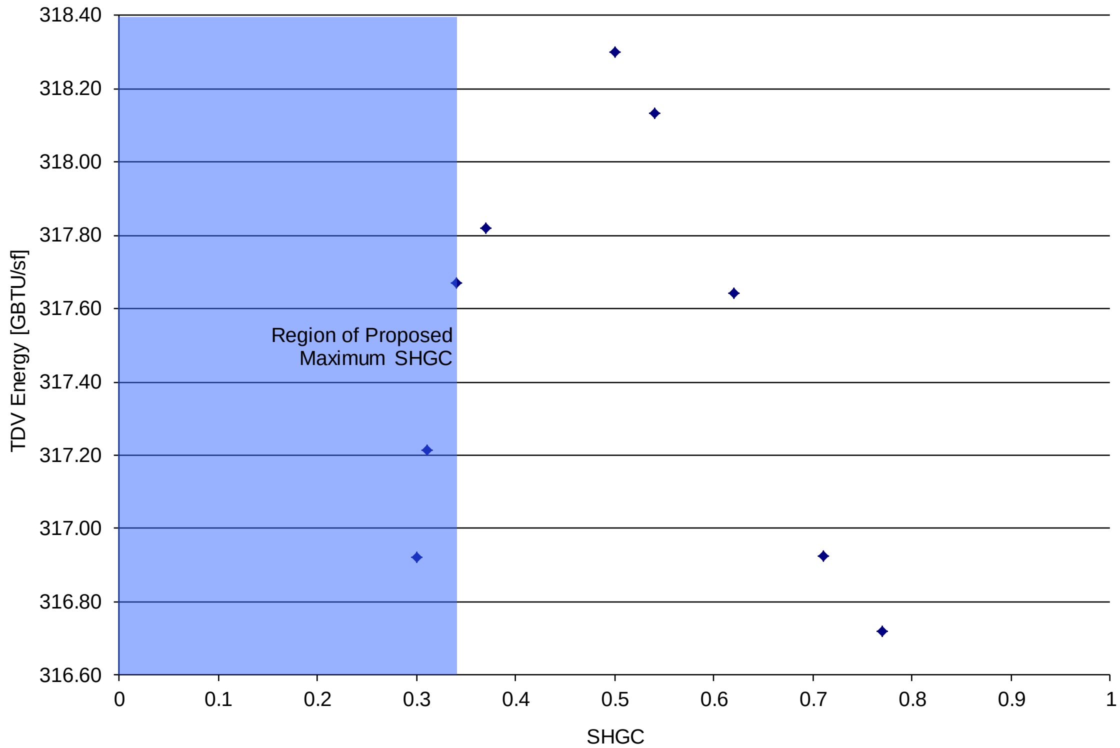



**Figure 4-8 Statewide TDV Energy versus SHGC for High-Rise Residential Plastic Skylights**

### *4.11 Stakeholder feedback*

A detailed documentation of stakeholder comments and CASE author responses are given in the Appendices. The main outstanding stakeholder comments are given in this section.

***Stakeholder Comment: Either the Effective Aperture or Light-to-Solar Gain approach should be used in lieu of the area-weighted minimum VT approach.***

***CASE Author Response:***

The recommended effective aperture (EA) results in an energy penalty compared to the proposed minimum area weighted VT (AW VT). The EA recommended by the stakeholder is 0.15. Analysis estimated the penalties to be notable for nonresidential fixed windows at this EA versus the proposed 0.42 minimum AW VT. The impacts on the State of California are estimated to be:

1. A cumulative gain each year of 0.003 – 4.81 MW in the statewide electric utility peak each year, at worst, the equivalent of new peak power plant every 10 years[5].

[5] Per http://energyalmanac.ca.gov/powerplants/POWER_PLANTS.XLS the median peak power plant capacity is 49.8 MW.

2. A cumulative gain each year of 0.96 – 17.20 GWh in statewide electricity use, at worst, the equivalent of electricity for about 2,900 new houses every year[6].
3. A loss of 7.8 – 196.2 M$ in present value savings over the next 10 years, at worst, close to four times the General Fund expenditures of California's EPA for 2011-2012[7].
4. A cumulative gain each year of 27.8 – 495.8 Mlbs of CO2, at worst, the equivalent pollution of 43,300 new cars on the road each year[8].

The reason that the EA approach is an energy penalty is that it results in low VTs at crucial WWRs. Crucial WWRs are those WWRs for which there is a combination of high forecasted construction and high building energy impact. The crucial WWRs are 30% and 40%.

| **WWR (12' façade)** | **4' X 5' Windows 3' Sill** | **9' High window No sill** |
|---|---|---|
| 10% | 0.49 | 0.25 |
| 20% | 0.48 | 0.22 |
| 30% | 0.33 | 0.22 |
| 40% | 0.25 | 0.21 |

**Figure 4-9 VTs by WWR and Window Configuration at 0.15 EA**

[6] Per http://www.energy.ca.gov/reports/400-04-009/2004-08-17_400-04-009VOL2B.PDF the average annual household electricity usage is approximately 6,000 kWh.

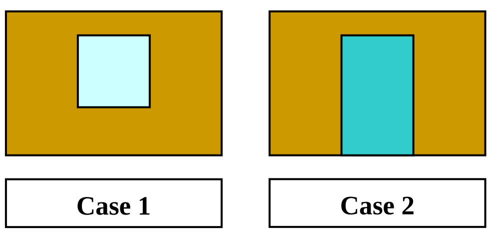
[7] Per http://www.ebudget.ca.gov/pdf/Enacted/BudgetSummary/SummaryCharts.pdf the General Fund expenditures of California's EPA is $51M.

[8] Per http://www.epa.gov/oms/consumer/f00013.pdf the CO2 emissions of the average passenger car is 11,450 lbs/year.

To achieve the minimum penalty of the above, the EA formula would need to go beyond what is recommended by the stakeholder and beyond the current Title 24-2008 specification by:

1. Applying EA to every climate zone and in every type of space. The stakeholder's recommendations only include certain climate zones and certain spaces.
2. Requiring a minimum sill height (~ 2.5'). Without this, windows that extend below this height will have unusable daylight that falls on the floor (i.e. not on the workplane) and will also have darker windows than necessary. Figure 4-10 presents a graphic of the situation.

$$\Pr imary\ Sidelit\ Effective\ Aperture = \frac{\sum Window\ Area \times VT}{\Pr imary\ Sidelit\ Daylight\ Area}$$

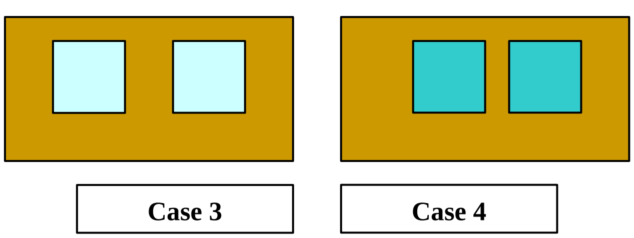



Case 1 and Case 2 have the same primary sidelit area. However, since Case 2 has a larger window area the effective aperture formula lowers the VT.

**Figure 4-10 Effect of Sill Height on Effective Aperture**

3. Require that windows be evenly distributed across a space. Without this, windows that are too close together will be darker than necessary. Figure 2 presents a graphic of the situation.

$$\Pr imary\ Sidelit\ Effective\ Aperture = \frac{\sum Window\ Area \times VT}{\Pr imary\ Sidelit\ Daylight\ Area}$$




Case 3 and Case 4 have the same window area. However, since the windows are closer in Case 2 the primary sidelit areas overlap, the effective aperture formula lowers the VT.

**Figure 4-11 Effect of Overlapping Daylit Areas on Effective Aperture**

The result of the above additional rules and complexity to the Code is a minimized penalty, not a benefit over or equivalence to, the proposed AW minimum VT.

It is then arguable that raising the EA above 0.15 could eliminate this penalty. However, raising the EA is only effective if it raises VTs to the proposed 0.42 minimum AW VT. Raising the EA above 0.15 could also mandate windows with higher VTs than current technology can offer. The 4' X 5' windows at 10% and 20% WWR in Figure 4-9 are already close to the highest VTs available from current technology.

It is also arguable that since EA results in darker windows, that interior shading is used less and therefore there is a net energy savings. However, the stakeholder has presented no evidence that a 0.42 VT causes significant glare. Nor has the stakeholder presented any evidence that blinds or shades cause a significant reduction in daylighting. Only limited anecdotal evidence and opinion has been given.

To contrast that evidence, Figure 4-12 shows that VTs even higher than 0.42 VT can significantly reduce glare and that 0.42 VT can be considered more dark than bright.

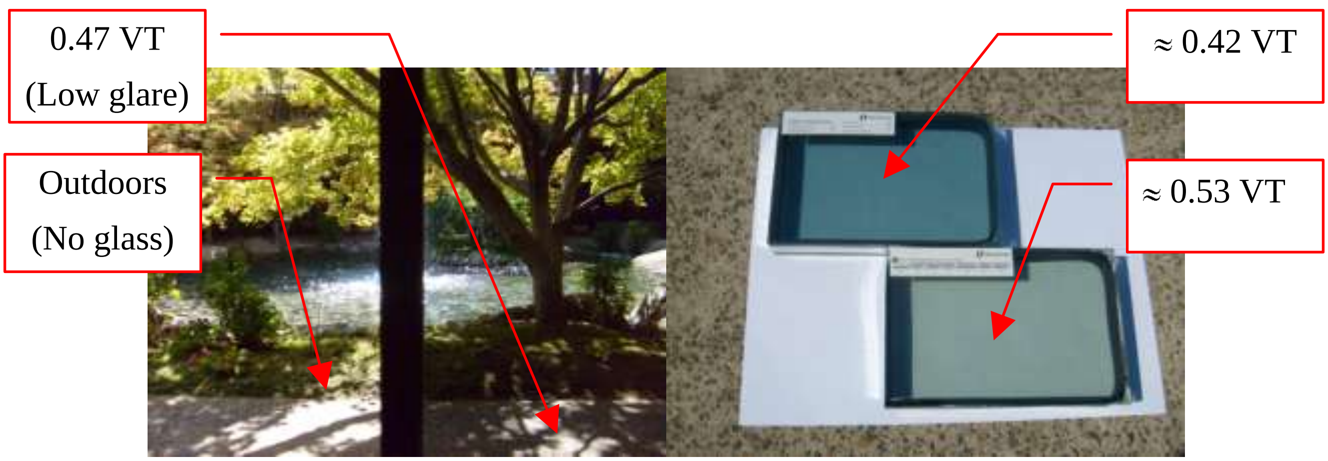



**Figure 4-12 Approximate Glare and Darkness of the Proposed Min AW VT**

Furthermore, Figure 4-13 shows that closed blinds do not necessarily impact lighting levels significantly.


**Figure 4-13 Daylight Level for Open and Closed Blinds**

But most importantly, if a project believes glare is a concern and that dark windows will mitigate this concern, the AW VT approach allows dark view windows to be used with light clerestory windows. This combination has no energy penalty in contrast with the EA approach.

Finally, to address the 1.1 LSG (light to solar gain) recommendation, LSG leaves no guarantee of adequate daylighting potential. For example, a window with an SHGC of 0.10 and an LSG of 1.1 would have a VT of 0.11 which is considered to be exceedingly low.

The code committees of ASHRAE, IECC and the IgCC referenced by the stakeholder are consensus based bodies. Their voting members represent not only energy-efficiency interests but industry interests as well. Therefore the daylighting portions of those codes, no matter by whom they are authored, must consider the agenda of all these voting parties.

In conclusion, the EA approach results in a penalty. This penalty can be minimized by adding the complexity of more rules to the Code, but this works contrary to the CEC goal of simplification. Even after minimization, the penalty causes notable impact on utilities, economics and air quality. As the next section documents, multiple adjustments have already been made over the course of the analysis to accommodate industry concerns over "high" VT, revenue and jobs. For these reasons the effective aperture formula is not recommended.

For the proposed AW VT there is no loophole for windows to be dark if they extend uselessly below the workplane as in Figure 4-10. Nor is there a loophole for windows to be dark if they are too close to each other as in Figure 4-11. Finally, AW VT accomplishes this with a much simpler formula and no energy penalty. For these reasons the AW VT formula is recommended.

***Stakeholder Comment: The area-weighted minimum VT approach is an inappropriate specification for daylighting and limits the glazing choices to proprietary products.***

***CASE Author Response:***

Stakeholders voiced concerns over the area-weighted minimum VT requirement. Although VT was the focus of these concerns, it was ultimately a proxy for opposition to the use of proprietary triple-silver coatings as the sole basis for the proposed update.

To address this issue two pre-existing clauses in the current code were cited and seven adjustments to the proposed update were made. After these considerations, a large number of glazings were identified that could meet the proposed update without the use of triple-silver coatings.

The two pre-existing clauses in the Standard that were cited in response to stakeholder concerns were:

1. RSHG – allows for the use of overhangs to lower the effective SHGC but without analogously lowering the effective VT.
2. The Performance Approach – allows the use of any fenestration[9] provided that, with tradeoffs, the whole building meets a TDV energy budget. Note that this also means that no fenestration is made illegal by the proposed update.

The seven adjustments made to the proposed update were:

1. The lowering of the nonresidential VT center-of-glass basis from 0.622 to 0.535. This was accomplished by choosing the statewide LCC methodology discussed in section 3.16. By using this methodology for code-simplification instead of other methods, a reasonable justification for lowering of the VT was made.
2. The lowering again of the nonresidential VT center-of-glass basis from 0.535 to 0.510 and the lowering of the high-rise residential VT basis from 0.622 to 0.593. This was done to accommodate safety glass. Details are given in the Appendices. In lieu of adding an exception that lowered VTs for code-mandated safety glass, the VT values were lowered slightly. These adjustments have minimal impact on energy use.
3. The raising of the nonresidential SHGC requirement center-of-glass basis from 0.252 to 0.282 for the proposed update's basis. This adjustment has minimal impact on energy use. However, it allowed for clear substrates which have an energy-saving advantage at low to mid WWRs.
4. The mapping of the performance ratings into fixed, operable, curtain wall/storefront and glazed doors. Details are given in the Appendices. This adjustment made it easier for non-fixed windows to meet the proposed update's VT requirement by taking many different frames into account. Details of the mapping methodology are given in the Appendices.

[9] Fenestration that can comply under the Performance Approach must be available in the compliance software.

5. The modification of the requirement’s structure to an area-weighted VT, area-weighted SHGC and area-weighted U-factor.
6. The modification of the RSHG formula to include fins and window recesses. Window recesses are very common in commercial windows and would not require any change in typical practices in the industry and are therefore, in many cases, cost neutral. A credit can now be taken for this energy-saving practice.
7. Envelope and Daylighting Tradeoff Calculation – A forthcoming clause in the Code will allow the use of any fenestration provided that, with tradeoffs, the envelope and daylighting meet a TDV energy budget.

Considering the above, Figure 4-14 lists a sample of fenestration that can meet the nonresidential fixed window requirements of the proposed update. This is not a complete list and more fenestration will be identified later.

| Compliance Approach | Fenestration ID[10] | U-factor | SHGC | VT | COG U-factor | COG SHGC | COG VT |
|---|---|---|---|---|---|---|---|
| Prescriptive, Window only | D-DB-C-eL-Al-Ai-NC-C-eP | 0.342 | 0.236 | 0.489 | 0.231 | 0.271 | 0.576 |
| | D-DB-C-eL-Al-Ar-NC-C-eP | 0.314 | 0.233 | 0.489 | 0.194 | 0.268 | 0.576 |
| | D-DB-C-eL-Al-Ar-NC-C-NC | 0.351 | 0.246 | 0.528 | 0.238 | 0.282 | 0.622 |
| | D-DB-Gr-eL-Al-Ai-NC-C-eP | 0.342 | 0.213 | 0.421 | 0.231 | 0.245 | 0.496 |
| | D-DB-Gr-eL-Al-Ar-NC-C-eP | 0.314 | 0.207 | 0.421 | 0.194 | 0.237 | 0.496 |
| | D-DB-Gr-eL-Al-Ar-NC-C-NC | 0.351 | 0.221 | 0.454 | 0.238 | 0.252 | 0.535 |
| | D-DB-DG-eM-Al-Ar-NC-C | 0.352 | 0.228 | 0.453 | 0.239 | 0.261 | 0.533 |
| | D-DB-BG-eM-Al-Ar-NC-C | 0.354 | 0.227 | 0.451 | 0.241 | 0.260 | 0.532 |
| | D-DB-Gr-eM-Al-Ar-NC-C-eP | 0.315 | 0.252 | 0.481 | 0.195 | 0.290 | 0.567 |
| | D-DB-HP-eH-Al-Ai-NC-C-eP | 0.352 | 0.254 | 0.460 | 0.244 | 0.293 | 0.541 |
| | D-DB-HP-eH-Al-Ar-NC-C-eP | 0.326 | 0.249 | 0.460 | 0.210 | 0.287 | 0.541 |
| | D-DB-HP-eM-Al-Ai-NC-C-eP | 0.342 | 0.223 | 0.424 | 0.232 | 0.257 | 0.500 |
| | D-DB-HP-eM-Al-Ar-NC-C-eP | 0.315 | 0.217 | 0.424 | 0.195 | 0.249 | 0.500 |
| | D-DB-HP-eM-Al-Ar-NC-C-NC | 0.352 | 0.231 | 0.458 | 0.239 | 0.265 | 0.539 |
| | T-Al-C-eL-Al-Ai-NC-C-NC-Al-Ai-NC-C-eP | 0.341 | 0.219 | 0.430 | 0.180 | 0.247 | 0.515 |
| | T-Al-C-eL-US-Ai-NC-C-NC-US-Ai-NC-C-NC | 0.364 | 0.231 | 0.463 | 0.215 | 0.261 | 0.554 |
| | T-Al-C-eL-Al-Ar-NC-C-NC-Al-Ar-NC-C-eP | 0.323 | 0.218 | 0.430 | 0.151 | 0.245 | 0.515 |
| | T-Al-C-eL-Al-Ar-NC-C-NC-Al-Ar-NC-C-NC | 0.343 | 0.229 | 0.463 | 0.179 | 0.257 | 0.554 |
| | T-Al-C-eM-Al-Ai-NC-C-eM-Al-Ai-NC-C-eP | 0.313 | 0.253 | 0.433 | 0.136 | 0.288 | 0.518 |
| | T-Al-C-eM-Al-Ar-NC-C-eM-Al-Ar-NC-C-eP | 0.292 | 0.253 | 0.433 | 0.106 | 0.288 | 0.518 |
| | T-Al-Gr-eM-Al-Ai-NC-C-NC-Al-Ai-NC-C-eP | 0.341 | 0.237 | 0.424 | 0.180 | 0.269 | 0.507 |
| | T-Al-Gr-eM-UT-Ai-NC-C-NC-UT-Ai-NC-C-NC | 0.363 | 0.252 | 0.456 | 0.215 | 0.286 | 0.546 |
| | T-Al-Gr-eM-Al-Ar-NC-C-NC-Al-Ar-NC-C-eP | 0.323 | 0.234 | 0.424 | 0.152 | 0.265 | 0.507 |
| | T-Al-Gr-eM-Al-Ar-NC-C-NC-Al-Ar-NC-C-NC | 0.343 | 0.246 | 0.456 | 0.180 | 0.279 | 0.546 |
| | T-Al-HP-eH-Al-Ai-NC-C-eH-Al-Ai-NC-C-NC | 0.337 | 0.230 | 0.420 | 0.171 | 0.260 | 0.502 |
| | T-DB-HP-eH-Al-Ai-NC-C-NC-Al-Ai-NC-C-NC | 0.319 | 0.245 | 0.437 | 0.226 | 0.283 | 0.523 |
| | T-Al-HP-eH-Al-Ar-NC-C-eH-Al-Ar-NC-C-NC | 0.313 | 0.224 | 0.420 | 0.134 | 0.253 | 0.502 |
| | T-Al-HP-eH-Al-Ar-NC-C-NC-Al-Ar-NC-C-NC | 0.351 | 0.244 | 0.437 | 0.192 | 0.276 | 0.523 |
| Prescriptive, RSHG[11] | 3" Overhang/Fin/Recess | | | | | | |

[10] The IDs DG, BG and Bz have been added to denote Dark Green, Blue-green and Bronze tints, respectively.

| Compliance Approach | Fenestration ID[10] | U-factor | SHGC | VT | COG U-factor | COG SHGC | COG VT |
|---|---|---|---|---|---|---|---|
| | All of the above plus… | | | | | | |
| | D-DB-Gr-eM-Al-Ai-NC-C-eP | 0.342 | 0.257 | 0.481 | 0.232 | 0.297 | 0.567 |
| | T-DB-C-eM-Al-Ar-NC-C-eM-Al-Ar-NC-C-NC | 0.247 | 0.260 | 0.466 | 0.119 | 0.301 | 0.558 |
| | T-DB-Gr-eH-Al-Ai-NC-C-eH-Al-Ai-NC-C-eP | 0.265 | 0.260 | 0.434 | 0.147 | 0.301 | 0.520 |
| | T-DB-Gr-eH-Al-Ar-NC-C-eH-Al-Ar-NC-C-eP | 0.246 | 0.258 | 0.434 | 0.118 | 0.298 | 0.520 |
| | 6" Overhang/Fin/Recess | | | | | | |
| | All of the above plus… | | | | | | |
| | T-Al-C-eM-Al-Ar-NC-C-eM-Al-Ar-NC-C-NC | 0.302 | 0.265 | 0.466 | 0.119 | 0.301 | 0.558 |
| | T-Al-Gr-eH-Al-Ai-NC-C-eH-Al-Ai-NC-C-eP | 0.320 | 0.264 | 0.434 | 0.147 | 0.301 | 0.520 |
| | T-Al-Gr-eH-Al-Ar-NC-C-eH-Al-Ar-NC-C-eP | 0.301 | 0.262 | 0.434 | 0.118 | 0.298 | 0.520 |
| | T-DB-C-eH-Al-Ai-NC-SF-NC-Al-Ai-NC-C-NC | 0.265 | 0.264 | 0.428 | 0.164 | 0.306 | 0.512 |
| | T-DB-C-eH-Al-Ar-NC-SF-NC-Al-Ar-NC-C-NC | 0.240 | 0.262 | 0.428 | 0.127 | 0.303 | 0.512 |
| | T-DB-C-eM-Al-Ai-NC-C-eM-Al-Ai-NC-C-NC | 0.273 | 0.262 | 0.466 | 0.156 | 0.303 | 0.558 |
| | 9" Overhang/Fin/Recess | | | | | | |
| | All of the above plus… | | | | | | |
| | D-DB-Gr-eM-Al-Ar-NC-C-NC | 0.352 | 0.267 | 0.519 | 0.239 | 0.308 | 0.611 |
| | D-DB-HP-eH-MS-Ar-NC-C-NC | 0.364 | 0.267 | 0.496 | 0.260 | 0.307 | 0.584 |
| | T-Al-C-eH-Al-Ai-NC-SF-NC-Al-Ai-NC-C-NC | 0.320 | 0.269 | 0.428 | 0.164 | 0.306 | 0.512 |
| | T-Al-C-eH-Al-Ar-NC-SF-NC-Al-Ar-NC-C-NC | 0.295 | 0.266 | 0.428 | 0.127 | 0.303 | 0.512 |
| | T-Al-C-eM-Al-Ai-NC-C-eM-Al-Ai-NC-C-NC | 0.328 | 0.267 | 0.466 | 0.156 | 0.303 | 0.558 |
| | T-DB-Gr-eH-Al-Ar-NC-C-eH-Al-Ar-NC-C-NC | 0.258 | 0.270 | 0.468 | 0.134 | 0.312 | 0.560 |
| | 1' Overhang/Fin/Recess | | | | | | |
| | All of the above plus… | | | | | | |
| | T-Al-Gr-eH-Al-Ar-NC-C-eH-Al-Ar-NC-C-NC | 0.313 | 0.274 | 0.468 | 0.134 | 0.312 | 0.560 |
| | T-DB-C-NC-Al-Ar-NC-SF-NC-Al-Ar-NC-C-NC | 0.268 | 0.274 | 0.447 | 0.169 | 0.318 | 0.535 |
| | T-DB-Gr-eH-Al-Ai-NC-C-eH-Al-Ai-NC-C-NC | 0.282 | 0.274 | 0.468 | 0.171 | 0.318 | 0.560 |
| | 2' Overhang/Fin/Recess | | | | | | |
| | All of the above plus… | | | | | | |
| | T-Al-C-eM-Al-Ai-NC-C-NC-Al-Ai-NC-C-eP | 0.341 | 0.287 | 0.486 | 0.180 | 0.329 | 0.581 |
| | T-Al-C-eM-Al-Ar-NC-C-NC-Al-Ar-NC-C-eP | 0.323 | 0.288 | 0.486 | 0.152 | 0.329 | 0.581 |
| | T-Al-C-NC-Al-Ai-NC-SF-NC-Al-Ai-NC-C-NC | 0.349 | 0.283 | 0.447 | 0.206 | 0.323 | 0.535 |
| | T-Al-C-NC-Al-Ar-NC-SF-NC-Al-Ar-NC-C-NC | 0.323 | 0.279 | 0.447 | 0.169 | 0.318 | 0.535 |

[11] A 4' high window was assumed for all Overhang/Recess cases. Although curtain walls would typically have a higher window height, the 40% WWR limit for the prescriptive approach gives curtain walls a very sparse aesthetic. For example, for a 10' high wall with a 3' plenum, there would need 9' of wall between each curtain wall. For an 8' high wall with a 3' plenum, there would need to be 6.5' of wall between each curtain wall. Therefore it is considered less likely that curtain walls will attempt to qualify under the prescriptive approach. Storefronts are more likely to use the prescriptive approach. However they often have large overhangs.

Frame depth (3", 6", etc.) can be used to qualify as a recess.

The listed glazing for overhangs/recesses can be used for all orientations. If a "by-orientation" approach is used, the set of glazing that can meet the proposed update's requirements expands by a very large amount.

| Compliance Approach | Fenestration ID[10] | U-factor | SHGC | VT | COG U-factor | COG SHGC | COG VT |
|---|---|---|---|---|---|---|---|
| | T-Al-Gr-eH-Al-Ai-NC-C-eH-Al-Ai-NC-C-NC | 0.337 | 0.279 | 0.468 | 0.171 | 0.318 | 0.560 |
| | T-Al-Gr-eH-Al-Ai-NC-C-NC-Al-Ai-NC-C-eP | 0.346 | 0.285 | 0.452 | 0.188 | 0.326 | 0.541 |
| | T-Al-Gr-eH-Al-Ar-NC-C-NC-Al-Ar-NC-C-eP | 0.329 | 0.284 | 0.452 | 0.162 | 0.325 | 0.541 |
| | T-DB-HP-NC-Al-Ar-NC-C-NC-Al-Ar-NC-C-NC | 0.357 | 0.284 | 0.454 | 0.283 | 0.330 | 0.544 |
| | T-DB-HP-NC-UT-Ai-NC-C-NC-UT-Ai-NC-C-NC | 0.362 | 0.287 | 0.454 | 0.307 | 0.333 | 0.544 |
| | 3' Overhang/Fin/Recess | | | | | | |
| | All of the above plus… | | | | | | |
| | D-DB-Gr-eH-Al-Ar-NC-C-eP | 0.326 | 0.308 | 0.513 | 0.210 | 0.357 | 0.604 |
| | T-Al-C-eM-Al-Ar-NC-C-NC-Al-Ar-NC-C-NC | 0.343 | 0.302 | 0.523 | 0.179 | 0.345 | 0.626 |
| | T-Al-C-eM-UT-Ai-NC-C-NC-UT-Ai-NC-C-NC | 0.363 | 0.303 | 0.523 | 0.215 | 0.347 | 0.626 |
| | T-Al-Gr-eH-Al-Ar-NC-C-NC-Al-Ar-NC-C-NC | 0.351 | 0.300 | 0.487 | 0.192 | 0.344 | 0.582 |
| | T-DB-Gr-eH-Al-Ai-NC-C-NC-Al-Ai-NC-C-NC | 0.319 | 0.300 | 0.487 | 0.226 | 0.348 | 0.582 |
| | 4' Overhang/Fin/Recess | | | | | | |
| | All of the above plus… | | | | | | |
| | D-DB-C-eM-Al-Ai-NC-C-eP | 0.342 | 0.312 | 0.552 | 0.232 | 0.361 | 0.650 |
| | D-DB-C-eM-Al-Ar-NC-C-eP | 0.315 | 0.310 | 0.552 | 0.195 | 0.359 | 0.650 |
| | D-DB-Gr-eH-Al-Ai-NC-C-eP | 0.352 | 0.312 | 0.513 | 0.244 | 0.361 | 0.604 |
| Prescriptive, AW | Any of the following as view windows… | | | | | | |
| | D-DB-Br-eM-US-Ar-NC-C-NC | 0.341 | 0.228 | 0.357 | 0.239 | 0.262 | 0.421 |
| | T-Al-C-eL-Al-Ai-NC-C-eL-Al-Ai-NC-C-eP | 0.312 | 0.185 | 0.340 | 0.136 | 0.206 | 0.406 |
| | T-Al-Gr-eM-Al-Ai-NC-SF-NC-Al-Ai-NC-C-NC | 0.316 | 0.188 | 0.345 | 0.158 | 0.209 | 0.413 |
| | T-Al-HP-eM-Al-Ar-NC-C-eM-Al-Ar-NC-C-NC | 0.302 | 0.190 | 0.359 | 0.119 | 0.211 | 0.430 |
| | T-DB-Gr-eL-UT-Ar-NC-C-NC-UT-Ar-NC-C-eP | 0.256 | 0.188 | 0.371 | 0.151 | 0.216 | 0.443 |
| | …with any of the following as clerestory windows… | | | | | | |
| | D-DB-C-eM-Al-Ar-NC-C-NC | 0.352 | 0.327 | 0.595 | 0.239 | 0.377 | 0.701 |
| | D-DB-C-eM-US-Ar-NC-C-eP | 0.303 | 0.310 | 0.585 | 0.195 | 0.359 | 0.650 |
| | …or… | | | | | | |
| | View: D-DB-Br-eM-US-Ar-NC-C-NC<br>Clerestory: D-DB-C-eL-Al-Ar-NC-C-NC | 0.359<br>0.340 | 0.211<br>0.245 | 0.233<br>0.528 | 0.262<br>0.238 | 0.242<br>0.282 | 0.274<br>0.622 |
| Envelope & Daylighting Tradeoff Calculation | Any, provided that the envelope and daylighting meet a TDV energy budget | | | | | | |
| Performance | Any, provided that the whole building meet a TDV energy budget | | | | | | |

**Figure 4-14 Sample of Glazing That Can Meet the Proposed Update's Nonresidential Fixed Window Standard**

In conclusion, through several clauses in the current code and several adjustments made to the proposed update, many varieties of fenestration from all six major manufacturers can be used to show compliance. In fact, as Figure 4-14 shows, the final structure of the code encourages new and innovative technologies and existing but under-utilized strategies such as triple-silver low-e coatings, overhangs, fins and window recesses, low VT view windows with high VT clerestory windows, triple-pane windows, room-side low-e coatings and suspended film glazing. Many of these technologies and strategies have been struggling to gain wide use despite their energy benefits and many of these were called out specifically by stakeholders as needing inclusion in the code.

Code's that employ this level of SHGC and VT are gaining momentum. The technology is affordable and available now and the combination of significant protection against solar heat gain and simultaneous significant daylighting potential are what California will need to meet its energy targets. Given that windows often have a very significant code-regulated impact on building energy use, it is one of the first, basic and necessary steps needed to reach the 2030 goal. ASHRAE 90.1 came to the same conclusion as this analysis, that triple-silver coatings were the cost-effective, energy saving fenestration for California.

The CASE authors feel that the concerns of the stakeholders have been met, that through careful consideration, analysis and adjustments, market and visual glare concerns have been accommodated while compromising neither California's energy targets nor its cost-effectiveness criteria nor its move towards code simplification. New and innovative technologies and strategies have actually been encouraged which benefits both California and the glazing industry. This proposed update positions California to continue to be the leader in energy efficiency as it has in the past.

***Stakeholder Comment: The proposed VT for nonresidential plastic skylights will result in installation of low diffusing skylights and skylights that cannot meet smoke vent requirements.***

***CASE Author Response:***

The stakeholder recommended lowering the proposed AW VT to 0.60. This could result in a significant energy penalty especially considering that retail buildings comprise a large portion of the buildings that will require skylights. Retail buildings have much higher daylighting saturation threshold than the modeled prototype building and are therefore sensitive to VT. Significant savings could be lost.

The basis for the proposed 0.69 AW VT was a triple-pane high white acrylic aluminum framed skylight. A 2008 ASHRAE study stated that this fenestration had at least a 0.90 haze value which is sufficient to meet Title 24 requirements. However, the stakeholder stated that 0.90 was a minimum and not optimal.

A double-pane clear prismatic over high-white prismatic skylight is available with a tested and documented 0.68 VT and 100% haze value. Calculations based on the aforementioned ASHRAE study showed that the cost premium for prismatic glazing is approximately $2.86/sf. Using the cost premiums from Figure 4-1 and the prismatic cost premium, a double-pane clear prismatic over high-white prismatic with a thermally broken frame costs slightly less than the proposed update's basis, triple-pane high-white with an aluminum frame. The former could therefore become the new basis for the proposed update.

However, smoke vents are limited to 0.62 VT. In lieu of creating a smoke vent exception, an area-weighted adjustment was made. Typically smoke vents, when required, must make up 1% of the roof area. When skylights are required in T24-2013 they must make up 3% of the roof area. Weighting 0.62 as 1/3 of the area and 0.68 as 2/3 of the area, an AW VT of 0.66 results. Therefore, further adjusting for uncertainties in skylight VT ratings, the AW VT was lowered to 0.64.

An AW VT of 0.64 still lies close enough to the daylight saturation region in Figure 4-7 to consider it cost-effective. The lower VT will correspond to very diffuse skylights. And finally, smoke vents are accommodated without adding an exception to the Standard.

***Stakeholder Comment: The proposed U-factor for nonresidential is not based on measured data. Measured data is now available from NFRC and should be used instead.***

***CASE Author Response:***

NFRC U-factors for double-pane, thermally broken plastic skylights given by the stakeholder were 0.82 and 0.86. Double-pane, thermally broken skylights had the same U-factor as triple-pane, aluminum frame skylights in the analysis. Triple-pane, aluminum frame skylights formed the basis for the U-factor requirement for the proposed update. Therefore, the proposed update's U-factor criteria was lowered to 0.88.

### *4.12 Final performance rating selection*

The results presented in **Error! Reference source not found.** demonstrate that after the preceding adjustments the proposed update will remain cost-effective and only marginally lower than the minimum life-cycle's performance. Given these considerations, the performance ratings presented in the code language in Figure 5-1 and Figure 5-2 are recommended for the update.

Notable proposed changes to the Prescriptive Component Approach of T24-2008 include:

- To adequately capture the savings from the update, the proposed update includes a new VT requirement.
- To accommodate variations in performance ratings by fenestration type, fenestration type categories are proposed.
- In the interest of code simplification, the proposed update recommends the elimination of climate zone-, orientation- and fenestration ratio-specific performance ratings.
- All performance ratings are area-weighted to allow for many different fenestration configurations.
- Diffusive materials or diffusers will be prescriptively required for skylights.

### *4.13 Statewide Savings Estimates*

Figure 4-15 presents estimated results for statewide savings that includes the effect of forecasted construction. The assumptions are:

- That the forecasted construction accumulates linearly from zero to the total square footage of construction at the end of 10 years (approximately 1.8 billion square feet), given by the forecasted California construction developed by the California Energy Commission Forecasting Office.
- The following $CO_2$ equivalents per PG&E's Carbon Footprint Calculator Assumptions:
    - Electric: 0.524 lbs $CO_2$ per kWh

  - Natural Gas: 13.446 lbs $CO_2$ per therm
- A discount rate of 6.10% for the present value calculation per the Cash Flow Projections and Life Cycle Cost Model For Financing Energy Efficiency & Conservation Measures ("LCCA Model"), DGS Inputs, Version 2.0, release date 09/16/2009.

| | TDV Savings [GBTU] | Greenhouse Gas Reduction [Mlbs $CO_2$] | Present Value Savings [M$] |
|---|---|---|---|
| **Title 24-2013** | 14,226.8 | 1,569.9 | 1,058.1 |

**Figure 4-15 Overall Estimated 10 year Statewide Impact Including Forecasted Construction**

Figure 4-16**Error! Reference source not found.** presents the statewide annual savings impact of the implementation of the proposed measures based on forecasted construction for 2014. The values are intended to represent the annual impact and therefore the net impact will be cumulative over successive years.

| | Forecasted Construction [Msf] | Electricity | Demand | Natural Gas | TDV | Energy Cost[1] |
|---|---|---|---|---|---|---|
| **Nonresidential Windows** | 168.41 | | | | | |
| Per square foot | | 0.254 kWh | 0.00006 kW | -0.00002 Therms | 6.48 kBTU | $ 1.00 |
| Total | | 42.78 GWh | 10.10 MW | -3.37 kTherms | 1,091.28 GBTU | M$ 168.05 |
| **High-rise Residential Windows** | 14.92 | | | | | |
| Per square foot | | 0.176 kWh | 0.00005 kW | -0.00514 Therms | 3.89 kBTU | $ 0.60 |
| Total | | 2.63 GWh | 0.75 MW | -76.68 kTherms | 58.03 GBTU | M$ 14.89 |
| **Nonresidential Glass Skylights** | 11.91 | | | | | |
| Per square foot | | 0.450 kWh | 0.18 W | -0.00025 Therms | 13.88 kBTU | $ 2.14 |
| Total | | 5.36 GWh | 2.14 MW | -2.98 kTherms | 165.31 GBTU | M$ 14.75 |
| **High-rise Residential Glass Skylights** | 0.06 | | | | | |
| Per square foot | | 0.112 kWh | 0.05 W | -0.00135 Therms | 3.19 kBTU | $ 0.49 |
| Total | | 0.01 GWh | 0.00 MW | -0.09 kTherms | 0.20 GBTU | M$ 0.08 |
| **Nonresidential Plastic Skylights** | 73.16 | | | | | |
| Per square foot | | 0.370 kWh | 0.12 W | -0.00047 Therms | 10.38 kBTU | $ 1.60 |
| Total | | 27.07 GWh | 8.78 MW | -34.39 kTherms | 759.41 GBTU | M$ 90.58 |
| **High-rise Plastic Glass Skylights** | 0.39 | | | | | |
| Per square foot | | 0.071 kWh | 0.03 W | -0.00102 Therms | 1.97 kBTU | $ 0.30 |
| Total | | 0.03 GWh | 0.01 MW | -0.40 kTherms | 0.77 GBTU | M$ 0.48 |
| **Overall** | | | | | | |
| Total | | 77.87 GWh | 21.79 MW | -117.90 kTherms | 2,075.01 GBTU | M$ 319.53 |

**Figure 4-16 Annual Statewide Savings Based on Year 2014**

1. This is the 30-year present value of energy cost of a building built in 2014 and does not include the forecasted construction of buildings built after today.

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

## *5.1 Section 101*

### 5.1.1 Clause (b)

**CURTAIN WALL/STOREFRONT** is an external nonbearing wall intended to separate the exterior and interior environments, which may consist entirely (or principally) of a combination of framing materials, glass and glazing, opaque in-fill and other surfacing materials supported by (or within) a framework.

**FIXED** in reference to fenestration, is fenestration that is not designed to be opened or closed.

**GLAZED DOOR** See DOOR.

**OPERABLE** in reference to fenestration, is fenestration that is designed to be opened or closed.

**DOOR** is an operable opening in the building envelope that is not a fenestration product, including swinging and roll-up doors, fire doors, and access hatches. Doors that are more than one-half glass in area are considered glazed doors~~a fenestration product~~.

**VISIBLE TRANSMITTANCE (VT)** is the ratio (expressed as a decimal) of visible light that is transmitted through a glazing to the light that strikes the material as calculated in **NFRC 200**. For skylights whose transmittances are not within the scope of NFRC 200, transmittance shall be the solar photometric transmittance of the skylight glazing material(s) determined in accordance with ASTM E972.

**FIN** is a contiguous opaque surface, oriented vertically and projecting outward horizontally from an exterior vertical surface.

**OVERHANG** is a contiguous opaque surface, oriented horizontally and projecting outward horizontally from an exterior vertical surface.

**FIN PROJECTION** is the horizontal distance, measured outward horizontally from the surface of exposed exterior glazing at the jamb of a window to the outward edge of a fin.

**OVERHANG PROJECTION** is the horizontal distance, measured outward horizontally from the surface of exposed exterior glazing at the head of a window to the outward edge of an overhang.

**FIN OFFSET** is the horizontal distance from the edge of exposed exterior glazing at the jamb of a window to the fin.

**OVERHANG OFFSET** is the vertical distance from the edge of exposed exterior glazing at the head of a window to the overhang.

## *5.2 Section 10-111*

Multiple revisions (TBD)

***5.3 Section 143***

### 5.3.1 Clause (a).5

B. Have ~~a~~ an area-wieghted U-factor no greater than the applicable value in TABLE 143-A, TABLE 143-B, or TABLE 143-C; and

C. Have ~~a~~ an area-wieghted relative solar heat gain, excluding the effects of interior shading, no greater than the applicable value in TABLE 143-A, TABLE 143-B, or TABLE 143-C. The relative solar heat gain of windows is:

i. The solar heat gain coefficient of the windows; or

ii. Relative solar heat gain as calculated by EQUATION 143-A, if an overhang extends beyond both sides of the window jamb a distance equal to the overhang projection~~.~~ or, for a fin and overhang combination, the fin projection is at least equal to the overhang projection, the fin offset is at least equal to the overhang offset and the fin extends from at least the sill to the head of the window.

**EXCEPTION to Section 143(a)5C:** ~~The applicable "north" value for relative solar heat gain in TABLE 143-A, TABLE 143-B, or TABLE 143-C or~~ 0.56~~, whichever is greater,~~ shall be used for windows:

a. That are in the first story of exterior walls that form a display perimeter; and

b. For which codes restrict the use of overhangs to shade the windows.

D. Have an area-weighted VT no less than the applicable value in TABLE 143-A or TABLE 143-B. The sill height of vertical fenestration with higher VTs shall be greater than or equal to the head height of vertical fenestration with lower VTs.

E. Area-weighted performance ratings shall be calculated according to Equation 143-B

*EQUATION 143-B – AREA WEIGHTED PERFORMANCE RATING CALCULATION*

$$Area-Weighted\ Performance\ Rating = \frac{\sum Fenestration\ Area \times Fenestration\ Performance\ Rating}{Total\ Fenestration\ Area}$$

Where:

Area-Weighted Performance Rating = the area-weighted U-factor, SHGC or VT of the fenestration on a contiguous exterior surface at a single orientation

Fenestration Area = rough opening of fenestration in $ft^2$

Fenestration Performance Rating = the U-factor, SHGC or VT of the fenestration

Total Fenestration Area = the gross area of the rough opening of all fenestration on the façade in $ft^2$.

## 5.3.2 Clause (a).6

B. Have ~~a~~ an area-wieghted U-factor no greater than the applicable value in TABLE 143-A, TABLE 143-B, or TABLE 143-C; and

C. Have ~~a~~ an area-wieghted solar heat gain coefficient no greater than the applicable value in TABLE 143-A, TABLE 143-B, or TABLE 143-C.

D. Have an area-weighted VT no less than the applicable value in TABLE 143-A, TABLE 143-B, or TABLE 143-C.

E. Area-weighted performance ratings shall be calculated according to Equation 143-B.

F. Have a glazing material or diffuser that has a measured haze value greater than 90 percent, tested according to ASTM D1003 (notwithstanding its scope) or other test method approved by the Commission.

## 5.3.3 Table 143-A

*TABLE143-A – PRESCRIPTIVE ENVELOPE CRITERIA FOR NONRESIDENTIAL BUILDINGS (INCLUDING RELOCATABLE PUBLIC SCHOOL BUILDINGS WHERE MANUFACTURER CERTIFIES USE ONLY IN SPECIFIC CLIMATE ZONE; NOT INCLUDING HIGH-RISE RESIDENTIAL BUILDINGS AND GUEST ROOMS OF HOTEL/MOTEL BUILDINGS)*

Remove the sections pertaining to Windows and Skylights and append the below to the table.

| All Climate Zones | | | | | |
|---|---|---|---|---|---|
| Windows | | Fixed | Operable | Curtain wall/ Storefront | Glazed Doors |
| | Max AW U-factor | 0.36 | 0.47 | 0.41 | 0.45 |
| | Max AW RSHG | 0.25 | 0.22 | 0.26 | 0.23 |
| | Min AW VT | 0.42 | 0.32 | 0.46 | 0.17 |
| | Overall Max WWR | 40% | | | |
| Skylights | | Glass, Curb-mounted | Glass, Deck-mounted | Plastic, Curb-mounted | |
| | Max AW U-factor | 0.58 | 0.46 | 0.88 | |
| | Max AW RSHG | 0.25 | 0.25 | NR | |
| | Min AW VT | 0.49 | 0.49 | 0.64 | |
| | Overall Max SRR | 5% | | | |

**Figure 5-1 Table 143-A Proposed Update**

## 5.3.4 Table 143-B

*TABLE 143-B – PRESCRIPTIVE ENVELOPE CRITERIA FOR HIGH-RISE RESIDENTIAL BUILDINGS AND GUEST ROOMS OF HOTEL/MOTEL BUILDINGS*

Remove the sections pertaining to Windows and Skylights and append the below to the table.

| All Climate Zones | | | | | |
|---|---|---|---|---|---|
| Windows | | Fixed | Operable | Curtain wall/ Storefront | Glazed Doors |
| | Max AW U-factor | 0.36 | 0.45 | 0.40 | 0.45 |
| | Max AW RSHG | 0.25 | 0.22 | 0.26 | 0.23 |
| | Min AW VT | 0.49 | 0.44 | 0.53 | 0.19 |
| | Overall Max WWR | 40% | | | |
| Skylights | | Glass, Curb-mounted | Glass, Deck-mounted | Plastic, Curb-mounted | |
| | Max AW U-factor | 0.58 | 0.46 | 0.88 | |
| | Max AW RSHG | 0.25 | 0.25 | 0.34 | |
| | Min AW VT | 0.49 | 0.49 | NR | |
| | Overall Max SRR | 5% | | | |

**Figure 5-2 Table 143-B Proposed Update**

### *5.4 Nonresidential Alternative Calculation Manual Approval Method*

The new VT requirement will be incorporated into the ACM. Details are provided in the daylighting study.

### *5.5 Section 116*

Revise Table 116-A and Table 116-B and create a new Table 116-C for default VT values (TBD).

### *5.6 Appendix JA-1 Glossary*

*FIXED* in reference to fenestration, is fenestration that is not designed to be opened or closed.

*GLAZED DOOR* See DOOR.

*OPERABLE* in reference to fenestration, is fenestration that is designed to be opened or closed.

*DOOR* is an operable opening in the building envelope that is not a fenestration component, including swinging and roll-up doors, fire doors, and access hatches. Doors that are more than one-half glass in area are considered glazed doors~~a fenestration product~~.

*VISIBLE TRANSMITTANCE (VT)* is ratio (expressed as a decimal) of visible light that is transmitted through glazing to the light that strikes the material as calculated in NFRC 200. For skylights whose transmittances are not within the scope of NFRC 200, transmittance shall be the solar photometric transmittance of the skylight glazing material(s) determined in accordance with ASTM E972.

*FIN* is a contiguous opaque surface, oriented vertically and projecting outward horizontally from an exterior vertical surface.

| | |
|---|---|
| *OVERHANG* | is a contiguous opaque surface, oriented horizontally and projecting outward horizontally from an exterior vertical surface. |
| *FIN PROJECTION* | is the horizontal distance, measured outward horizontally from the surface of exposed exterior glazing at the jamb of a window to the outward edge of a fin. |
| *OVERHANG PROJECTION* | is the horizontal distance, measured outward horizontally from the surface of exposed exterior glazing at the head of a window to the outward edge of an overhang. |
| *FIN OFFSET* | is the horizontal distance from the edge of exposed exterior glazing at the jamb of a window to the fin. |
| *OVERHANG OFFSET* | is the vertical distance from the edge of exposed exterior glazing at the head of a window to the overhang. |

## *5.7 Appendix NA-6*

### 5.7.1 NA6.3

#### *NA6.3 Default Solar Heat Gain Coefficient and Visible Transmittance*

The VT of the fenestration component shall be calculated using the following equation:

**Equation NA6-3** $VT_T = 0.53 \times VT_T$

Where:

$VT_T$ = VT for the fenestration including glass and frame

$VT_C$ = VT for the center of glass alone

# 6. Bibliography and Other Research

Literature:


1. 90.1 Skylighting Requirements Code Change Proposal. Findings, costs and performance ratings were consulted for confirmation and reference.
2. A Characterization of the Nonresidential Fenestration Market, 2002. Consulted to understand the market share of various types of fenestration.
3. ASHRAE Standard 90.1-2007. Consulted for various comparisons.
4. ASHRAE Standard 90.1-2010. Data from the fenestration update was consulted as a reference only for methodology and cost information.
5. Assembly Bill 970 Emergency Rulemaking – 2001 Update of California Nonresidential Energy Standards, Volume I – Measure Analysis, November 17, 2000. Consulted to understand the methodology of the previous code update.
6. Assessment of Energy Use in Multibuilding Facilities. Consulted to help guide the energy model assumptions and to predict the statewide impact of the proposed update.
7. California Code of Regulations (CCR), Title 24-2001
8. California Code of Regulations (CCR), Title 24-2008
9. The California Commercial End-Use Survey. Consulted to help guide the energy model assumptions and to predict the statewide impact of the proposed update.
10. Daylight Metrics, California Energy Commission Public Interest Energy Research. Heschong Mahone Group. 2011. Consulted in reference to occupant behavior with interior blinds.
11. U.S. Department of Energy Commercial Reference Building Models of the National Building Stock. Consulted to help guide the energy model assumptions and to predict the statewide impact of the proposed update.
12. Visible Light Transmittance of Skylights. Jon McHugh, Rocelyn Dee & Mudit Saxena. Heschong Mahone Group. March 2004. Submitted to: New Buildings Institute. On behalf of the California Energy Commission Public Interest Energy Research (PIER) Program.


Interviews:

1. Benney, Jim. National Fenestration Rating Council. Provided responses to interview questions presented in section 3.2.
2. Burrell, Galen. ARUP. Provided information on daylighting practices.
3. Eley, Charles. Architectural Energy Corporation. Provided information regarding the previous code update and for possible approaches for the current update.
4. Ernst, Randy. FDR Design. Provided information on gas fill characteristics, practices, costs and availability.

5. Field, Kristin. National Renewable Energy Laboratory. Provided further information on U.S. Department of Energy Commercial Reference Building Models of the National Building Stock.
6. Hogan, John. City of Seattle, ASHRAE 90.1 Board member. Provided responses to interview questions presented in section 3.2.
7. Lewis, John. National Fenestration Rating Council. Provided responses to interview questions presented in section 3.2.
8. Lingnell, Bill. Insulating Glass Manufacturers Alliance. Provided responses to interview questions presented in section 3.2.
9. McMahon, Chris. Technoform. Provided responses to interview questions presented in section 3.2.
10. Nelson, Gary. ICC (Fire marshall). Provided information on fire codes and window frames.
11. Nelson, Steve. Cardinal Corporation. Provided responses to interview questions presented in section 3.2.
12. Rogers, Zack. Daylighting Innovations. Provided general information on daylighting and responses to interview questions presented in section 3.2.
13. Sciarra, Leonard. ASHRAE 90.1 Envelope Committee. Provided general information on the ASHRAE 90.1-2007 and 2010 updates and responses to interview questions presented in section 3.2.
14. Theios, Jason. Guardian Industries. Provided responses to interview questions presented in section 3.2.

Websites:

1. The Efficient Windows Collaborative, www.efficientwindows.org/technologies.cfm. Consulted to get general ideas about technologies and strategies for energy efficient fenestration.
2. Emerging Technologies Index, www.socalgas.com/construction/builders/Builders Resource Guide/Emerging Technologies Index.htm. Consulted to get further information on the latest technologies for fenestration.

# 7. Appendices

## *7.1 Energy Model Additional Details*

Presents additional details not included in section 4.6.

| **Envelope** | | **Source** | **Notes** |
|---|---|---|---|
| Walls | Steel-frame, Title 24-2008 minimally compliant by Climate Zone. 60% visible reflectance. | T24-2008 Reference Appendices for U-factor. Research for mass of layers. | Most popular construction by construction forecast. |
| Windows | Per section 4.6, 3' sill height, evenly spaced on the facades.<br>Nominal ¼" glazing.<br>Nominal ½" air space where applicable. | | |
| Skylights | Per section 4.6, evenly spaced rows and columns across the roof.<br>Nominal ¼" glazing.<br>Nominal ½" air space where applicable. | | |
| Roof | Wood-framed rafter roof, Title 24-2008 minimally compliant by Climate Zone. | T24-2008 Reference Appendices for U-factor. Title 24-2008 Table 146A for reflectance and emittance. Research for mass of layers. | Although Span Deck and Concrete Roofs were the most popular construction per the construction forecast and DOE ref bldgs. Wood-frame chosen because is the baseline roof in Title 24-2008. |
| Ceiling | 80% visible reflectance. | | |
| Floor | 20% visible reflectance. | | |
| Floor-Ceiling height | 10' | | |
| **Lighting Loads** | | | |
| Power | Per section 4.6 | Suspended overhead flourescent light. T-8 lamps (basis of T24-2008 LPDs). | |

| | | | |
|---|---|---|---|
| Fraction of Energy | | Lighting Handbook: Reference & Application, 8th Edition, Illuminating Engineering Society of North America, New York, 1993, p. 355 | |
| Return Air Heat | 0.0 | | |
| Space Radiant | 29.4 | | |
| Space Visible | 23.4 | | |
| Daylighting Controls | | | |
| Type | On/50%/Off<br>Sensor at the edge of the primary daylit, secondary daylit, and skylit zones | Control zones as defined in T24-2008. | On/50%/Off Matches both the mandatory daylighting and mandatory bi-level switch requirements. |
| Lights controlled | Only lights within the primary daylit zones, secondary daylit zones, and skylit zones. | | |
| Well Efficiency | Curb: 0.49<br>Deck: 0.43 | Title 24-2008 Table 146-A | Curb: 4.5' X 4' X 4' Well<br>Deck: 4' X 4' X 4' Well |
| Dirt Derating | Glass: 0.7<br>Plastic: 0.8 | eQUEST defaults | |
| **System** | | | |
| Type | Packaged Single Zone | Title 24-2008 minimally compliant System 1 | Most popular HVAC type per construction forecast and DOE Reference Buildings. 5 tons is the most popular size unit per major manufacturer interview |
| Heating | Autosized, Furnace, 78% efficient | 2010 Appliance Efficiency Regulations | Title 24-2008 does not cover this level of capacity |
| Cooling | Autosized, DX Coils, 11.2 EER | Title 24-2008 Table 112A | Minimum efficiency of the most popular size unit. Cooling efficiency adjusted in model per Title 24-2008 ACM. |
| Economizer | Integrated differential dry-bulb, 65 F max, 40 F min. | Assumption | Technically not necessary on a 5-ton unit. |

| | | | |
|---|---|---|---|
| Fan | Autosized, centrifugal forward-curved, 60% mechanical efficiency, 1.5" static pressure | | |
| Fan Motor | 86.5% efficient, all heat to airstream. | NEMA Standard efficiency, 4-pole, 1800, open | Assumes a 3 hp motor which is the size for the most popular size unit. |

**Figure 7-1 Additional Energy Model Assumptions**

### 7.2 TDV energy-use curve fit

This section documents the curve fit structure, parameters and agreement metrics used in the analysis.

$$TDV_i = C_u FR^{pfU}\,\mathrm{U\text{-}factor}^{\mathrm{pU}} + C_s FR^{pfS}\,\mathrm{SHGC}^{\mathrm{pS}} + C_V FR^{pfV} VT^{\mathrm{pV}} + TDV_{Base}$$

Where:

$TDV_i$ = The TDV energy use of the i$^{th}$ fenestration alternative

$C_x$, pf$x$ and p$x$ are constants that vary by climate zone, occupancy type and fenestration category.

$x$ is a subscript that references a performance rating parameter by the following schedule:

U: U-factor

S: SHGC

V: VT

FR = the fenestration ratio

$TDV_{Base}$ = A baseline TDV that is very roughly analogous to a non-windowed prototype building.

| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$TDV_{Base}$** | 8.189 | 5.210 | 5.083 | 5.338 | 4.973 | 5.394 | 5.416 | 5.502 | 5.423 | 5.606 | 5.611 | 5.427 | 5.652 | 5.662 | 5.349 | 7.252 |
| Cu | 0.227 | 1.263 | 0.510 | 1.361 | 0.070 | 1.082 | 0.763 | 1.476 | 1.521 | 1.688 | 2.217 | 1.765 | 2.207 | 1.953 | 2.983 | 1.063 |
| Cs | 2.730 | 4.241 | 3.725 | 4.243 | 4.362 | 4.426 | 4.303 | 4.399 | 4.739 | 4.771 | 4.667 | 4.439 | 4.572 | 5.010 | 7.272 | 4.039 |
| Cv | -6.070 | -3.731 | -3.122 | -3.909 | -3.016 | -3.779 | -3.653 | -4.063 | -3.867 | -4.183 | -4.476 | -4.128 | -4.459 | -4.389 | -6.204 | -5.067 |
| pu | 0.035 | 0.090 | 0.109 | 0.074 | 0.076 | 0.073 | 0.046 | 0.077 | 0.121 | 0.108 | 0.120 | 0.106 | 0.120 | 0.121 | 0.171 | 0.162 |
| ps | 0.419 | 0.473 | 0.438 | 0.472 | 0.412 | 0.465 | 0.455 | 0.472 | 0.494 | 0.483 | 0.490 | 0.480 | 0.489 | 0.490 | 0.321 | 0.558 |
| pv | 0.014 | 0.049 | 0.034 | 0.044 | 0.053 | 0.046 | 0.045 | 0.041 | 0.054 | 0.047 | 0.047 | 0.045 | 0.048 | 0.050 | 0.070 | 0.024 |
| pfu | 0.751 | 0.786 | 0.773 | 0.789 | 0.791 | 0.786 | 0.793 | 0.786 | 0.773 | 0.778 | 0.776 | 0.783 | 0.777 | 0.778 | 0.868 | 0.906 |
| pfs | 1.062 | 1.042 | 1.078 | 1.024 | 1.092 | 1.026 | 1.039 | 1.015 | 1.024 | 1.032 | 1.029 | 1.040 | 1.032 | 1.033 | 1.076 | 1.020 |
| pfv | 0.079 | 0.328 | 0.269 | 0.320 | 0.297 | 0.316 | 0.291 | 0.321 | 0.346 | 0.337 | 0.344 | 0.334 | 0.343 | 0.344 | 0.641 | 0.136 |
| **Agreement with Model** | | | | | | | | | | | | | | | | |
| Slope | 0.979 | 0.985 | 0.982 | 0.985 | 0.981 | 0.984 | 0.984 | 0.985 | 0.986 | 0.986 | 0.987 | 0.986 | 0.987 | 0.987 | 0.987 | 0.986 |
| Intercept | 0.072 | 0.060 | 0.068 | 0.059 | 0.073 | 0.064 | 0.065 | 0.062 | 0.063 | 0.060 | 0.055 | 0.057 | 0.058 | 0.056 | 0.063 | 0.056 |
| $R^2$ | 0.979 | 0.985 | 0.982 | 0.985 | 0.981 | 0.984 | 0.984 | 0.985 | 0.986 | 0.986 | 0.987 | 0.986 | 0.987 | 0.987 | 0.987 | 0.986 |
| **Discrepancy from Model** | | | | | | | | | | | | | | | | |
| Average | 0.29% | 0.37% | 0.37% | 0.37% | 0.38% | 0.38% | 0.37% | 0.39% | 0.43% | 0.40% | 0.41% | 0.39% | 0.41% | 0.42% | 0.44% | 0.41% |
| Standard Deviation | 0.27% | 0.40% | 0.33% | 0.40% | 0.34% | 0.40% | 0.37% | 0.41% | 0.45% | 0.44% | 0.44% | 0.42% | 0.43% | 0.45% | 0.47% | 0.43% |

**Figure 7-2 Curve Fit Parameters for Nonresidential Windows**

| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$TDV_{Base}$** | 2.224 | 1.993 | 1.868 | 1.964 | 1.791 | 1.867 | 1.848 | 1.904 | 2.026 | 2.062 | 2.319 | 2.164 | 2.303 | 2.288 | 2.485 | 2.226 |
| Cu | 0.924 | 2.588 | 1.430 | 1.500 | 1.150 | 1.205 | 0.750 | 1.392 | 1.831 | 2.011 | 2.441 | 2.293 | 2.494 | 2.465 | 2.910 | 2.479 |
| Cs | 2.005 | 5.098 | 3.644 | 5.780 | 4.078 | 6.047 | 4.611 | 6.444 | 7.443 | 6.710 | 6.577 | 6.446 | 7.046 | 6.407 | 9.531 | 5.008 |
| Cv | -1.118 | -4.922 | -2.883 | -4.614 | -2.690 | -4.516 | -2.973 | -5.002 | -6.082 | -5.541 | -5.694 | -5.773 | -6.296 | -5.460 | -8.561 | -4.529 |
| pu | 0.191 | 0.116 | 0.124 | 0.179 | 0.175 | 0.177 | 0.172 | 0.166 | 0.169 | 0.164 | 0.189 | 0.162 | 0.176 | 0.181 | 0.178 | 0.180 |
| ps | 0.984 | 0.304 | 0.387 | 0.256 | 0.428 | 0.271 | 0.342 | 0.253 | 0.238 | 0.258 | 0.263 | 0.235 | 0.232 | 0.292 | 0.202 | 0.324 |
| pv | 0.074 | 0.083 | 0.104 | 0.090 | 0.156 | 0.096 | 0.115 | 0.089 | 0.088 | 0.083 | 0.095 | 0.078 | 0.083 | 0.102 | 0.078 | 0.113 |
| pfu | 0.720 | 0.876 | 0.830 | 0.872 | 0.911 | 0.875 | 0.864 | 0.872 | 0.855 | 0.866 | 0.875 | 0.879 | 0.870 | 0.888 | 0.847 | 0.937 |
| pfs | 1.934 | 1.264 | 1.241 | 1.179 | 1.414 | 1.166 | 1.098 | 1.144 | 1.149 | 1.178 | 1.202 | 1.205 | 1.179 | 1.233 | 1.118 | 1.315 |
| pfv | 0.367 | 0.934 | 0.818 | 0.938 | 0.950 | 0.942 | 0.819 | 0.936 | 0.954 | 0.947 | 0.954 | 0.964 | 0.962 | 0.967 | 0.947 | 0.978 |
| **Agreement with Model** | | | | | | | | | | | | | | | | |
| Slope | 0.982 | 0.991 | 0.991 | 0.990 | 0.991 | 0.990 | 0.989 | 0.990 | 0.990 | 0.991 | 0.990 | 0.990 | 0.990 | 0.990 | 0.990 | 0.989 |
| Intercept | 0.035 | 0.019 | 0.018 | 0.020 | 0.017 | 0.020 | 0.020 | 0.021 | 0.021 | 0.021 | 0.024 | 0.022 | 0.025 | 0.024 | 0.027 | 0.027 |
| $R^2$ | 0.982 | 0.991 | 0.991 | 0.990 | 0.991 | 0.990 | 0.989 | 0.990 | 0.990 | 0.991 | 0.990 | 0.990 | 0.990 | 0.990 | 0.990 | 0.989 |
| **Discrepancy from Model** | | | | | | | | | | | | | | | | |
| Average | 0.30% | 0.49% | 0.43% | 0.54% | 0.41% | 0.61% | 0.60% | 0.62% | 0.63% | 0.60% | 0.57% | 0.53% | 0.57% | 0.56% | 0.66% | 0.50% |
| Standard Deviation | 0.31% | 0.57% | 0.49% | 0.62% | 0.48% | 0.70% | 0.66% | 0.72% | 0.74% | 0.69% | 0.64% | 0.61% | 0.65% | 0.64% | 0.76% | 0.58% |

**Figure 7-3 Curve Fit Parameters for High-Rise Residential Windows**

| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$TDV_{Base}$** | 3.948 | 4.912 | 4.591 | 5.118 | 5.276 | 5.759 | 5.545 | 6.024 | 5.301 | 5.688 | 5.385 | 5.194 | 6.138 | 5.386 | 6.253 | 5.208 |
| Cu | -2.665 | -1.917 | -1.913 | -1.053 | -0.498 | -11.769 | -22.686 | -1.981 | -0.490 | -1.757 | -1.316 | -4.563 | -2.456 | -1.072 | -0.285 | -0.465 |
| Cs | 8.458 | 17.094 | 9.678 | 15.530 | 10.469 | 14.156 | 13.196 | 13.631 | 21.611 | 18.356 | 16.822 | 17.851 | 17.966 | 22.089 | 23.565 | 16.340 |
| Cv | -2.871 | -2.800 | -2.624 | -2.829 | -3.090 | -3.235 | -3.275 | -3.395 | -2.849 | -3.022 | -2.792 | -2.801 | -3.227 | -2.881 | -3.092 | -2.807 |
| pu | 2.185 | 2.190 | 0.295 | 1.877 | 1.244 | 0.393 | 1.264 | 2.202 | 3.697 | 2.191 | 2.283 | 2.599 | 2.215 | 2.195 | 2.192 | 2.190 |
| ps | 2.068 | 1.914 | 1.832 | 1.881 | 1.776 | 1.507 | 1.572 | 1.579 | 1.915 | 1.856 | 1.866 | 1.891 | 1.815 | 1.816 | 1.769 | 1.918 |
| pv | 0.151 | 0.114 | 0.107 | 0.098 | 0.071 | 0.081 | 0.084 | 0.071 | 0.130 | 0.075 | 0.101 | 0.098 | 0.065 | 0.115 | 0.075 | 0.096 |
| pfu | 2.021 | 2.021 | 1.382 | 1.728 | 1.184 | 2.130 | 2.481 | 2.027 | 1.941 | 2.019 | 2.077 | 2.334 | 2.040 | 2.021 | 2.023 | 2.021 |
| pfs | 0.948 | 1.031 | 0.924 | 0.998 | 0.898 | 0.948 | 0.928 | 0.923 | 1.063 | 1.021 | 0.992 | 1.020 | 0.985 | 1.045 | 1.055 | 1.017 |
| pfv | 0.365 | 0.262 | 0.257 | 0.235 | 0.174 | 0.212 | 0.213 | 0.189 | 0.296 | 0.193 | 0.232 | 0.234 | 0.146 | 0.269 | 0.212 | 0.221 |
| **Agreement with Model** | | | | | | | | | | | | | | | | |
| Slope | 0.995 | 0.993 | 0.995 | 0.994 | 0.994 | 0.994 | 0.995 | 0.995 | 0.993 | 0.994 | 0.993 | 0.993 | 0.993 | 0.994 | 0.993 | 0.994 |
| Intercept | 0.017 | 0.028 | 0.020 | 0.025 | 0.022 | 0.026 | 0.023 | 0.025 | 0.034 | 0.028 | 0.031 | 0.028 | 0.032 | 0.026 | 0.037 | 0.026 |
| $R^2$ | 0.995 | 0.993 | 0.995 | 0.994 | 0.994 | 0.994 | 0.995 | 0.995 | 0.993 | 0.994 | 0.993 | 0.993 | 0.993 | 0.994 | 0.993 | 0.994 |
| **Discrepancy from Model** | | | | | | | | | | | | | | | | |
| Average | 0.17% | 0.16% | 0.15% | 0.16% | 0.17% | 0.15% | 0.15% | 0.16% | 0.16% | 0.16% | 0.16% | 0.17% | 0.17% | 0.15% | 0.17% | 0.14% |
| Standard Deviation | 0.14% | 0.15% | 0.14% | 0.14% | 0.13% | 0.13% | 0.13% | 0.12% | 0.15% | 0.14% | 0.14% | 0.14% | 0.14% | 0.14% | 0.14% | 0.14% |

**Figure 7-4 Curve Fit Parameters for Nonresidential Glass Skylights**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$TDV_{Base}$** | 2.161 | 2.365 | 2.078 | 2.407 | 2.138 | 2.690 | 2.510 | 2.720 | 2.516 | 2.424 | 2.935 | 2.852 | 2.733 | 2.652 | 3.023 | 2.589 |
| Cu | 0.308 | 1.169 | 0.862 | 0.122 | 0.453 | 0.092 | -0.432 | 0.010 | -0.152 | -0.551 | 1.949 | 1.730 | 2.087 | 1.991 | 1.875 | 3.850 |
| Cs | 12.641 | 16.913 | 13.029 | 15.405 | 12.642 | 12.495 | 11.959 | 13.198 | 19.742 | 19.450 | 14.347 | 15.604 | 19.244 | 24.644 | 23.745 | 18.400 |
| Cv | -1.389 | -0.817 | -0.848 | -0.781 | -0.932 | -0.949 | -0.948 | -0.948 | -0.762 | -0.763 | -0.841 | -0.972 | -1.059 | -1.699 | -1.015 | -1.436 |
| pu | 0.678 | 1.353 | 0.866 | 1.486 | 1.472 | 1.491 | 1.493 | 1.491 | 1.500 | 1.534 | 1.176 | 0.854 | 1.471 | 1.490 | 1.995 | 1.711 |
| ps | 1.895 | 1.622 | 1.792 | 1.575 | 1.613 | 1.428 | 1.446 | 1.443 | 1.624 | 1.679 | 1.574 | 1.533 | 1.523 | 1.542 | 1.656 | 1.633 |
| pv | 0.247 | 0.173 | 0.203 | 0.161 | 0.184 | 0.139 | 0.139 | 0.141 | 0.259 | 0.222 | 0.115 | 0.084 | 0.269 | 0.355 | 0.277 | 0.321 |
| pfu | 0.902 | 1.720 | 1.655 | 1.772 | 1.762 | 1.777 | 1.789 | 1.779 | 1.781 | 1.801 | 1.631 | 1.608 | 1.819 | 1.776 | 1.976 | 1.965 |
| pfs | 1.373 | 1.120 | 1.143 | 1.066 | 1.095 | 0.988 | 0.985 | 0.990 | 1.088 | 1.098 | 1.025 | 1.063 | 1.076 | 1.172 | 1.103 | 1.196 |
| pfv | 0.574 | 0.301 | 0.405 | 0.271 | 0.355 | 0.277 | 0.271 | 0.275 | 0.371 | 0.347 | 0.190 | 0.159 | 0.457 | 0.687 | 0.461 | 0.627 |
| **Agreement with Model** | | | | | | | | | | | | | | | | |
| Slope | 0.994 | 0.997 | 0.997 | 0.998 | 0.997 | 0.997 | 0.997 | 0.997 | 0.997 | 0.997 | 0.997 | 0.996 | 0.996 | 0.998 | 0.997 | 0.997 |
| Intercept | 0.012 | 0.006 | 0.006 | 0.004 | 0.005 | 0.007 | 0.007 | 0.007 | 0.007 | 0.008 | 0.009 | 0.009 | 0.010 | 0.006 | 0.008 | 0.007 |
| $R^2$ | 0.994 | 0.997 | 0.997 | 0.998 | 0.997 | 0.997 | 0.997 | 0.997 | 0.997 | 0.997 | 0.997 | 0.996 | 0.996 | 0.998 | 0.997 | 0.997 |
| **Discrepancy from Model** | | | | | | | | | | | | | | | | |
| Average | 0.08% | 0.15% | 0.11% | 0.13% | 0.13% | 0.14% | 0.16% | 0.15% | 0.17% | 0.19% | 0.16% | 0.16% | 0.19% | 0.14% | 0.17% | 0.11% |
| Standard Deviation | 0.07% | 0.12% | 0.10% | 0.09% | 0.08% | 0.12% | 0.13% | 0.12% | 0.15% | 0.16% | 0.14% | 0.15% | 0.15% | 0.11% | 0.14% | 0.09% |

**Figure 7-5 Curve Fit Parameters for High-Rise Residential Skylights**

## *7.3 Non-Residential Construction Forecast details*

### 7.3.1 Summary

The Non-Residential construction forecast dataset is data that is published by the California Energy Commission's (CEC) demand forecast office. This demand forecast office is charged with calculating the required electricity and natural gas supply centers that need to be built in order to meet the new construction utility loads. Data is sourced from Dodge construction database, the demand forecast office future generation facility planning data, and building permit office data.

All CASE reports should use the statewide construction forecast for 2014. The TDV savings analysis is calculated on a 15 or 30 year net present value, so it is correct to use the 2014 construction forecast as the basis for CASE savings.

### 7.3.2 Additional Details

The demand generation office publishes this dataset and categorizes the data by demand forecast climate zones (FCZ) as well as building type (based on NAICS codes). The 16 climate zones are organized by the generation facility locations throughout California, and differ from the Title 24 building climate zones (BCZ). HMG has reorganized the demand forecast office data using 2000 Census data (population weighted by zip code) and mapped FCZ and BCZ to a given zip code. The construction forecast data is provided to CASE authors in BCZ in order to calculate Title 24 statewide energy savings impacts. Though the individual climate zone categories differ between the demand forecast published by the CEC and the construction forecast, the total construction estimates are consistent; in other words, HMG has not added to or subtracted from total construction area.

The demand forecast office provides two (2) independent data sets: total construction and additional construction. Total construction is the sum of all existing floor space in a given category (Small office, large office, restaurant, etc.). Additional construction is floor space area constructed in a given year (new construction); this data is derived from the sources mentioned above (Dodge, Demand forecast office, building permits).

Additional construction is an independent dataset from total construction. The difference between two consecutive years of total construction is not necessarily the additional construction for the year because this difference does not take into consideration floor space that was renovated, or repurposed.

In order to further specify the construction forecast for the purpose of statewide energy savings calculation for Title 24 compliance, HMG has provided CASE authors with the ability to aggregate across multiple building types. This tool is useful for measures that apply to a portion of various building types' floor space (e.g. skylight requirements might apply to 20% of offices, 50% of warehouses and 25% of college floor space).

The main purpose of the CEC demand forecast is to estimate electricity and natural gas needs in 2022 (or 10-12 years in the future), and this dataset is much less concerned about the inaccuracy at 12 or 24 month timeframe.

It is appropriate to use the CEC demand forecast construction data as an estimate of future years construction (over the life of the measure). The CEC non-residential construction forecast is the best publicly available data to estimate statewide energy savings.

### 7.3.3 Citation

"NonRes Construction Forecast by BCZ v7"; Developed by Heschong Mahone Group with data sourced August, 2010 from Abrishami, Moshen at the California Energy Commission (CEC)

## *7.4 Curb-mounted glass skylight correlation*

The curve fit used to create the U-factors for curb-mounted glass skylights is given here. It is based on a correlation developed from the previous code update's U-factors.

- Poured and debridged thermal break

  $\text{U-factor}_{Curb} = 1.1899 * \text{U-factor}_{Deck} + 0.0319$

  $R^2 = 0.9983$

- Standard Aluminum frame

  $\text{U-factor}_{Curb} = 1.0998 * \text{U-factor}_{Deck} + 0.0788$

  $R^2 = 0.9996$

## 7.5 *Plastic skylight performance ratings*

The following table gives the plastic skylight performance ratings. These were developed in the 2001 code update. Some corrections were made from the that code's documentation. These values agree very well with the ASHRAE 90.1 update assumptions.

| **U-factor** | | | | |
|---|---|---|---|---|
| **Frame Type** | **Single-pane** | **Double-pane** | **Triple-pane** | **Quadruple-pane** |
| Aluminum | 1.92 | 1.29 | 1.10 | 0.93 |
| Aluminum with thermal break | 1.92 | 1.12 | 0.91 | 0.74 |
| Vinyl frame | N/A | 0.84 | 0.65 | 0.48 |
| **SHGC** | | | | |
| **Tint** | **Single-pane** | **Double-pane** | **Triple-pane** | **Quadruple-pane** |
| Clear | 0.83 | 0.77 | 0.71 | 0.65 |
| Bronze | 0.46 | 0.37 | 0.3 | 0.23 |
| High white | 0.65 | 0.62 | 0.58 | 0.55 |
| Medium white | 0.58 | 0.54 | 0.5 | 0.46 |
| Low white | 0.39 | 0.34 | 0.31 | 0.26 |
| **VT** | | | | |
| Clear | 0.92 | 0.89 | 0.85 | 0.81 |
| Bronze | 0.27 | 0.25 | 0.23 | 0.21 |
| High white | 0.82 | 0.75 | 0.69 | 0.63 |
| Medium white | 0.53 | 0.49 | 0.45 | 0.41 |
| Low white | 0.32 | 0.29 | 0.27 | 0.25 |

**Figure 7-6 Plastic Skylight Performance Ratings**

## 7.6 *Minimum life-cycle cost performance ratings*

The performance ratings that correspond to the minimum life-cycle fenestration alternatives are documented below.

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nonresidential Windows** | | | | | | | | | | | | | | | | |
| **10% WWR** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
| U-factor | 0.474 | 0.34 | 0.34 | 0.34 | 0.351 | 0.34 | 0.34 | 0.34 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.34 |
| SHGC | 0.335 | 0.245 | 0.245 | 0.245 | 0.246 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 |
| VT | 0.578 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 |
| **20% WWR** | | | | | | | | | | | | | | | | |
| U-factor | 0.473 | 0.34 | 0.34 | 0.34 | 0.473 | 0.34 | 0.34 | 0.34 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.34 |
| SHGC | 0.256 | 0.245 | 0.245 | 0.245 | 0.256 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 |
| VT | 0.513 | 0.528 | 0.528 | 0.528 | 0.513 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 |
| **30% WWR** | | | | | | | | | | | | | | | | |
| U-factor | 0.473 | 0.34 | 0.34 | 0.34 | 0.473 | 0.34 | 0.34 | 0.34 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.34 |
| SHGC | 0.256 | 0.245 | 0.22 | 0.22 | 0.256 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 |
| VT | 0.513 | 0.528 | 0.454 | 0.454 | 0.513 | 0.454 | 0.454 | 0.454 | 0.454 | 0.454 | 0.454 | 0.454 | 0.454 | 0.454 | 0.454 | 0.454 |
| **40% WWR** | | | | | | | | | | | | | | | | |
| U-factor | 0.473 | 0.34 | 0.34 | 0.34 | 0.473 | 0.34 | 0.34 | 0.34 | 0.34 | 0.34 | 0.335 | 0.34 | 0.335 | 0.335 | 0.335 | 0.34 |
| SHGC | 0.256 | 0.22 | 0.22 | 0.22 | 0.232 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 |
| VT | 0.513 | 0.454 | 0.454 | 0.454 | 0.441 | 0.454 | 0.454 | 0.454 | 0.454 | 0.454 | 0.454 | 0.454 | 0.454 | 0.454 | 0.454 | 0.454 |
| **High-Rise Residential Windows** | | | | | | | | | | | | | | | | |
| **10% WWR** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
| U-factor | 0.353 | 0.335 | 0.335 | 0.335 | 0.341 | 0.335 | 0.34 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 |
| SHGC | 0.467 | 0.245 | 0.245 | 0.245 | 0.326 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 |
| VT | 0.642 | 0.528 | 0.528 | 0.528 | 0.595 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 |
| **20% WWR** | | | | | | | | | | | | | | | | |
| U-factor | 0.336 | 0.335 | 0.34 | 0.335 | 0.34 | 0.335 | 0.34 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 |
| SHGC | 0.326 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 |
| VT | 0.595 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 |
| **30% WWR** | | | | | | | | | | | | | | | | |
| U-factor | 0.341 | 0.335 | 0.34 | 0.335 | 0.34 | 0.34 | 0.34 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 |
| SHGC | 0.326 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 |
| VT | 0.595 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 |

| **40% WWR** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U-factor | 0.341 | 0.335 | 0.34 | 0.335 | 0.34 | 0.34 | 0.34 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 | 0.335 |
| SHGC | 0.326 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 |
| VT | 0.595 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 | 0.528 |

**Figure 7-7 Minimum Life-Cycle Cost Performance Ratings for Windows**

| **Nonresidential Glass Curb-Mounted Skylights** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2% SRR** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
| U-factor | 0.577 | 0.577 | 0.577 | 0.577 | 0.644 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 |
| SHGC | 0.329 | 0.329 | 0.329 | 0.329 | 0.254 | 0.252 | 0.252 | 0.252 | 0.329 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.329 |
| VT | 0.584 | 0.584 | 0.584 | 0.584 | 0.518 | 0.518 | 0.518 | 0.518 | 0.584 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.584 |
| **5% SRR** | | | | | | | | | | | | | | | | |
| U-factor | 0.577 | 0.577 | 0.644 | 0.577 | 0.644 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 |
| SHGC | 0.329 | 0.252 | 0.254 | 0.252 | 0.254 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 |
| VT | 0.584 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 |
| **Nonresidential Glass Deck-Mounted Skylights** | | | | | | | | | | | | | | | | |
| **2% SRR** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
| U-factor | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 |
| SHGC | 0.329 | 0.329 | 0.329 | 0.329 | 0.252 | 0.252 | 0.252 | 0.252 | 0.329 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.329 |
| VT | 0.584 | 0.584 | 0.584 | 0.584 | 0.518 | 0.518 | 0.518 | 0.518 | 0.584 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.584 |
| **5% SRR** | | | | | | | | | | | | | | | | |
| U-factor | 0.458 | 0.458 | 0.514 | 0.458 | 0.514 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 |
| SHGC | 0.329 | 0.252 | 0.254 | 0.252 | 0.254 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 |
| VT | 0.584 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 |
| **Nonresidential Plastic Curb-Mounted Skylights** | | | | | | | | | | | | | | | | |
| **2% SRR** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
| U-factor | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.29 | 1.12 | 1.29 | 1.29 | 1.29 | 1.29 |
| SHGC | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 |
| VT | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 |
| **5% SRR** | | | | | | | | | | | | | | | | |
| U-factor | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.29 | 1.92 |
| SHGC | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.39 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.62 | 0.65 |
| VT | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | 0.32 | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | 0.75 | 0.82 |

**Figure 7-8 Minimum Life-Cycle Cost Performance Ratings for Nonresidential Skylights**

| **High-Rise Residential Glass Curb-Mounted Skylights** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2% SRR** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
| U-factor | 0.325 | 0.577 | 0.325 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 |
| SHGC | 0.338 | 0.252 | 0.263 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 |
| VT | 0.565 | 0.518 | 0.501 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 |
| **5% SRR** | | | | | | | | | | | | | | | | |
| U-factor | 0.325 | 0.577 | 0.325 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.577 | 0.325 | 0.325 | 0.577 | 0.577 | 0.577 | 0.325 |
| SHGC | 0.338 | 0.252 | 0.263 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.263 | 0.263 | 0.252 | 0.252 | 0.252 | 0.263 |
| VT | 0.565 | 0.518 | 0.501 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.501 | 0.501 | 0.518 | 0.518 | 0.518 | 0.501 |
| **High-Rise Residential Glass Deck-Mounted Skylights** | | | | | | | | | | | | | | | | |
| **2% SRR** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
| U-factor | 0.127 | 0.458 | 0.127 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 |
| SHGC | 0.338 | 0.252 | 0.263 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 |
| VT | 0.565 | 0.518 | 0.501 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 |
| **5% SRR** | | | | | | | | | | | | | | | | |
| U-factor | 0.127 | 0.127 | 0.127 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.127 | 0.127 | 0.458 | 0.458 | 0.458 | 0.127 |
| SHGC | 0.338 | 0.263 | 0.263 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.252 | 0.263 | 0.263 | 0.252 | 0.252 | 0.252 | 0.263 |
| VT | 0.565 | 0.501 | 0.501 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.518 | 0.501 | 0.501 | 0.518 | 0.518 | 0.518 | 0.501 |
| **High-Rise Residential Plastic Curb-Mounted Skylights** | | | | | | | | | | | | | | | | |
| **2% SRR** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
| U-factor | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.29 | 1.29 | 1.29 | 1.29 | 1.92 | 1.12 |
| SHGC | 0.65 | 0.65 | 0.65 | 0.39 | 0.65 | 0.65 | 0.65 | 0.39 | 0.39 | 0.39 | 0.34 | 0.34 | 0.34 | 0.34 | 0.39 | 0.62 |
| VT | 0.82 | 0.82 | 0.82 | 0.32 | 0.82 | 0.82 | 0.82 | 0.32 | 0.32 | 0.32 | 0.29 | 0.29 | 0.29 | 0.29 | 0.32 | 0.75 |
| **5% SRR** | | | | | | | | | | | | | | | | |
| U-factor | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 |
| SHGC | 0.65 | 0.39 | 0.65 | 0.39 | 0.65 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 |
| VT | 0.82 | 0.32 | 0.82 | 0.32 | 0.82 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 |

**Figure 7-9 Minimum Life-Cycle Cost Performance Ratings for High-Rise Residential Skylights**

### *7.7 T24-2008 cost data correlation*

The curve fit used to calculate the first cost for the current code baseline is given here. It is based on the costs and performance ratings of the fenestration alternatives generated for this update. Costs are in $/sf

- Windows:

  First Cost = -22.9871*U-factor + 14.7359*SHGC + -60.1080*VT + 48.5206

  $R^2$ = 0.9282

- Glass skylights:

  First Cost = -2.6709*U-factor + -3.3581*SHGC + -42.9458*VT + 36.4264

  $R^2$ = 0.8021

- Plastic skylights:

  First Cost = 4.74. (The basis for plastic skylights was a double-pane tinted skylight for every climate zone and SRR.)

### *7.8 T24-2008 VT correlation*

For glass fenestration, a survey of 6 major manufacturers' published center-of-glass (COG) SHGCs and VTs were used to develop a correlation of VT versus SHGC. The linear curve fit of this correlation provided the T24-2008 VTs that were used to determine the statewide impact of the proposed update. Although the curve fit is based on COG values, the fit should be valid for whole windows as well since the frame affects VT and SHGC in a similar way.

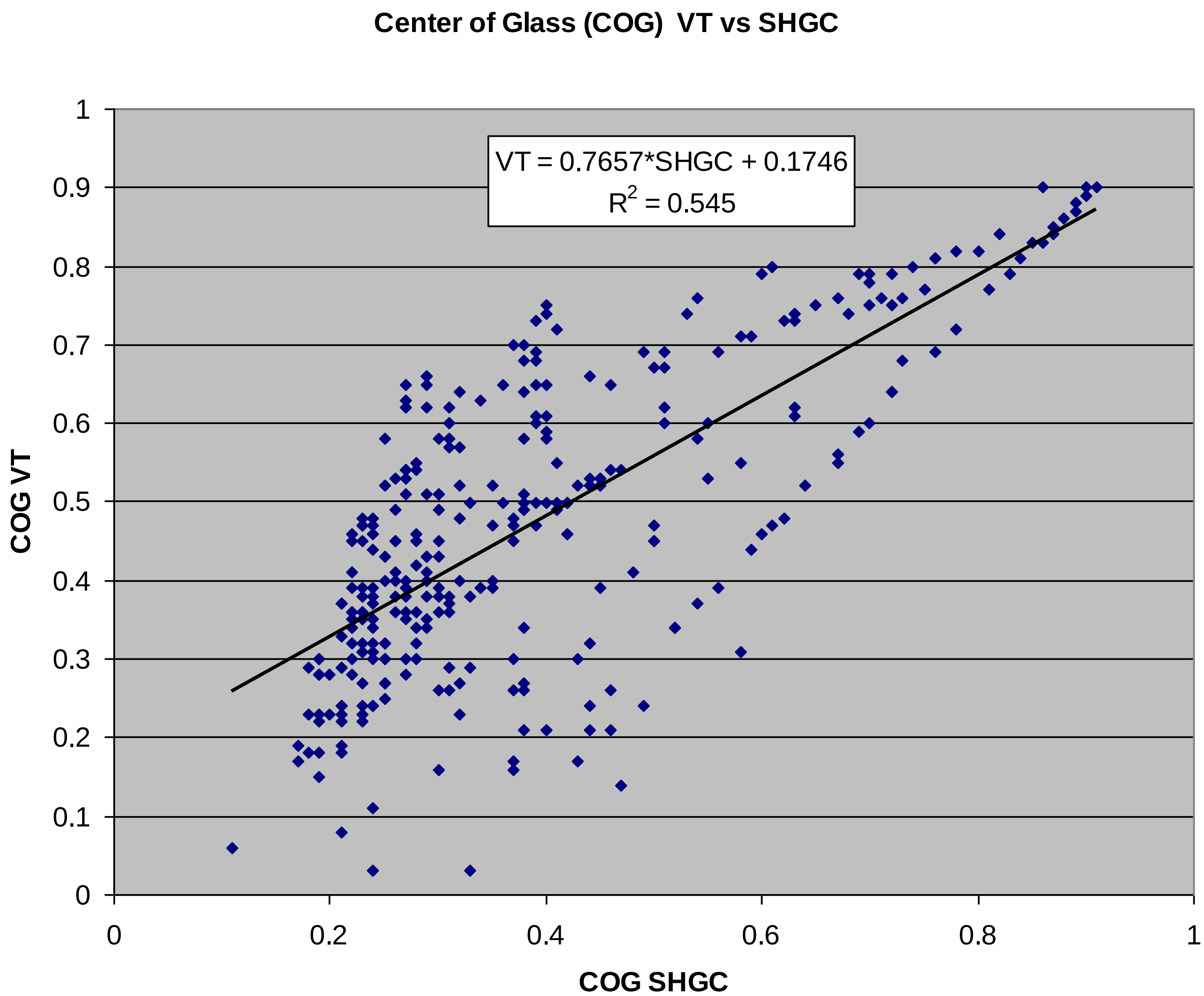



**Figure 7-10 T24-2008 Glass Fenestration VT Curve Fit**

For plastic skylights, the VTs developed in the previous code update and presented in Figure 7-6 were used.

### 7.9 California construction forecast

Figure 7-11 presents the share of forecasted construction over the next 10 years by climate zone. It was developed by the California Energy Commission Forecasting Office. It was used to assess the statewide impact of fenestration alternatives.

| Climate Zone | California Forecasted Construction Share |
|---|---|
| 1 | 0.24% |
| 2 | 2.30% |
| 3 | 9.33% |
| 4 | 5.70% |
| 5 | 1.11% |
| 6 | 7.63% |
| 7 | 10.07% |
| 8 | 9.48% |
| 9 | 19.13% |
| 10 | 5.61% |
| 11 | 3.09% |
| 12 | 15.57% |
| 13 | 7.22% |
| 14 | 1.30% |
| 15 | 0.57% |
| 16 | 1.65% |

**Figure 7-11 California Forecasted Construction by Climate Zone**

Figure 7-12 and Figure 7-13 present the mapping of the California construction forecast into the U.S. Department of Energy Commercial Reference Building Models. This mapping helped to guide the analysis including energy model assumptions and the statewide impact of fenestration alternatives.

| Nonresidential | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **California Forecasted Construction** | | **DOE Reference Building Model**[1] | | | | | | | | | | | |
| **Type**[2] | **Share** | **Type**[2] | **Share of CA Type**[2] | **Net Share** | **Walls** | **Roofs** | **Floors** | **Floor Area** | **Window Type** | **WWR**[5] | **Share of Roofs with Skylights**[6] | **SRR**[7] |
| Small Office | 4.96% | Small Office | 100% | 4.96% | Mass | Attic Roof | 1 | 5,500 | Fixed | 30% | 5% | 2% |
| Large Office | 15.38% | Large Office | 50% | 7.69% | Steel Frame[3] | IEAD | 12 | 498,588 | Fixed | 40% | 25% | 2% |
| Large Office | 15.38% | Medium Office | 50% | 7.69% | Steel Frame | IEAD | 3 | 53,628 | Fixed | 40% | 25% | 2% |
| Restaurant | 2.69% | Full-Service Restaurant | 40% | 1.08% | Steel Frame | Attic Roof | 1 | 5,500 | Fixed | 20% | 5% | 2% |
| Restaurant | 2.69% | Quick-Service Restaurant | 60% | 1.62% | Wood Frame | Attic Roof | 1 | 2,500 | Fixed | 20% | 5% | 2% |
| Retail | 16.99% | Stand-Alone Retail | 50% | 8.50% | Mass | IEAD[4] | 1 | 24,962 | Fixed | 10% | 95% | 5% |
| Retail | 16.99% | Strip Mall | 50% | 8.50% | Steel Frame | IEAD | 1 | 22,500 | Fixed | 20% | 95% | 5% |
| Food | 4.54% | Supermarket | 100% | 4.54% | Mass | IEAD | 1 | 45,000 | Fixed | 20% | 95% | 5% |
| Non-refrigerated Warehouse | 16.55% | Warehouse | 100% | 16.55% | Metal Building | Metal Roof | 1 | 52,045 | Operable | 10% | 95% | 5% |
| Refrigerated Warehouse | 1.02% | Warehouse | 100% | 1.02% | Metal Building | Metal Roof | 1 | 52,045 | Operable | 10% | 0% | N/A |
| School | 5.45% | Primary School | 34% | 1.85% | Steel Frame | IEAD | 1 | 73,960 | Fixed | 40% | 25% | 2% |

| Nonresidential | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **California Forecasted Construction** | | **DOE Reference Building Model[1]** | | | | | | | | | |
| **Type[2]** | **Share** | **Type[2]** | **Share of CA Type[2]** | **Net Share** | **Walls** | **Roofs** | **Floors** | **Floor Area** | **Window Type** | **WWR[5]** | **Share of Roofs with Skylights[6]** | **SRR[7]** |
| School | 5.45% | Secondary School | 66% | 3.60% | Steel Frame | IEAD | 2 | 210,887 | Fixed | 40% | 25% | 2% |
| College | 4.04% | N/A[8] | 100% | 4.04% | Steel Frame | IEAD | 3 | 1,393,000 | Fixed | 30% | 25% | 2% |
| Hospital | 5.24% | Outpatient Healthcare | 50% | 2.62% | Steel Frame | IEAD | 3 | 40,946 | Fixed | 20% | 25% | 2% |
| Hospital | 5.24% | Hospital | 50% | 2.62% | Mass | IEAD | 5 | 241,351 | Fixed | 20% | 25% | 2% |
| Miscellaneous | 15.00% | N/A[8] | 100% | 15.0%[9] | Steel Frame | IEAD | 1 | 5,000 | Fixed | 20% | 5% | 2% |
| **High-rise Residential** | | | | | | | | | | | | |
| **California Forecasted Construction** | | **DOE Reference Building Model** | | | | | | | | | | |
| Hotel | 3.83% | Small Hotel | 50% | 1.91% | Steel Frame | IEAD | 4 | 43,200 | Operable in guest rooms, others fixed | 20% | 5% | 2% |
| Hotel | 3.83% | Large Hotel | 50% | 1.91% | Mass | IEAD | 6 | 122,120 | Operable in guest rooms, others fixed | 30% | 5% | 2% |

| Nonresidential | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **California Forecasted Construction** | | **DOE Reference Building Model**[1] | | | | | | | | | | |
| **Type**[2] | **Share** | **Type**[2] | **Share of CA Type**[2] | **Net Share** | **Walls** | **Roofs** | **Floors** | **Floor Area** | **Window Type** | **WWR**[5] | **Share of Roofs with Skylights**[6] | **SRR**[7] |
| Miscellaneous | 4.32% | Midrise Apartment | 100% | 4.32% | Steel Frame | IEAD | 4 | 33,740 | Operable | 20% | 0% | N/A |

**Figure 7-12 California Forecasted Construction Envelope Characteristics**

1. Refers to the U.S. Department of Energy Commercial Reference Building Models
2. Multiple Types appear when more than one DOE Reference Building Model Type maps into the California Forecasted Construction Type or vice versa. In these cases, an assumption was made about the split of Share.
3. The DOE Reference Building Model Type actually lists Mass as the Large Office construction. However, on consulting with NREL staff, it was found that the split between Steel Frame and Mass was roughly even in surveys.
4. IEAD = Insulation Entirely Above Deck.
5. These are the rounded WWRs of the DOE Reference Building Models. In addition, curtain walls/storefronts were assumed to be 1% and 4% of the share of 30% WWR and 40% WWR. Note that is considered unlikely that curtain walls will be used extensively under the Prescriptive Envelope Component Approach. The reasoning is that at 40% WWR, there will be large gaps between fenestration for curtain walls, creating a sparse aesthetic. Glazed doors were assumed to be 2% of the operable window share.
6. These shares are assumptions.
7. The SRRs are assumptions roughly based on whether the space typically has mandatory skylight requirements. Research also showed that plastic skylights made up 86% of the market share, while glass made up 14%.
8. There was no similar DOE Reference Building Model Type. For colleges the Assessment of Energy Use in Multibuilding Facilities was used for certain characteristics. For other types and characteristics, assumptions were made.

9. The shares for the Miscellaneous type were split between nonresidential and high-rise residential.  The split was an assumption.

| Nonresidential | | | | |
|---|---|---|---|---|
| **California Forecasted Construction** | **DOE Reference Building Model** | | | |
| **Type** | **Type** | **Heating** | **Cooling** | **Air**[1] |
| Small Office | Small Office | Furnace | Packaged DX | SZ CAV |
| Large Office | Large Office | Boiler | Chiller, water-cooled | MZ VAV |
| Large Office | Medium Office | Boiler | Packaged DX | MZ VAV |
| Restaurant | Full-Service Restaurant | Furnace | Packaged DX | SZ CAV |
| Restaurant | Quick-Service Restaurant | Furnace | Packaged DX | SZ CAV |
| Retail | Stand-Alone Retail | Furnace | Packaged DX | SZ CAV |
| Retail | Strip Mall | Furnace | Packaged DX | SZ CAV |
| Food | Supermarket | Furnace | Packaged DX | MZ CAV |
| Non-refrigerated Warehouse | Warehouse | Furnace and unit heaters | Packaged DX | SZ CAV |
| Refrigerated Warehouse | Warehouse | Furnace and unit heaters | Packaged DX | SZ CAV |
| School | Primary School | Boiler | Packaged DX | SZ CAV and MZ CAV |
| School | Secondary School | Boiler | Chiller, air-cooled | SZ CAV and MZ CAV |
| College | N/A | Boiler | Chiller, water-cooled | MZ VAV |

| Nonresidential | | | | |
|---|---|---|---|---|
| **California Forecasted Construction** | **DOE Reference Building Model** | | | |
| **Type** | **Type** | **Heating** | **Cooling** | **Air**[1] |
| Hospital | Outpatient Healthcare | Furnace central heat, hot water reheat from natural gas boiler | Packaged DX | MZ VAV |
| Hospital | Hospital | Boiler | Chiller, water-cooled | MZ CAV and MZ VAV |
| Miscellaneous | N/A | Furnace | Packaged DX | SZ CAV |
| **High-rise Residential** | | | | |
| **California Forecasted Construction** | **DOE Reference Building Model** | | | |
| **Type** | **Type** | **Heating** | **Cooling** | **Air** |
| Hotel | Hotel | Gas furnace and electric heating | Packaged DX AC and PTAC units | SZ CAV |
| Miscellaneous | Small Hotel | Boiler | Chiller, air-cooled | MZ VAV and FCU |
| Large Hotel | Midrise Apartment | Furnace | Packaged DX split system | SZ CAV |

**Figure 7-13 California Forecasted Construction HVAC Characteristics**

1. SZ = Single Zone, MZ = Multizone, CAV = Constant Air Volume, VAV = Variable Air Volume, FCU = Fan coil Unit

2. See Figure 7-12 for additional notes.

***7.10 Detailed Stakeholder Comments and CASE author responses***

### 7.10.1 Draft report comments

The following summarizes comments received from stakeholders during the draft review of this report.

1. **Comment**: The single U-factor, SHGC and VT rating that is based on a fixed window cannot accommodate wider frames, operable windows and doors.

   **Response**: The proposed performance ratings for windows were mapped into four window types: fixed, operable, curtain wall/storefront and glazed doors. This was done through CMAST by using the code-simplified fenestration component's characteristics as a basis, then mapping those characteristics into different frame types.

   If there were multiple configurations that fell within a certain type (e.g. casement, awning and horizontal slider for operable), then the proposed performance ratings were set to the maximum U-factor, maximum SHGC and the minimum VT of all the configurations. However, none of the performance ratings were set above the maximums or below the minimums specified in Title 24-2008. Figure 7-14 through Figure 7-17 document the process.

| | |
|---|---|
| Layers | Double-pane |
| Frame | 2-1/4" frame, fixed aluminum frame with a poured and debridged thermal break |
| Substrate | Outter lite: ¼"Green tint<br>Inner lite: ¼" Clear |
| Coating | Triple-silver low-e on 2nd surface |
| Spacer | Hybrid stainless steel |
| Gas | ½" Argon |
| Performance Ratings (From section 4.9) | |
| U-factor | 0.340 (0.238 COG) |
| SHGC | 0.220 (0.252 COG) |
| VT | 0.454 (0.535 COG) |

**Figure 7-14 Nonresidential Fenestration Basis**

| | Configuration 1 Mapping | Configuration 2 Mapping | Configuration 3 Mapping | Final Mapped Performance Rating |
|---|---|---|---|---|
| | Fixed Frame, 2 ¼” | Fixed Frame, 3 ¼” | Fixed Frame, 3 ¼” Safety Glass[3] | **Fixed** |
| U-factor | 0.340 | 0.363 | | 0.363 |
| SHGC | 0.220 | 0.222 | | 0.222 |
| VT | 0.454 | 0.443 | 0.423 | 0.423 |
| | Casement, 4 ½” | Awning, 4 ½” | Awning, 4 ½” Safety Glass | **Operable** |
| U-factor | 0.573 | 0.569 | | 0.47[1] |
| SHGC | 0.174 | 0.174 | | 0.174 |
| VT | 0.332 | 0.332 | 0.316 | 0.316 |
| | Curtain wall, 2 ½” | None | Curtain wall, 2 ½” Safety Glass | **Curtain wall/ Storefront** |
| U-factor | 0.407 | | | 0.407 |
| SHGC | 0.238 | | | 0.238 |
| VT | 0.481 | | 0.459 | 0.459 |
| | French door, 3 ¼” | Sliding Door, 4 ½” | French door, 3 ¼” Safety Glass | **Glazed Doors** |
| U-factor | 0.397 | 0.454 | | 0.454 |
| SHGC | 0.176 | 0.204 | | 0.204 |
| VT | 0.351 | 0.413 | 0.335 | 0.1675[2] |

**Figure 7-15 Mapping of Nonresidential Fenestration Basis into Other Configurations**

1. The proposed U-factor maximum was set to the T24-2008 maximum.
2. The proposed VT was set considering that only 50% of the door was glazed.
3. For “Safety Glass” both a 1” inner lite and ¼” over ¼” laminated lite were input into CMAST and the VT recalculated. This lowered the VT. Neither the U-factor nor SHGC were considered in this mapping.

| | |
|---|---|
| Layers | Double-pane |
| Frame | 2-1/4" deep, fixed aluminum frame with a poured and debridged thermal break |
| Substrate | Outter lite: ¼" Clear<br>Inner lite: ¼" Clear |
| Coating | Triple-silver low-e on 2nd surface |
| Spacer | Hybrid stainless steel |
| Gas | ½" Argon |
| Performance Ratings (From section 4.9) | |
| U-factor | 0.335 (0.238 COG) |
| SHGC | 0.245 (0.282 COG) |
| VT | 0.528 (0.622 COG) |

**Figure 7-16 High-Rise Residential Fenestration Basis**

| | Configuration 1 Mapping | Configuration 2 Mapping | Configuration 1 Mapping | Final Mapped Performance Rating |
|---|---|---|---|---|
| | Fixed Frame, 2 ¼” | Fixed Frame, 3 ¼” | Fixed Frame, 3 ¼”<br>Safety Glass[3] | **Fixed** |
| U-factor | 0.335 | 0.359 | | 0.359 |
| SHGC | 0.245 | 0.247 | | 0.247 |
| VT | 0.528 | 0.515 | 0.491 | 0.491 |
| | Horizontal Slider[1], 3 ¼” | None | Horizontal Slider<br>Safety Glass | **Operable** |
| U-factor | 0.450 | | | 0.450 |
| SHGC | 0.221 | | | 0.221 |
| VT | 0.461 | | 0.440 | 0.440 |
| | Curtain wall, 2 ½” | None | Curtain wall, 2 ½”<br>Safety Glass | **Curtain wall/ Storefront** |
| U-factor | 0.402 | | | 0.402 |
| SHGC | 0.264 | | | 0.264 |
| VT | 0.559 | | 0.533 | 0.533 |
| | French door, 3 ¼” | Sliding Door, 4 ½” | French door, 3 ¼”<br>Safety Glass | **Glazed Doors** |
| U-factor | 0.392 | 0.451 | | 0.451 |
| SHGC | 0.195 | 0.226 | | 0.226 |
| VT | 0.408 | 0.480 | 0.389 | 0.1945[2] |

**Figure 7-17 Mapping of High-Rise Residential Fenestration Basis into Other Configurations**

1. Operable windows make up a a high percentage of the fenestration in high-rise residential buildings. Therefore, to avoid high U-factors, only horizontal slider windows were considered.
2. The proposed VT was set considering that only 50% of the door was glazed.
3. For “Safety Glass” both a 1” inner lite and ¼” over ¼” laminated lite were input into CMAST and the VT recalculated. This lowered the VT. Neither the U-factor nor SHGC were considered in this mapping.

2. **Comment**: Different types of glass have their appropriate application. There is not just one VT solution. Glare is a significant issue that can cause occupant discomfort and energy penalties from closed blinds. HMG has studies reflecting this. There are many aspects to daylighting (effective aperture, penetration, window distribution, etc.) that make it difficult to codify. What really matters are the lumens on the workspace. Considering these it is better to use a larger, lower VT window, or a lower VT vision area with a clerestory as better solutions.

**Response**:

The VT has been lowered from 0.52 to 0.44 for nonresidential windows since the preliminary analysis. 0.44 VT is not generally considered high. High-rise residential occupancies have less of a glare concern as they are mostly unoccupied during the day.

If the designer believes that the Standard is not sufficient to meet the project goals, the Prescriptive Overall Envelope TDV Energy Approach or the Performance Approach can be used. The Prescriptive Envelope Component Approach is intended to be an optimum fit for a reasonably comprehensive set of building configurations. It is not intended to be a universally optimum fit for each project.

The Standard will not be moving towards encouraging larger window area. In addition, note that a properly specified combination of clerestory and vision window can meet the Standard in the Prescriptive Overall Envelope TDV Energy Approach and the Performance Approach. The Standard also allows overhangs to reduce the RSHG without penalizing the VT, a feature that tends to mitigate glare.

Lower VT glazing does not reduce the contrast of direct sunlight. Reflective glare on computer screens can be mitigated by low-reflectance computer accessories which are expected to advance much more quickly than the life-cycle of a buildings fenestration.

Occupant orientation can always mitigate or eliminate glare.

HMG's current research in Daylight Metrics indicates that occupants will actively engage blinds, aiming to have as much view as possible. Thus minimizing energy penalties and occupant discomfort.

If an LSG of 1.2 is assumed for all climate zones and all window-to-wall ratios, then 100% of the current standard is susceptible to VTs greater than 0.44.

3. **Comment**: Exterior shading and interior blinds should be considered in the analysis.

   **Response**: Given a window, with fixed exterior shading, it is better to have a higher VT for daylighting. Most commercial blinds allow some daylight to enter even when closed. The exceptions is if blinds are the blackout type which is not common in commercial buildings and even with these blinds installed, they must be in the full blackout position which is also uncommon. Therefore, given the active view control of interior blinds mentioned in the above HMG study, it is better to have a high VT for when blinds are closed.

4. **Comment**: The SHGC and VT combination chosen cannot be met by a casement, awning or curtain wall windows because of differences in frame dimensions.

   **Response**: The Standard has been adjusted to accommodate these window types in a similar manner as explained in the response to Comment 1.

5. **Comment**: The glazing technology proposed in the standard is proprietary to only two companies. It also eliminates a major portion of the glazing industry, including dynamic glazing.

**Response**: The glazing technology, although proprietary to two companies, is available from four of the six major manufacturers. Only pyrolytic-only manufacturers do not offer it. In addition, Title 24 updates do not have a proprietary technology constraint. Among other implied constraints they notably have cost-effectiveness and market availability constraints. Finally, none of these glazings are eliminated as they can show compliance under either the Prescriptive Overall Envelope TDV Energy Approach or the Performance Approach.

6. **Comment**: Effective aperture and LSG (i.e. VT/SHGC) should be considered in lieu of VT.

   **Response**: Effective aperture was considered but it's complexities with calculation and enforcement are considered substantial. It's effectiveness in daylighting deep into the space are also in question. LSG does not capture the lighting power reduction level that was the crux of the VT savings in the analysis.

It is the balance between a maximum SHGC and a minimum VT of the selected fenestration alternative that optimizes life-cycle savings. A significant life-cycle savings loss occurs if a VT requirement is not included. This phenomenon is presented in Figure 7-18. The "Standard without VT" fenestration has the same U-factor and SHGC as the "Standard with VT", but has a VT of 0.21. The only difference between the two is that in lieu of a green tint with a triple-silver low-e coating, the "Standard without VT" has a gray tint with a double-silver low-e coating.

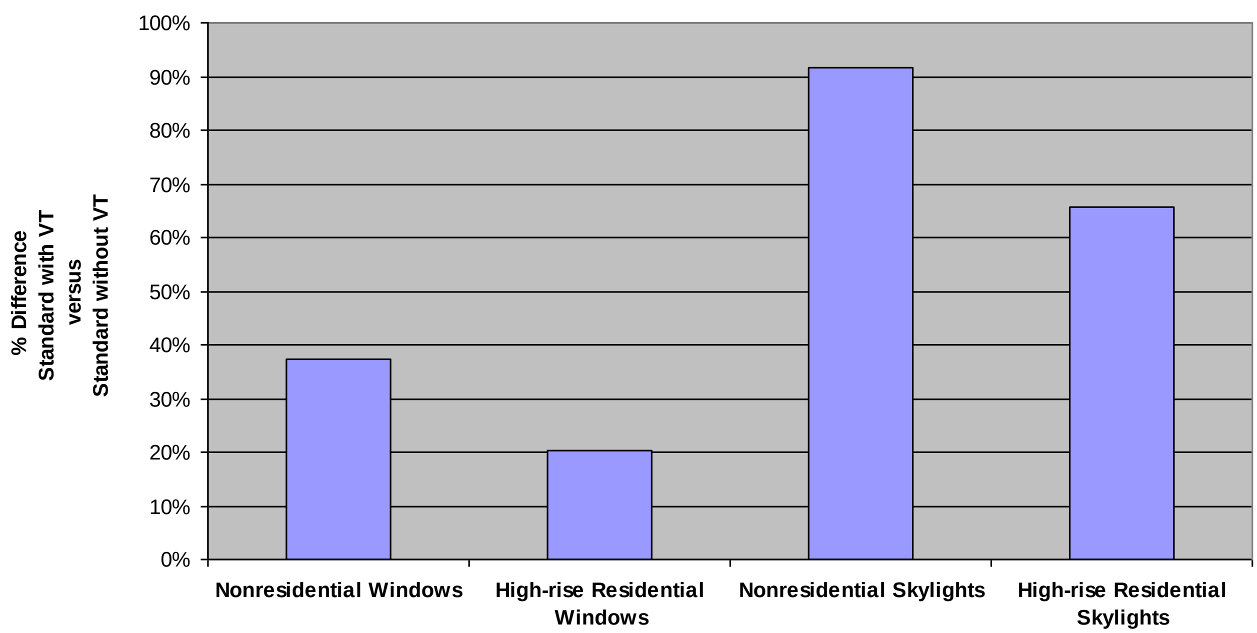



**Figure 7-18 Loss in Statewide Savings Potential if VT is Not Required**

### 7.10.2 Docketed comments

The remaining stakeholder comments addressed below were docketed after the presentation of the final results.

***Stakeholder Comment: Daylighting design has many aspects to it. Therefore specifying VT as the metric is incorrect.***

***CASE Author Response:***

The intent of the Prescriptive Envelope Component Approach is not to provide a complete set of rules that optimize every aspect of every scenario for design. The Code allows for flexibility and relies on good standard practices as well. The stakeholder notes that there are a number of aspects to daylighting that contribute to its effectiveness. This is true of all aspects of building design. For example, the Code specifies minimum efficiencies for HVAC equipment. However it does not regulate duct size or diffuser placement. It specifies maximum lighting power densities but does not regulate luminaire placement or type. In like manner, it can specify window efficiency (e.g. VT) without specifying every other aspect of the window design.

The stakeholder's concerns do not provide sufficient detail for the CASE author to address them with scientific rigor. The stakeholder has mentioned similar concerns during the process of the Code development. On two occasions the CASE author requested that sufficient specific information be provided by the stakeholder so that a quantitative, analytical, scientific and engineering analysis can address the concerns. The CASE author requested "glazing orientation, time of day, interior conditions such as occupant orientation, surface reflectance or any other pertinent details". To date, this has not been provided. In their absence the CASE author will attempt to provide adequate analysis.

The stakeholder has cited the following as affecting daylighting design, therefore arguing that VT is the wrong metric. The stakeholder's comments are numbered below. The CASE author's responses are lettered and given below each numbered stakeholder argument.

1. Geometry of the building and room, window distribution, window size, window properties:

a. See the opening paragraphs regarding intent of the Code.

b. All other things being equal, VTs lower than the minimum VT will bring in less light and have correspondingly lower energy savings.

2. Glare, interior shading, exterior shading:

a. Fixed exterior shading blocks a portion of the visible light. Given this, a minimum VT ensures adequate daylight enters the space. In fact, because exterior shading blocks visible light, it encourages higher VTs.

b. Also, assuming exterior shading is a gross assumption. It is possible to categorize by environment (e.g. urban, suburban, rural, hilly, etc.) and reduce that gross assumption. However, that would create an added burden on code officials and designers as it would be an aspect to verify for each project.

c. Most commercial shades allow some daylight to enter even when closed to control glare. The exception is if blinds are the blackout type which is not common in commercial buildings and even with these blinds installed, they must be in the full blackout position which is also uncommon. Therefore, given the active view control of interior blinds mentioned in the HMGs "Daylighting Metrics" study, it is better to have a minimum VT for when blinds are closed. In fact, because interior shading blocks visible light, it encourages higher VTs.

3. Lighting fixture location, lighting control strategies:

a. See the opening paragraphs regarding intent of the Code.

b. All other things being equal, VTs lower than the minimum VT will bring in less light and have correspondingly lower energy savings.

4. Purpose of the space:

a. All sidelit spaces greater than 250 sq ft, regardless of purpose, will require bi-level daylighting controls in T24-2013.

b. All skylit spaces, regardless of purpose, if they have at least a single 4' X 4' skylight will require bi-level daylighting controls in T24-2013.

c. All daylit spaces require a minimum of bi-level manual controls, every space can benefit from daylighting controls in T24-2013.

d. In addition to daylighting controls, occupants benefit from the view through a higher VT window in T24-2013.

5. Safety, structural loads, fire resistance, seismic performance:

a. Building code safety standards were considered in the analysis and the fenestration basis meet the codes. However, an exception for laminated glazing and thicker glazing is considered appropriate and is addressed later in the document.

6. The forums and standards referenced are consensus-based and opposition to VT requirements came from industry-based organizations with goals other than energy-efficiency and cost-effectiveness. Title 24 is not a consensus-based; it is cost-effectiveness-based. Even so, the current recommendations have made many adjustments to address industry concerns as is reflected in the final report.

***Stakeholder Comment: A 30% WWR at 0.22 VT spreads light out more than a 15% WWR at 0.44 VT and is therefore better. This simple example shows that VT is the wrong metric.***

***CASE Author Response:***

The flaw in the stakeholder's logic lies in the simplicity of the examination by the stakeholder. It actually requires further scrutiny.

1. From an overall energy-use perspective, the 30% case has double the penalty from effective solar heat gain (i.e. twice the area times the SHGC).

2. From an overall energy-use perspective, the 30% case has double the penalty from effective conductivity (i.e. twice the area times the U-factor).
3. From an overall energy-use perspective the 30% case has 15% less wall area. Walls are far superior to windows in terms of insulation and protection from solar radiation. The minimum steel-framed overall assembly R-value in California is R-10.2 to R-16.1. By comparison, the proposed nonresidential (NR) fixed window is R-2.8. The SHGC of the proposed NR fixed window is 0.25. A conservative solar heat gain of a wall is around 0.05.
4. If the designer desires more light to enter the space and therefore chooses a 30% WWR and then used a 0.44 VT, they would have twice the daylighting benefit.

***Stakeholder Comment: Larger, darker windows do a better job of providing daylight. They spread the light out more and reduce glare.***

***CASE Author Response:***

Larger, darker glazing does not save energy

1. The stakeholder argues that larger, darker windows that spread out light do a better job at daylighting. In fact, the opposite would typically be true.

   The stakeholder did not define "better job". For the purposes of this analysis, "better job" is assumed to mean higher energy savings. With this assumption, given that bi-level controls are required by the Code, there is a threshold lighting level below which lights are not lowered. With darker windows, no matter the size, that threshold will be achieved for fewer hours in the year and will result in less daylighting savings.
2. Also note that darker glazing does nothing to mitigate glare from direct sun contrast.
3. The photo evidence presented by the stakeholder showing drawn blinds/shades is anecdotal. It shows four buildings at one orientation at one point in time. This is not considered adequate evidence to represent all buildings in California on all orientations at all points in time. Similar photos could be presented showing the opposite conclusion, undrawn blinds/shades at a point in time for several buildings.

***Stakeholder Comment: There was no cost effectiveness analysis for overhangs. Therefore adjusting the RSHG via overhangs can't be justified as an alternative.***

***CASE Author Response:***

1. The inclusion of overhangs as a way to meet the proposed VT was added as an accommodation for the industry so that lower-performing glazing could meet the Standard. From the analysis, we know that the proposed VT can be achieved on a cost-effectiveness basis by a window without an overhang. Therefore overhangs do not need to be included in the cost-effectiveness analysis.
2. In terms of interior blinds, it is considered very highly unlikely that a significant number of buildings will be furnished without interior blinds, making them cost-neutral in the analysis. Also, the stakeholder has not provided detailed evidence that given the 0.42 VT, glare will be a problem in a significant portion of the forecasted construction.

***Stakeholder Response: The VT requirement creates barriers to products that save more energy.***

***CASE Author Response:***

The final report includes many more fenestration products that comply.

1. The final report recommendations included a number of adjustments to accommodate many other fenestration technologies without triple-silver coatings, without any overhangs and without using an alternate compliance approach. These include products mentioned by the stakeholder including triple-pane fenestration and double-pane room-side low-e coated fenestration. The stakeholder is mistaken about tinting on triple-silver not qualifying for nonresidential windows. In fact, triple-silver coatings on a tinted substrate were the original basis for nonresidential windows. A list of these and other technologies is provided in Figure 4-14.
2. Dynamic glazing and building integrated photovoltaics would almost certainly never have used the Prescriptive Envelope Component Approach for compliance.

***Stakeholder Comment: Moderate VTs provide better daylight.***

***CASE Author Response:***

The stakeholder has not quantified the term “moderate VT”. Most daylighting resources recommend at least 0.50 VT and consider daylighting with VTs between 0.35 and 0.50 helpful, but not ideal. In the CASE author’s opinion, this would define “moderate” and therefore the proposed 0.42 minimum AW VT would be considered moderate.

***Stakeholder Comment: The VT requirement creates barriers to products used for safety and other purposes.***

***CASE Author Response:***

1. Fire-resistance was considered in the analysis and the proposed update complies with safety codes.
2. Frame depth was considered in the analysis and the proposed update complies with safety codes.
3. Safety glazing was constructed in CMAST considering 1” thick glazing and ¼” over ¼” laminated glazing. From this study, the required minimum AW VT was lowered by approximately 5%.

***Stakeholder Comment: Area-weighted averaging and trade-off options are not sufficient solutions.***

***CASE Author Response:***

1. The stakeholder’s argument that vision/clerestory combinations are not typical can actually be seen as an argument in favor of including area-weighting in the Code. An important purpose of building codes is to require beneficial practices that would not otherwise be utilized were they not law. By including area-weighting, the code provides a compelling incentive to implement view/clerestory windows.

2. Neither the Performance Approach nor the Prescriptive Overall Envelope TDV Energy Approach is presented as a way to get around a problem in the Prescriptive Envelope Component Approach. They are presented as ways to accommodate glazing that does not comply under the latter. The stakeholder's statement also assumes that there is a problem with the proposed AW VT. This assumption has not been proven.
3. Replacement windows and small area retrofits can use any of the fenestration alluded to above and listed in the final report. These do not require area-weighting, overhangs, or triple-silver coatings.

***Stakeholder Comment: The energy savings from controls far outweighs savings from VT. An ASHRAE presentation provides evidence of this.***

***CASE Author Response:***

1. Daylighting controls will be installed in the majority of spaces in T24-2013 as was discussed above. Therefore, discussing the effects of their inclusion/exclusion is not relevant.
2. Figure 7-19 presents a comparison of the ASHRAE and CASE study parameters, showing the significant differences and the impacts of those differences.

| Parameter | ASHRAE Study | CASE Study | Impact |
|---|---|---|---|
| WWR | 30% | All WWRs, weighted by forecasted construction | Penalties will appear lower if only one WWR is shown, and especially if it is a high WWR such as 30% where daylight saturates a space easily. |
| Savings Metric | Energy | TDV Energy | Energy alone does not value peaking. California uses TDV to properly value peaking. |
| VT Comparisons | 0.36 vs. 0.53 | 0.10, 0.20, 0.30 vs. 0.42 | At the higher VTs of the ASHRAE study, daylight benefits always "flatten out" more. VTs below this level are more valid for comparison to the proposed 0.42 VT. In these ranges, energy use with VT drops significantly. |
| Climate Zone | Atlanta | All of California | Although Atlanta shares the same ASHRAE climate zone as portions of California, climate zones are based more on temperature, humidity and winds than solar resource for daylighting. Therefore, the ASHRAE study's climate zone is not particularly appropriate. |

**Figure 7-19 Comparison of ASHRAE and CASE Study Daylighting**

3. Figure 7-20 presents the penalties of different VTs as compared to the proposed 0.42 minimum AW VT. These penalties are based on forecasted construction and would compound each year, adding to the total of the previous year. The aforementioned differences between the ASHRAE and CASE studies account for major differences between the results presented by the stakeholder and those from the CASE study. Figure 7-21 lists estimated equivalences for these energy penalties. See section 4.11 for equivalence assumptions.

| VT | % TDV gain | Peak Electricity Gain [MW] | Annual Electricity Gain [GWh] | 10-yr Present Value [M$] | Greenhouse Gases [Mlbs $CO_2$] |
|---|---|---|---|---|---|
| 0.10 | 47.45% | 8.10 | 26.39 | 262.4 | 760.5 |
| 0.20 | 21.43% | 3.47 | 12.21 | 118.5 | 351.8 |
| 0.30 | 8.30% | 1.29 | 4.81 | 45.9 | 138.7 |

**Figure 7-20 Penalty Comparison for Lower VTs**

| VT | Peak Electricity Equivalent: **Years Until a New Peaker Plant is Needed just to offset NR windows in CA** | Annual Electricity Equivalent: **Number of New Households** | 10-yr Present Value Equivalent: **Portion of the CA EPA's 2011-2012 spending** | Greenhouse Gases Equivalent: **Number of New Cars on the Road Each Year** |
|---|---|---|---|---|
| 0.10 | 6 | 4,400,000 | 525% | 66,400 |
| 0.20 | 14 | 2,000,000 | 240% | 30,700 |
| 0.30 | 39 | 800,000 | 100% | 12,100 |

**Figure 7-21 Equivalence of Penalty Comparison for Lower VTs**

4. Other parameters such as room depth, etc. were mentioned by the stakeholder. The discussion above regarding intent and flexibility of the Standard apply here. Also note that all other things equal, fenestration with a higher VT will let in more light and therefore have more daylighting potential than lower VT fenestration.
5. Finally, the statement that daylighting controls account for the majority of daylighting savings and therefore VT is not significant is not valid. This argument is a similar to saying that air-conditioning equipment accounts for most of the HVAC penalty therefore HVAC efficiency is not significant. Take out the air-conditioning equipment and a project will save much more than any air-conditioning efficiency can. Again a similar analogy can be made with lighting and lighting efficiency. However, the Code will address air-conditioning equipment, lights, and daylighting controls in the majority of spaces. Therefore saving energy at the margins of efficiency is important.

***Stakeholder Comment: SHGC for the colder climates should be higher.***

***CASE Author Response:***

Passive solar strategies did not prove beneficial

1. Passive solar gains were investigated in the study and did not prove beneficial. The impact on California of electric cooling outweighs the impact of natural gas heating, even considering colder climates.
2. Passive solar strategies are also sensitive to the ratio of envelope surface area to building space volume. Codifying passive solar gains therefore becomes complex and problematic.
3. If a designer believes a project would benefit from passive solar strategies they can use the Performance approach or the Prescriptive Overall Envelope Tradeoff Approach to show compliance.

***Stakeholder Comment: SHGC should vary by orientation because different exposures have different potentials for solar heat gain.***

***CASE Author Response:***

SHGC by orientation has not historically been used by most projects and has created problems where it has been used.

1. Through interviews it was found that not many buildings utilized the north versus non-north SHGC requirements of the previous Code.
2. When different fenestration was utilized for non-north versus north orientation problems sometimes occurred in that fenestration were installed in the wrong orientation.
3. If a designer believes a project would benefit from orientation-specific fenestration they can use the Performance approach or the Prescriptive Overall Envelope Tradeoff Approach to show compliance.

***Stakeholder Comment: Even if the NFRC ratings are varied by product type, different sub-types within that product type still couldn't meet that standard (e.g. sliders versus casement windows).***

***CASE Author Response:***

The product types used in the proposed update incorporate the worst scenario from all sub-types. For operable windows, casement, awning and slider were analyzed. The worst (maximum) U-factor, the worst (maximum) SHGC and the worst (minimum) VT became the recommended ratings. The process is documented in the final report.

***Stakeholder Comment: Not even the windows used in the analysis curve fit could meet the Standard.***

***CASE Author Response:***

It is not necessary that the curve-fitting windows meet the proposed Code. The stakeholder may misunderstand the methodology of the analysis. The windows used to develop the curve fit were not intended to meet the SHGC and VT requirements. They were intended to represent the effect of varying U-factor, SHGC and VT.