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Codes and Standards Enhancement (CASE) Initiative

2019 California Building Energy Efficiency Standards

Advanced Daylighting Design – Final Report

Measure Number: 2019-NR-LIGHT5-F

Nonresidential Lighting, Nonresidential Envelope

August 2017

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EXECUTIVE SUMMARY

Introduction

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support California Energy Commission's (Energy Commission) efforts to update California's Building Energy Efficiency Standards (Title 24, Part 6) to include new requirements or to upgrade existing requirements for various technologies. The four California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company, San Diego Gas and Electric, Southern California Edison, and SoCalGas® – and two Publicly Owned Utilities (POUs) – Los Angeles Department of Water and Power and Sacramento Municipal Utility District – sponsored this effort. The program goal is to prepare and submit proposals that will result in cost-effective enhancements to improve energy efficiency and energy performance in California buildings. This report and the code change proposals presented herein is a part of the effort to develop technical information for proposed requirements on building energy efficient design practices and technologies.

The Statewide CASE Team submits code change proposals to the Energy Commission, the state agency that has authority to adopt revisions to Title 24, Part 6. The Energy Commission will evaluate proposals submitted by the Statewide CASE Team and other stakeholders. The Energy Commission may revise or reject proposals. See the Energy Commission's 2019 Title 24 website for information about the rulemaking schedule and how to participate in the process: http://www.energy.ca.gov/title24/2019standards/.

Measure Description

This CASE Report documents the rationale behind three code change proposals (Proposal A, B, and C) related to daylighting in Title 24, Part 6.

Proposal A: Power Adjustment Factors and Performance Compliance Options

The proposed measure will allow Power Adjustment Factors (PAFs)[1] and performance compliance options (PCOs) for indoor lighting that are controlled by daylighting controls when certain technologies are installed in the proposed building. The PAFs and PCOs may be applied to any nonresidential building subject to the provisions of Title 24, Part 6.

The proposed technologies include: fixed slats (louvers), light shelves, clerestories, and daylight redirecting devices. These technologies tend to increase the daylight potential (area or number of hours) of a space.

Previously, no credit could be taken for certain innovative technologies that increase the daylight potential of a space. Offering PAFs and PCOs for these encourages their use. It is possible that the introduction of these technologies into the 2019 update may provide a gradual path to their prescriptive requirement in future updates.

The Statewide CASE Team completed a detailed analysis to determine the appropriate PAFs for all daylighting devices. This report documents the methodology and assumptions used in the analysis.

[1] Power Adjustment Factors are multipliers on the proposed design's lighting power. From a compliance perspective, they effectively reduce the proposed design's lighting power. As such, a higher lighting power may be reduced enough to meet the maximum allowed lighting power of Title 24, Part 6.

Electric lighting energy impacts were included in the savings analysis but heating, ventilation and air-conditioning energy impacts were not.

Proposal B: Min VT Interpretation for TDDs

An interpretation of the Minimum Visible Transmittance (Min VT) requirement for plastic skylights (Table 140.3-C) is proposed for Tubular Daylighting Devices (TDDs). This is based on a new National Fenestration Rating Council (NFRC) Test Procedure (NFRC 203) for TDDs.

Proposal C: Update to Daylit Zones Definitions

An update to the Skylit Daylit Zone definition is proposed to ensure proper interpretation for skylights in atriums, and to the Sidelit Daylit Zones definition for building with large exterior overhangs.

Scope of Code Change Proposal

Table 1 summarizes the scope of the proposed changes and which sections of the Standards, Reference Appendices, Alternative Calculation Manual (ACM) Reference Manual, and compliance documents will be modified as a result of the proposed change.

Table 1: Scope of Code Change Proposal

Measure Name	Type of Requirement	Modified Section(s) of Title 24, Part 6	Modified Title 24, Part 6 Appendices	Will Compliance Software Be Modified	Modified Compliance Document(s)
Advanced Daylighting Design (Proposal A)	Prescriptive PAFs. Performance compliance option of lighting credits also made available in the performance method.	100.1, 140.3, 140.6	NA7.4	Yes	NRCC-ENV-05-E NRCA-ENV-02-F NRCI-ENV-01-E NRCI-LTI-05 NRCC-PRF-01-E
Min VT Interpretation for TDDs (Proposal B)	Update to prescriptive requirements for building envelopes	140.3	N/A	No	NRCC-ENV-02-E
Update to Daylit Zones Definitions (Proposal C)	Update to daylit zones definitions under mandatory indoor lighting controls	130.1	N/A	No	N/A

In addition to supporting the 2019 code cycle and the proposed code changes presented in this report, the PAFs and the work completed to create the PAFs could provide benefit for: other codes or standards such as proposed changes to Title 24, Part 11 (the California Green Building Code, or CALGreen); local building code ordinances; utility programs, such as Savings By Design; or as a guideline or starting point for the Attachments Energy Rating Council (AERC) when rating daylight redirecting devices. The Statewide CASE Team recognizes that the calculation for daylight redirecting devices (DRDs) is the most complex PAF calculation. The Statewide CASE Team is available to discuss the methodology and assumptions with the Energy Commission or other interested parties in support of the 2019 Title 24, Part 6 code change proposal.

Market Analysis and Regulatory Impact Assessment

When developing code change proposals, the Statewide CASE Team interviewed market actors involved in the code compliance process to simplify and streamline the compliance and enforcement of this proposal.

Proposal A:

Fixed slats and light shelves are available from a multitude of manufacturers ranging from large aluminum window frame manufacturers (Alcoa, EFCO, etc.) to smaller companies that manufacture custom solutions. These companies are located across the United States, including California. Daylight redirection devices are available from a select but varied set of manufacturers again including both large (e.g., 3M), medium-sized, and smaller companies (LightLouver). A more complete list is available in Section 3.1.1. Clerestories, which are simply windows mounted high on a wall, are available wherever windows are manufactured. Because of the wide range of manufacturers of these technologies, availability is considered sufficient to offer PAFs and PCOs.

These technologies are installed onto the building envelope, so the useful life is expected to be equivalent of other building features such as windows. Appropriate degradation factors (e.g., dirt accumulation) were considered in this analysis; therefore, persistence of predicted savings is considered to be good. These technologies generally do not have any moving parts and therefore do not, as a rule, require maintenance. Regular cleaning, if practiced, will increase their savings beyond those presented here in this analysis.

This proposal is cost-neutral over the period of analysis. Overall, this proposal neither increases nor decreases the wealth of the state of California.

The proposed changes to Title 24, Part 6 have some impact on the complexity of the standards or the cost of enforcement.

Proposals B & C:

The proposed updates provide clarity and better interpretation of the standard for daylit zones definitions, and the use of Tubular Daylighting Devices (TDDs) in the prescriptive method. These are cost-neutral proposals that are expected to increase the overall usability of the standard.

The proposals are expected to have negligible impact on the standard's complexity or the cost of enforcement.

Cost-Effectiveness

Proposal A:

The proposed PAFs balance the energy savings from the technology with the energy debit of increased lighting power; therefore, they claim to be energy neutral or provide low energy savings and no cost savings. However, PAFs are not subject to the cost-effectiveness criteria as they are not requirements of the code; they are power tradeoffs that result in no claimed net energy impact.

PCOs use energy modeling to calculate the net TDV energy savings therefore no cost-effectiveness calculation is required.

Proposal B & C:

The proposed code changes do not change the stringency of the standards, so they not impact energy savings or the cost of compliance. They provide clarity in interpretation of the code. Cost-effectiveness was hence not warranted.

Statewide Energy Impacts

Proposal A:

The proposed PAFs balance the energy savings from the technology with the energy debit of increased lighting power. Therefore, they do not have any claimed statewide energy impact.

PCOs use energy modeling to calculate the net TDV energy savings therefore no statewide energy impact calculation is required.

Proposal B & C:

The proposed code changes do not impact statewide energy use. They provide clarity in interpretation of the code without modifying stringency.

Compliance and Enforcement

The Statewide CASE Team worked with stakeholders to develop and recommend a compliance and enforcement process to identify the impacts this process will have on various market actors. The compliance process is described in Section 2.5. The impacts the proposed measure will have on various market actors is described in Section 3.3 and Appendix A. The key issues related to compliance and enforcement are summarized below:

Proposal A:

- Awareness of the new PAFs and PCOs, their variety and their requirements;
- Ease of completion of the compliance documents to demonstrate compliance with the PAFs and PCOs;
- Ensuring coordination of envelope and lighting designers;
- Assuring that the technologies are not removed or adjusted over time.

Proposal B & C:

- Awareness of the new updates for daylit zones definitions, VTannual method for TDDs.

Although a needs analysis has been conducted with the affected market actors while developing the code change proposal, the code requirements may change between the time the final CASE Report is submitted and the time the 2019 standards are adopted. The recommended compliance process and compliance documentation may also evolve with the code language. To effectively implement the adopted code requirements, a plan should be developed that identifies potential barriers to compliance when rolling-out the code change and approaches that should be deployed to minimize the barriers.

1. INTRODUCTION

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support California Energy Commission's (Energy Commission) efforts to update California's Building Energy Efficiency Standards (Title 24, Part 6) to include new requirements or to upgrade existing requirements for various technologies. The four California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company, San Diego Gas and Electric, Southern California Edison and SoCalGas® – and two Publicly Owned Utilities (POUs) – Los Angeles Department of Water and Power and Sacramento Municipal Utility District – sponsored this effort. The program goal is to prepare and submit proposals that will result in cost-effective enhancements to energy efficiency in buildings. This report and the code change proposal presented herein is a part of the effort to develop technical information for proposed requirements on building energy efficient design practices and technologies.

The Statewide CASE Team submits code change proposals to the Energy Commission, the state agency that has authority to adopt revisions to Title 24, Part 6. The Energy Commission will evaluate proposals submitted by the Statewide CASE Team and other stakeholders. The Energy Commission may revise or reject proposals. See the Energy Commission's website for information about the 2019 Title 24, Part 6 rulemaking schedule and how to participate in the process: http://www.energy.ca.gov/title24/2019standards/.

The overall goal of this CASE Report is to propose a code change proposal for advanced daylighting design. The report contains pertinent information supporting the code change.

When developing the code change proposal and associated technical information presented in this report, the Statewide CASE Team worked with a number of industry stakeholders including building officials, manufacturers, builders, utility incentive program managers, Title 24 energy analysts, and others involved in the code compliance process. The proposal incorporates feedback received during a public stakeholder workshop that the Statewide CASE Team held on December 15, 2016 and March 30, 2017.

Section 2 of this CASE Report provides a description of the measure and its background. This section also presents a detailed description of how this change is accomplished in the various sections and documents that make up the Title 24, Part 6.

Section 3 presents the market analysis, including a review of the current market structure. Section 3.2 describes the feasibility issues associated with the code change, including whether the proposed measure overlaps or conflicts with other portions of the building standards including fire, seismic, and other safety standards and whether technical, compliance, or enforceability challenges exist.

Section 4 presents the per-unit energy, demand, and energy cost savings associated with the proposed code change. This section also describes the methodology that the Statewide CASE Team used to estimate energy, demand, and energy cost savings.

Section 5 presents the lifecycle cost and cost-effectiveness analysis. This includes a discussion of additional materials and labor required to implement the measure and a quantification of the incremental cost. It also includes estimates of incremental maintenance costs. That is, equipment lifetime and various periodic costs associated with replacement and maintenance during the period of analysis.

Section 6 presents the statewide energy savings and environmental impacts of the proposed code change for the first-year after the 2019 standards take effect. This includes the amount of energy that will be saved by California building owners and tenants, and impacts (increases or reductions) on material with emphasis placed on any materials that are considered toxic. Statewide water consumption impacts are also considered.

Section 7 concludes the report with specific recommendations with ~~strikeout~~ (deletions) and <u>underlined</u> (additions) language for the Standards, Reference Appendices, Alternative Calculation Method (ACM) Reference Manual, Compliance Manual, and compliance documents.

2. MEASURE DESCRIPTION

2.1 Measure Overview

2.1.1 Proposal A: Power Adjustment Factors

The proposed measure will allow Power Adjustment Factors (PAFs) and performance compliance options (PCOs) for indoor lighting that are controlled by daylighting controls when certain technologies are installed pertinent to vertical fenestration on the proposed building. The PAFs and PCOs may be applied to any nonresidential building subject to the provisions of Title 24, Part 6.

The proposed technologies include: fixed slats (louvers), light shelves, clerestories, and daylight redirection devices. Daylight redirecting devices may be devices mounted adjacent to fenestration or films applied to fenestration.

Several technologies on the market, which increase daylight potential, previously could not receive credit under the prescriptive path. The proposed PAFs provide a prescriptive credit for these technologies. The performance path will also incorporate these technologies as compliance options which reduce modeled lighting power.

It is possible that the introduction of these technologies into the 2019 update may provide a gradual path to their prescriptive requirement in future updates.

Existing code language for PAFs in Sections 100.1, 140.3 and 140.6 will be modified to incorporate these new PAFs.

2.1.2 Proposal B: Min VT Interpretation for TDDs

The proposed change provides clarification (by way of offering an interpretation) of the existing Minimum Visible Transmittance (Min VT) requirements for plastic, curb mounted skylights (under Section 140.3), for Tubular Daylighting Devices (TDDs).

The code change will impact the prescriptive requirement in that it adds a Min VTannual requirement for TDDs. Existing prescriptive requirements for all other fenestration types are not changed. TDDs are a type of skylight with complex optics that cannot be rated accurately using the traditional VT rating methodology (NFRC 200, ASTM E972). National Fenestration Rating Council (NFRC) has recently developed a new rating method called NFRC 203 to address the needs for fenestrations with complex geometries like TDDs. The code change adds a new Min VTannual threshold for TDDs based on NFRC 203.

2.1.3 Proposal C: Update to Daylit Zones Definitions

The proposed change provides clarification on the interpretation of daylit zone definitions for uses cases involving atriums and large exterior overhangs.

The code changes modify the definitions of daylit zones in the code language providing more clarity to users in interpreting the code for their use cases.

2.2 Measure History

2.2.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

Daylighting design remains one of the most effective energy reducing measures for nonresidential buildings. The three key aspects of good daylighting design are allowing adequate daylight into the space, distributing the daylight in a useful way and controlling the electric lights appropriately in response to daylight. The goal of the proposed measure is to improve the first and second aspect in Title 24, Part 6.

Shading, daylight redirection, and clerestories are common features of energy efficient design and are recommended in many design guidelines including American Society of Heating, Refrigerating and Air-Conditioning Engineers' (ASHRAE) Advanced Energy Design Guide, Energy Design Resources' Energy Design Guidelines, the Federal Government's Whole Building Design Guide, and others.

The Statewide CASE Team has been observed that fixed slats are appearing more frequently in architectural design. Offering these PAFs and PCOs may increase the momentum of this trend as well as offer optimized design guidance in their implementation.

Credits for mitigating heat gain are currently offered for shading in Title 24, Part 6 as a Relative Solar Heat Gain Coefficient (RSHGC) credit on vertical fenestration. ASHRAE Standard 189 also has shading requirements intended to mitigate heat gain. However, as of now there are no known daylighting credits for the daylighting benefits offered from shading and daylight redirection in any model standard.

2.2.2 Proposal B: Min VT Interpretation for TDDs

In 2014, NFRC developed a new procedure (NFRC 203) for determining Visible Transmittance (VT) of TDDs, termed VTannual. This new procedure calculates VT more appropriately for the complex geometry of various TDDs.

The Statewide CASE Team is proposing a code change to the Title 24, Part 6 prescriptive requirements for Min VT, to align California's Title 24, Part 6 Standard with the changes from NFRC, thus keeping the code current and relevant for California's design and construction community.

2.2.3 Proposal C: Update to Daylit Zones Definitions

Energy Commission staff reported questions received from users (via Title 24, Part 6 Energy Standards Hotline) on the need for correct interpretation of the Daylit Zones definitions in specific use cases involving atriums. Additionally, the Statewide CASE Team was informed of another use case involving large overhangs that needed a better interpretation. Based on this, the Statewide CASE Team is proposing an update to the daylit zone definition that allows users to more accurately interpret the Standard and its daylighting requirements.

2.3 Summary of Proposed Changes to Code Documents

The sections below provide a summary of how each Title 24, Part 6 document will be modified by the proposed change. See Section 7.1 of this report for detailed proposed revisions to code language.

2.3.1 Standards Change Summary

This proposal will modify the following sections of the Building Energy Efficiency Standards as shown below. See Section 7.1 of this report for the detailed proposed revisions to the code language.

2.3.1.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

SECTION 100.1 – DEFINITIONS AND RULES OF CONSTRUCTION

Definitions pertinent to slats, light shelves, clerestories, and daylight redirecting devices will be added to this section.

SECTION 140.3 – PRESCRIPTIVE REQUIREMENTS FOR ENVELOPES

Subsection 140.3(d): The envelope requirements of the proposed PAFs will be added to this section. Additions will include requirements for qualifying for the PAFs for each technology.

SECTION 140.6 – PRESCRIPTIVE REQUIREMENTS FOR INDOOR LIGHTING

Subsection 140.6(a).2: The lighting control requirements of the proposed PAFs will be added to this section. Additions will include requirements for qualifying for the PAFs as well as the values of the PAFs for the given technology.

2.3.1.2 Proposal B: Min VT Interpretation for TDDs

SECTION 140.3 – PRESCRIPTIVE REQUIREMENTS FOR BUILDING ENVELOPES

Table 140.3-C: Proposal adds a new column next to "Skylights" called "Tubular Daylighting Devices" and adds a Min VT rating value of 0.38.

2.3.1.3 Proposal C: Update to Daylit Zones Definitions

SECTION 130.1 – MANDATORY INDOOR LIGHTING CONTROLS

Subsection 130.1(d): Proposal adds language to interpret skylit daylit zone in an atrium.

Subsection 130.1(d)1.B & C: Proposal adds language to interpret lighting controls requirements in daylit zone for use cases with large exterior overhangs.

2.3.2 Reference Appendices Change Summary

Section NA7.4 will include a subsection documenting acceptance testing of the proposed measures.

2.3.3 Alternative Calculation Method (ACM) Reference Manual Change Summary

This proposal will modify the following sections of the Nonresidential Alternative Calculation Method (ACM) Reference Manual as shown below. See Section 7.3 of this report for the detailed proposed revisions to the text of the ACM Reference Manual.

SECTION 5 – BUILDING DESCRIPTORS REFERENCE

Subsection 5.4.4 Power Adjustment Factors (PAF): Proposal adds language in this section that includes tabulated lighting power savings fractions for a wider variety of designs than is available in the prescriptive PAF. Associated adjustment calculations will also be included for proposed designs which differ from the tabulated savings assumptions (e.g., window VT).

2.3.4 Compliance Manual Change Summary

The proposed code change will modify the following section of the Title 24, Part 6 Nonresidential Compliance Manual:

- Chapter 2, Table 2-3 may require some clarifying modifications.
- Chapter 5, subsection 5.6.5 of the Nonresidential Compliance Manual will need to be revised.

2.3.5 Compliance Documents Change Summary

The proposed code change will modify the compliance documents listed below.

- NRCC-ENV-05-E, NRCI-ENV-01-E and NRCA-ENV-02-F – A section for fenestration attachments will be added to these compliance documents. This section will have subsections for the proposed PAFs and their requirements.

- NRCC-LTI-02-E – The compliance document language pertaining to PAFs will be modified from addressing daylighting controls only to addressing both daylighting controls and the proposed measures.
- NRCC-PRF-01-E – The envelope and lighting sections of the performance method compliance documents will have language to accommodate the proposed measure.

2.4 Regulatory Context

2.4.1 Existing Title 24, Part 6 Standards

2.4.1.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

The proposed measure is not yet included in Title 24, Part 6 except for clerestories which are vertical fenestration.

2.4.1.2 Proposal B: Min VT Interpretation for TDDs

2016 Title 24, Part 6 requires that TDDs be rated for the VT using the NFRC 203 in Section 110.6 (a) 4. However, the Min VT requirement in Section 140.3 Table 140.3-C does not consider NFRC 203. The proposed change adds an interpretation of the Min VT requirement for plastic, curb-mounted skylights, using NFRC 203, which remedies the issue of TDDs not complying with the current prescriptive requirement.

2.4.1.3 Proposal C: Update to Daylit Zones Definitions

Existing definitions for Skylit and Sidelit Daylit Zones do not address use cases with atriums and large exterior overhangs. The proposal addresses this missing context.

2.4.2 Relationship to Other Title 24 Requirements

2.4.2.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

Exterior-mounted fixed slats and light shelves are subject to seismic and wind loads. Fire code may apply if the window is an exit route.

2.4.2.2 Proposal B: Min VT Interpretation for TDDs

The inclusion of a Min VT requirement interpretation for TDDs does not impact other parts of the code.

2.4.2.3 Proposal C: Update to Daylit Zones Definitions

The inclusion of code language interpreting daylit zone definitions does not impact other parts of the code.

2.4.3 Relationship to State or Federal Laws

2.4.3.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

There are no federal or state regulatory requirements triggered by the proposed measure.

2.4.3.2 Proposal B: Min VT Interpretation for TDDs

There are no federal or state regulatory requirements triggered by the proposed measure.

2.4.3.3 Proposal C: Update to Daylit Zones Definitions

There are no federal or state regulatory requirements triggered by the proposed measure.

2.4.4 Relationship to Industry Standards

2.4.4.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

Credits for mitigating heat gain are currently offered for shading in Title 24, Part 6 as an RSHGC credit on vertical fenestration. ASHRAE Standard 189.1 also has shading requirements intended to mitigate heat gain. However, as of now there are no known daylighting credits for the daylighting benefits offered from shading and daylight redirection in any model standard.

2.4.4.2 Proposal B: Min VT Interpretation for TDDs

NFRC develops and operates a uniform rating system for energy and energy-related performance of fenestration and fenestration attachment products. The Rating System determines the U-factor, Solar Heat Gain Coefficient (SHGC), and VT of a product.

In 2014, NFRC published their new rating methodology to rate the VT of TDDs – called the NFRC 203. This established a new industry standard for rating of VT for TDDs. Our proposal to for a Min VT interpretation for TDDs develops an equivalent Min VT for TDDs using the NFRC 203 method.

2.4.4.3 Proposal C: Update to Daylit Zones Definitions

The proposal to update the Daylit Zone definition for interpretation in use cases with atriums and large exterior overhangs has not been addresses in other national codes such as ASHRAE 90.1. Seattle's Energy Code[2] has provided one interpretation of skylit daylit zones in use cases with atriums, which the Statewide CASE Team has referenced in the development of the proposed code language.

2.5 Compliance and Enforcement

The Statewide CASE Team collected input during the stakeholder outreach process on what compliance and enforcement issues may be associated with these measures. Appendix A presents a detailed description of how the proposed code changes could impact various market actors. When developing this proposal, the Statewide CASE Team considered methods to streamline the compliance and enforcement process and how negative impacts on market actors who are involved in the process could be mitigated or reduced.

The key steps changes to the compliance process are summarized below:

2.5.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

- **Design Phase**: Lighting designers and envelope designers coordinate to properly implement the proposed measures. Coordination ensures that the appropriate PAF on the LTI-02 compliance document is used. Energy modelers and/or energy consultants may input the parameters for the PCOs and verify compliance documentation at this stage.
- **Permit Application Phase**: Plan reviewers review the window-to-wall ratio (WWR), window orientation, daylighting controls, geometric and material features of the technology (e.g., slat spacing, slat angle, reflectance, transmittance, clerestory height and dimensions) to verify that the design meets the requirements to qualify for the PAFs and PCOs.
- **Construction Phase**: Installers verify that devices are installed on the correct windows and have the correct geometrical features. Inspection is not mandatory at this phase.
- **Inspection Phase**: No performance testing is required but verifying the geometrical features will be required and will take additional time.

To make the market actors aware of changes to Title 24, Part 6, the California IOUs offer classes and publications, such as those found on EnergyCodeAce.com. The new PAFs and PCOs and their requirements will be communicated through these means. In classes, the instructors will emphasize the need for coordination between envelope and lighting designers.

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[2] 2015 Seattle Energy Code FINALDRAFT (October 10, 2016).

To ease the completion of compliance documents that demonstrate compliance with the PAFs, the requirements and calculations for the prescriptive PAFs have been reduced greatly throughout the development of the PAFs by reducing the options in control, setpoint, etc.; these options remain available in the performance method, but the performance approach software will handle the complex lookups and calculations.

To ensure that envelope and lighting designers coordinate to meet the requirements of the PAFs, language in Title 24, Part 6 will cross-reference the envelope and lighting sections. This is intended to alert the respective parties of the need for this coordination. In addition, the Nonresidential Compliance Manual will specifically call out the need for coordination between these disciplines. Previous versions of Title 24, Part 6 included PAFs for skylights which required coordination between envelope and lighting designers, so these will be reviewed to provide guidance on how to further communicate this need.

To assure that technologies are not removed or adjusted, language in the code will require permanent fasteners, fixed assemblies, and permanent labels that warn of triggering Title 24, Part 6 compliance if the technology is removed.

Overhangs have been in the code for a significant period of time so inspectors will be familiar with checking the geometries of shading devices. The procedure for inspecting clerestories is similar to current inspection of vertical fenestration. The procedures for the proposed measures will be similar to these existing procedures, but will require more steps and more time.

Existing compliance documents will be modified, but no new compliance documents will be introduced. The modification of the existing PAF compliance documents will be the addition of 4 new PAFs. These PAFs will require examination of both the lighting controls and the technology installed on the window. The lighting controls inspection is already known by inspectors but the window attachment technologies inspection is new. Inspectors will need to become familiar with the procedure and modifications to the compliance documents. The Statewide CASE Team has simplified the PAF structure throughout the development of the PAFs to lessen the labor burden of the proposed measures.

These technologies will require the verification of certain geometries and physical characteristics of the technology and/or the verification of make and model. The geometry check for fixed slats and light shelves will be to verify the projection factor, and a manufacturer-submitted surface material specification for the reflectance requirement. Checks can most likely be done in a detailed way on one unit to verify the compliance of all the units as differences in geometry and color will be obvious. This sampling process will be documented in the acceptance test procedures.

For daylight redirecting devices, manufacturer-submitted documentation that the unit has been tested per the required standards and meets the required performance values will suffice for verification.

The Statewide CASE Team recommends that information presented in this section, Section 3, and Appendix A be used to develop a plan that identifies a process to develop compliance documentation and how to minimize barriers to compliance.

2.5.2 Proposal B: Min VT Interpretation for TDDs

This code change proposal will primarily affect buildings that use the prescriptive approach to compliance. The key steps changes to the compliance process are summarized below:

- **Design Phase:** Architects, Energy Consultants, and other building design professionals will use the new Min VT as a criterion to select TDDs that comply with the prescriptive standard.
- **Permit Application Phase:** Plan reviewers will make note of the new Min VT threshold to check against VT of TDDs that may be on a plan.
- **Construction Phase:** Permitting process remains unchanged.
- **Inspection Phase:** Field inspection process remains unchanged.

2.5.3 Proposal C: Update to Daylit Zones Definitions

This code change proposal will primarily affect buildings that use the prescriptive approach to compliance. The key step changes to the compliance process are summarized below:

- **Design Phase:** Architects and other building design professionals use the updated definitions to correctly interpret and draw Daylit Zones on their designs.
- **Permit Application Phase:** Plan review process remains unchanged.
- **Construction Phase:** Permitting process remains unchanged.
- **Inspection Phase:** Field inspection process remains unchanged.

3. MARKET ANALYSIS

The Statewide CASE Team performed a market analysis with the goals of identifying current technology availability, current product availability, and market trends. The Statewide CASE Team considered how the proposed standard may impact the market in general and individual market actors. Estimates of market size and measure applicability were identified through research and outreach with stakeholders including utility program staff, Energy Commission staff, and a wide range of industry representatives who were invited to participate in utility-sponsored stakeholder meetings held on March 30, 2016 and December 15, 2017.

Market analysis for two proposals - Proposal A: Power Adjustment Factors and Performance Compliance Options, and Proposal B: Min VT Interpretation for TDDs are provided in this section. Proposal C: Update to Daylit Zones Definitions only updates the definition of Daylit Zones and clarifies their interpretation. Therefore, market analysis for this proposal is not included.

3.1 Market Structure

3.1.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

Online research showed that Airolite, Alcoa, EFCO as well as other large, medium, and small companies manufacture a variety of fixed slat products under the general category of "sun control". Light shelves are also manufactured by these companies. The larger manufacturers advertise area representatives on their websites who sell their products and ship out from distribution centers across the United States.

Conversations between the Statewide CASE Team and Lawrence Berkeley National Laboratory yielded that LightLouver, 3M, Lucent Optics, and SerraGlaze offer daylight redirection devices. LightLouver is manufactured by a smaller company in Boulder, Colorado but can distribute their product in California. 3M, Lucent, and SerraGlaze are also represented in California.

Clerestories are vertical fenestration and are manufactured and distributed as such.

3.1.2 Proposal B: Min VT Interpretation for TDDs

TDDs have been in the market for over 15 years and have a well-established network of dealers and installers. Multiple manufacturers provide TDDs in the California market, such as Solatube, Velux, Big Ass Solutions, Natural Light Energy Systems, and Elite Solar Systems.

3.2 Technical Feasibility, Market Availability, and Current Practices

3.2.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

Fixed slats and light shelves are not a proprietary technology and are available from a wide variety of manufacturers that will be able to meet the market demand for implementation in Title 24, Part 6. This is especially true since these measures are PAFs and PCOs; the implementation rate is expected to be gradual over time, allowing the market ample time to respond.

Daylight redirection devices are proprietary technologies but are on the market and available from a wide variety of manufacturers. Larger companies will be able to meet the demand created by the proposed measures. For smaller companies, the implementation as PAFs and PCOs will help them to gradually adjust to the demand.

Clerestories are windows and are therefore a part of the very well-established vertical fenestration market. There are no concerns regarding supply and demand.

The proposed measure can increase occupant comfort and reliability of daylighting savings. These technologies can reduce electric lighting use which also reduces heating, ventilation, and air conditioning (HVAC) use. The reduction in use of the lighting and HVAC systems may lead to their longer effective useful lives. These technologies will affect building aesthetic, but they are optional since they are PAFs and PCOs.

3.2.2 Proposal B: Min VT Interpretation for TDDs

TDDs have been in the market for over 15 years and have a well-established network of dealers and installers. Multiple manufacturers provide TDDs in the California market. Many of the manufacturers have rated their TDD products under the new NFRC203 method to develop VTannual ratings. The Statewide CASE Team's analysis of the NFRC Certified Products Directory (CPD) shows that 39 out of 44 products (89 percent) listed under TDDs have been rated for VT using the NFRC 203 procedure.

3.3 Market Impacts and Economic Assessments

3.3.1 Impact on Builders

It is expected that builders will not be impacted significantly by any one proposed code change or the collective effect of all the proposed changes to Title 24, Part 6. Builders could be impacted for change in demand for new buildings and by construction costs. Demand for new buildings is driven more by factors such as the overall health of the economy and population growth than the cost of construction. The cost of complying with Title 24, Part 6 requirements represents a very small portion of the total building value. Increasing the building cost by a fraction of a percent is not expected to have a significant impact on demand for new buildings or the builders' profits. The Statewide CASE Team does not expect the proposed code changes for the 2019 code cycle to have an adverse impact on builders.

Market actors will need to invest in training and education to ensure the workforce, including designers and those working in construction trades, know how to comply with the proposed requirements. Workforce training is not unique to the building industry, and is common in many fields associated with the production of goods and services. Costs associated with workforce training are typically accounted for in long-term financial planning and spread out across the unit price of many units as to avoid price spikes when changes in designs and/or processes are implemented.

3.3.1.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

Builders will need training on how to install some of these technologies. The installation of fixed slats is a relatively simple procedure of mounting pre-manufactured frames onto the interior or exterior of the envelope. Light shelves and wall-mounted daylight redirecting devices have similar installation procedures.

The installation of daylight redirecting films will require more specialized training; however, mounting of window films is a growing field. Installers are readily available.

No further training will be necessary for the installation of clerestories.

3.3.1.2 Proposal B: Min VT Interpretation for TDDs

No direct and significant impact on builder will result from this code change proposal.

3.3.2 Impact on Building Designers and Energy Consultants

Adjusting design practices to comply with changing building codes practices is within the normal practices of building designers. Building codes (including the California Building Code and model national building codes published by the International Code Council, the International Association of Plumbing and Mechanical Officials, and ASHRAE 90.1) are typically updated on a three-year revision cycles. As discussed in Section 3.3.1, all market actors, including building designers and energy consultants, should (and do) plan for training and education that may be required to adjusting design practices to accommodate compliance with new building codes. As a whole, the measures the Statewide CASE Team is proposing for the 2019 code cycle aim to provide designers and energy consultants with opportunities to comply with code requirements in multiple ways, thereby providing flexibility in requirements can be met.

3.3.2.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

Being a long-established technology, envelope designers are likely to be familiar with fixed slats and light shelves.

Light redirection technologies are less common with some of these technologies being fairly new to the market. Therefore, educating the design community about these technologies will be necessary.

Seismic considerations will need to be handled for fixed slats, light shelves, and daylight redirecting devices of substantial mass (e.g., LightLouver).

Clerestories are a well-known alternative feature in building design.

Designers will still need to be informed of the credit offered for the proposed technologies and the necessary requirements to qualify for the PAFs and PCOs.

3.3.2.2 Proposal B: Min VT Interpretation for TDDs

Building designers will have a greater choice in products that qualify using the prescriptive method as a result of this code change proposal. Based on feedback received from the design community during the first stakeholder meeting, building designers welcome this code change proposal that increases their choice of products that can be used under the prescriptive compliance option.

3.3.3 Impact on Occupational Safety and Health

The proposed code change does not alter any existing federal, state, or local regulations pertaining to safety and health, including rules enforced by the California Division of Occupational Safety and Health. All existing health and safety rules will remain in place. Complying with the proposed code change is not anticipated to have adverse impacts on the safety or health of occupants or those involved with the construction, commissioning, and maintenance of the building.

3.3.4 Impact on Building Owners and Occupants

The Statewide CASE Team does not expect the proposed code change for the 2019 code cycle to impact building owners or occupants adversely.

3.3.4.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

No maintenance is necessary for the proposed measures. The technologies have no moving parts or internal resources that require replenishing, but regular cleaning will increase the effectiveness the proposed measures.

Occupants are expected to experience brighter spaces and/or less direct sunlight, which is expected to have a positive effect on mood and productivity.

3.3.4.2 Proposal B: Min VT Interpretation for TDDs

This code change proposal will give building owners more options for daylighting their buildings using skylights and TDDs, when using the prescriptive compliance option. The Statewide CASE Team expects building owners to be positively impacted due to the increase in choices of Title 24, Part 6 compliant skylight products.

3.3.5 Impact on Building Component Retailers (Including Manufacturers and Distributors)

3.3.5.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

Manufacturers and distributors of the technologies in the proposed measure will likely see a gradual increase in sales. Lighting controls manufacturers may see a slight increase in sales.

3.3.5.2 Proposal B: Min VT Interpretation for TDDs

Manufacturers and distributors of TDDs will likely see an increase in sales. Additionally, it is likely that lighting control manufactures will also see an increase in sales.

3.3.6 Impact on Building Inspectors

3.3.6.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

The inspection procedure for the proposed measures will be a visual inspection. Inspectors will confirm the WWR, fenestration orientation and lighting controls, make and model, and/or geometrical features (e.g., slat spacing, slat angle, clerestory height and dimensions) of the technology.

3.3.6.2 Proposal B: Min VT Interpretation for TDDs

It is expected that this measure will have no significant impact of the current activities of the building inspectors.

3.3.7 Impact on Statewide Employment

Section 3.4.1 discusses statewide job creation from the energy efficiency sector in general, including updates to Title 24, Part 6.

3.3.7.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

As PAFs and PCOs, it is not expected that the market impact will be sufficient to create new jobs. The proposed measure, even if implemented as a prescriptive requirement in future code updates, is not expected to eliminate jobs as they do not decrease the market share of any other building-related technology. Certain specialized skilled labor may increase (e.g., installation of window films).

3.3.7.2 Proposal B: Min VT Interpretation for TDDs

The impact of the code change proposal will be increased choices for building designers for skylights, which may lead to more buildings designed with skylights. However, since TDDs make up a small percentage of total skylight installations, the Statewide CASE Team does not expect this code change to result in any significant increase in statewide employment.

3.4 Economic Impacts

3.4.1 Creation or Elimination of Jobs

In 2015, California's building energy efficiency industry employed more than 321,000 workers who worked at least part time or a fraction of their time on activities related to building efficiency. Employment in the building energy efficiency industry grew six percent between 2014 and 2015 while the overall statewide employment grew three percent (BW Research Partnership 2016). Lawrence Berkeley National Laboratory's report titled *Energy Efficiency Services Sector: Workforce Size and Expectations for Growth* (2010) provides details on the types of jobs in the energy efficiency sector that are likely to be supported by revisions to building codes.

Building codes that reduce energy consumption provide jobs through *direct employment*, *indirect employment*, and *induced employment*.[3] Title 24, Part 6 creates jobs in all three categories with a significant amount attributed to induced employment, which accounts for the expenditure-induced effects in the general economy due to the economic activity and spending of direct and indirect employees (e.g., nonindustry jobs created such as teachers, grocery store clerks, and postal workers). A large portion of the induced jobs from energy efficiency are the jobs created by the energy cost savings due to the energy efficiency measures. For example, as mentioned in Section 3.3.4, the 2016 Standards are expected to save single family homeowners about $240 per year. Money saved from hundreds of thousands of homeowners over the entire life of the building will potentially be reinvested in local businesses. Wei, Patadia, and Kammen (2010) estimate that energy efficiency creates 0.17 to 0.59 net job-years[4] per GWh saved. By comparison, they estimate that the coal and natural gas industries create 0.11 net job-years per GWh produced.

3.4.1.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

Certain specialized skilled labor may increase (e.g., installation of window films) as a result of these PAFs and PCOs. However, it is not expected that the market impact will be sufficient to create new jobs. The proposed measure, even if implemented as a prescriptive requirement in future code updates, is not expected to eliminate jobs as the technologies do not decrease the market share of any other building-related technology.

3.4.1.2 Proposal B: Min VT Interpretation for TDDs

No significant increase or decrease in labor hours are expected to occur due to this code change proposal.

3.4.2 Creation or Elimination of Businesses in California

There are approximately 43,000 businesses that play a role in California's advanced energy economy (BW Research Partnership 2016). California's clean economy grew ten times more than the total state

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[3] The definitions of direct, indirect, and induced jobs vary widely by study. Wei et al. (2010) describes the definitions and usage of these categories as follows: "*Direct employment* includes those jobs created in the design, manufacturing, delivery, construction/installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration. *Indirect employment* refers to the ''supplier effect'' of upstream and downstream suppliers. For example, the task of installing wind turbines is a direct job, whereas manufacturing the steel that is used to build the wind turbine is an indirect job. *Induced employment* accounts for the expenditure-induced effects in the general economy due to the economic activity and spending of direct and indirect employees, e.g., nonindustry jobs created, such as teachers, grocery store clerks, and postal workers."

[4] One job-year (or ''full-time equivalent'' FTE job) is full time employment for one person for a duration of 1 year.

economy between 2002 and 2012 (20 percent compared to two percent). The energy efficiency industry, which is driven in part by recurrent updates to the building code, is the largest component of the core clean economy (Ettenson and Heavey 2015). Adopting cost-effective code changes for the 2019 Title 24, Part 6 code cycle will help maintain the energy efficiency industry.

Table 2 lists industries that will likely benefit from the proposed code change classified by their North American Industry Classification System (NAICS) Code.

3.4.2.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

The manufacturers of the technologies in the proposed measure will see a slight increase in their sales. The aluminum industry will also see a very slight increase in their demand as this material is used often in the fabrication of some of the proposed measures. Industries associated with lighting controls may likewise experience an increase. However, as PAFs and PCOs, it is not expected that the market impact will be sufficient to create businesses. The proposed measure, even if implemented as a prescriptive requirement in future code updates, is not expected to ever eliminate businesses as the technologies do not decrease the market share of any other building-related technology.

3.4.2.2 Proposal B: Min VT Interpretation for TDDs

Manufacturers of TDDs are likely to see an increase in business as a result of this code change proposal. Most TDD manufacturers have dealers located in California, including one of the largest, Solatube International Inc., being located in Vista, California. Another is SunOptics, which is located in Sacramento, California.

Solatube's entire operation from design to manufacturing happens in California. Their California region staff is approximately 200 staff members. Solatube deals with about 15 premier dealers that provide install services. Each dealership has a staff of about ten people, such as office managers, sales, warehouse managers, and certified installers. Above that, product sales and distributors employ about 30 to 40 people in the state that provide design consultation, design support, and other services. The proposed code change may result in more demand for TDDs, resulting in creation and retention of California workforce involved in the production and sales of TDDs.

Raw material for the development of TDDs includes mostly aluminum, acrylic, and polycarbonates. These raw materials are provided from local distributors who provide materials from multiple states in the United States and globally.

Table 2: Industries Receiving Energy Efficiency Related Investment, by North American Industry Classification System (NAICS) Code

Industry	NAICS Code
Nonresidential Building Construction	2362
Electrical Contractors	23821
Roofing Contractors	238160
Manufacturing	32412
Industrial Machinery Manufacturing	3332
Electric Lighting Equipment Manufacturing	3351
Engineering Services	541330
Building Inspection Services	541350
Environmental Consulting Services	541620
Other Scientific and Technical Consulting Services	541690
Advertising and Related Services	5418
Corporate, Subsidiary, and Regional Managing Offices	551114
Office Administrative Services	5611

3.4.3 Competitive Advantages or Disadvantages for Businesses in California

In 2014, California's electricity statewide costs were 1.7 percent of the state's gross domestic product (GPD) while electricity costs in the rest of the United States were 2.4 percent of GDP (Thornberg, Chong and Fowler 2016). As a result of spending a smaller portion of overall GDP on electricity relative to other states, Californians and California businesses save billions of dollars in energy costs per year relative to businesses located elsewhere. Money saved on energy costs can be otherwise invested, which provides California businesses with an advantage that will only be strengthened by the adoption of the proposed code changes that impact nonresidential buildings.

3.4.4 Increase or Decrease of Investments in the State of California

The proposed changes to the building code are not expected to impact investments in California on a macroeconomic scale, nor are they expected to affect investments by individual firms. The allocation of resources for the production of goods in California is not expected to change as a result of this code change proposal.

3.4.5 Effects on the State General Fund, State Special Funds and Local Governments

The proposed code changes are not expected to have a significant impact on the California's General Fund, any state special funds, or local government funds. Revenue to these funds comes from taxes levied. The most relevant taxes to consider for this proposed code change are: personal income taxes, corporation taxes, sales and use taxes, and property taxes. The proposed changes for the 2019 Title 24, Part 6 Standards are not expected to result in noteworthy changes to personal or corporate income, so the revenue from personal income taxes or corporate taxes is not expected to change. As discussed, reductions in energy expenditures are expected to increase discretionary income. State and local sales tax revenues may increase if homeowners spend their additional discretionary income on taxable items. Although logic indicates there may be changes to sales tax revenue, the impacts that are directly related to revisions to Title 24, Part 6 have not been quantified. Finally, revenue generated from property taxes is directly linked to the value of the property, which is usually linked to the purchase price of the property. The proposed changes will increase construction costs. As discussed in Section 3.3.1, however, there is no statistical evidence that Title 24, Part 6 drives construction costs or that construction costs have a significant impact on building price. Since compliance with Title 24, Part 6 does not have a clear impact on purchase price, it can follow that Title 24, Part 6 cannot be shown to impact revenues from property taxes.

3.4.5.1 Cost of Enforcement

Cost to the State

State government already has budget for code development, education, and compliance enforcement. While state government will be allocating resources to update the Title 24, Part 6 Standards, including updating education and compliance materials and responding to questions about the revised requirements, these activities are already covered by existing state budgets. The costs to state government are small when compared to the overall costs savings and policy benefits associated with the code change proposals.

State buildings will only be impacted by the proposed changes if they choose to implement the proposed measures.

Cost to Local Governments

All revisions to Title 24, Part 6 will result in changes to compliance determinations. Local governments will need to train building department staff on the revised Title 2, Part 6 Standards. While this re-training is an expense to local governments, it is not a new cost associated with the 2019 code cycle. The building code is updated on a triennial basis, and local governments plan and budget for retraining every time the code is updated. There are numerous resources available to local governments to support compliance training that can help mitigate the cost of retraining, including tools, training and resources provided by the IOU codes and standards program (such as Energy Code Ace). As noted in Section 2.5 and Appendix A, the Statewide CASE Team considered how the proposed code change might impact various market actors involved in the compliance and enforcement process and aimed to minimize negative impacts on local governments.

3.4.6 Impacts on Specific Persons

The proposed changes to Title 24, Part 6 are not expected to have a differential impact on any groups relative to the state population as a whole, including migrant workers, commuters, or persons by age, race or religion.

4. ENERGY SAVINGS

For Proposal A: Power Adjustment Factors and Performance Compliance Options, only the PAFs were analyzed. The TDV energy savings from PCOs is calculated in the energy model for each specific building seeking compliance. Therefore PCOs are not analyzed in this section.

For Proposal B: Min VT Interpretation for TDDs, the proposed code change interprets the already established ‘Min VT threshold for skylights’ for TDDs. The analysis to develop an equivalent Min VT threshold for TDDs was done using testing data on traditional skylights, and the published methodology on VTannual ratings using NFRC 203. No energy savings were needed to develop this new threshold, so energy savings were not calculated. Instead this section describes the analysis done to determine Min VT threshold for TDDs.

For Proposal C: Update to Daylit Zones Definitions, the proposed code changes provide a clarification for users on the daylit zone definitions for specific use cases of skylights in atriums and windows with large overhangs. Daylighting simulations were done to better understand daylight availability in these cases, but energy savings were not needed to develop the code change proposals. Instead, this section describes the daylighting simulation results and analysis to derive the proposals.

4.1 Key Assumptions for Energy Savings Analysis

4.1.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

As PAFs, the proposed measures are specifically analyzed to result in an offset of energy savings. The predicted energy savings from the technologies are offset by the increase in allowed lighting power. Discussion in this section will refer to the energy savings of the proposed measure’s technologies, which will in the end be a margin within which to allow increased lighting power. Appendix E discusses the conservative approach used to determine the final PAFs. This conservative approach results in the likelihood that energy savings will be realized on the implementation of PAFs for the proposed measures despite the offset in energy described above.

The TDV energy savings from PCOs is calculated in the energy model for each specific building seeking compliance. Therefore PCOs are not analyzed in this section.

4.1.2 Proposal B: Min VT Interpretation for TDDs

To interpret the ‘Min VT for skylights’ for TDDs, the Statewide CASE Team’s analysis plan was to:

a. Find testing data on traditional plastic skylights that includes a standard VT (VTnormal) and visible transmittance at various solar altitude angles.

b. Use this data to calculate each skylight's VTannual rating using the methodology described in NFRC 203.
c. Compare VTannual against each skylight's rated VTnormal rating, to determine a relationship between the two ratings. Based on this relationship determine the equivalent VTannual rating for a VTnormal rating of 0.64 – the current Min VT for plastic, curb mounted skylights in Section 140.3.

The Statewide CASE Team conducted a search for testing data of traditional skylights by requesting input from stakeholders. The most detailed and reliable data source was the Energy Commission PIER study on 'Skylight Photometric and Thermal Reports'. The study provided a detailed description of a testing procedure developed to generate photometric files for skylights. The data included solar-angle specific visible transmittance for using eight types of skylights most commonly used in commercial buildings. This data was deemed sufficient to conduct the analysis for this code change proposal.

4.1.3 Proposal C: Update to Daylit Zones Definitions

To develop appropriate guidance to users on Daylit Zones definitions, the Statewide CASE Team's analysis plan was to:

a. Conduct daylighting simulations using Radiance, to better understand daylight availability in a case of a building with an atrium and a room with large overhangs.
b. Interpret these results to determine changes in daylit zone definitions.

4.2 Energy Savings Methodology

To assess the energy, demand, and energy cost impacts, the Statewide CASE Team compared current design practices to design practices that will comply with the proposed requirements.

For Proposals B and C, energy savings were not needed for the analysis. This section describes analysis methodology used to determine the code change language.

4.2.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

The TDV energy savings from PCOs is calculated in the energy model for each specific building seeking compliance. Therefore PCOs are not analyzed in this section.

The proposed conditions are defined as the design conditions that will comply with the proposed code change. Specifically, the proposed code change will provide lighting credits depending on the fenestration technology used, fenestration orientation, space WWR ratio, and daylighting control type.

Radiance as implemented in OpenStudio was used to analyze the daylighting for measures. The software's Ruby code was modified so that it could process the variations in parameters necessary for the analysis. Python code was also written to process Radiance results and prepare the data for Excel. Savings were then calculated in Excel.

The Energy Commission provided guidance on the type of prototype buildings that must be modeled. However, when creating lighting credits, it is necessary to model all the variations in parameters which affect the total lighting energy use. Key parameters included all minimally compliant ranges of WWR, fenestration orientation, and a wide variation in daylighting control types and setpoints. These parameters were either not present or not sufficiently varied in the Energy Commission's prototype buildings. Therefore, prototypes that sufficiently varied the necessary parameters were created.

The parameters of the prototypes are listed in the tables below. The column labeled "Value" denotes how this parameter was varied across various prototypes. If there is only one value, then this parameter remained constant across all prototypes. In general, every combination of varied parameter was analyzed with every other varied parameter to capture all reasonably expected combinations in forecasted construction. The column labeled "Source" denotes the source of the value. If the Source is

"Judgment" then the value is derived from engineering best judgment considering typical practice, conservative outcomes, and best modeling practices.

The figures presented below provide a visual depiction of the prototypes used in the analysis.

Table 3: Envelope and Interior Parameters

Parameter	Value	Source	Comments
Floor-to-floor height	13 feet	Judgment	3 feet plenum not shown in figures
Windows	As shown in Figure 1 and Figure 2: 10%, 20%, 30%, 40% WWR from bottom to top. VT: 0.42	Title 24, Part 6	
Orientations	90°, 180° and 270° clockwise from North.	Judgment	
Reflectivity	Ceiling: 70% Walls: 50% Floor: 20%	IES-LM-83 Modeling Guidelines	
Furniture	Furniture factors that reduce daylighting savings: East/West: 0.57 South: 0.63 Daylight redirecting devices: 0.8	(Saxena 2011), (Shadd 2011) See Appendix B for details	

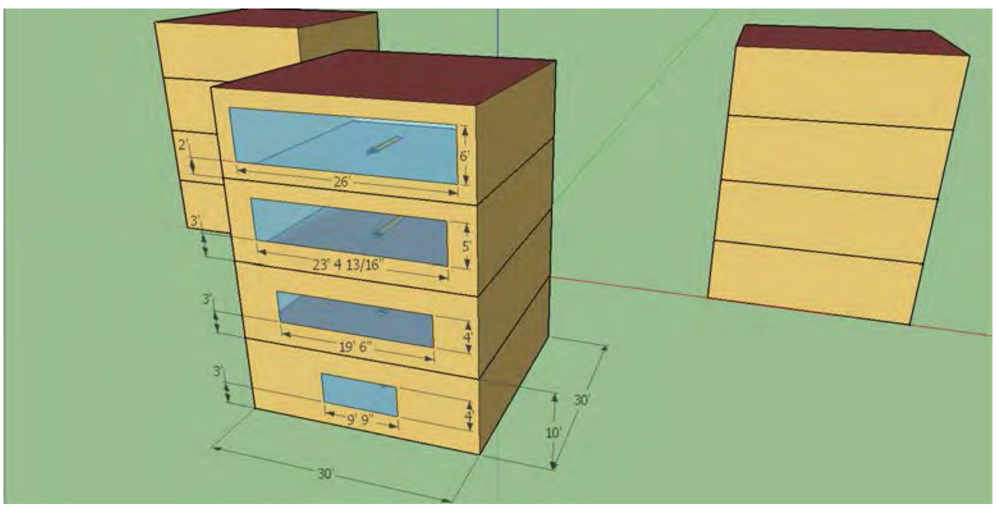


Figure 1: View-window-only prototypes' basic geometry

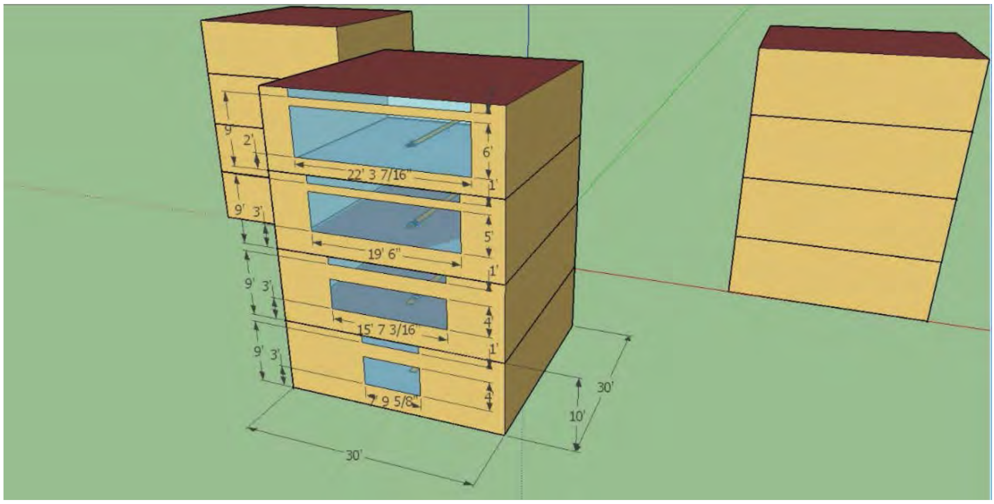


Figure 2: View window with clerestory prototypes' basic geometry

Table 4: Lighting Parameters

Parameter	Value	Source	Comments
Setpoint	100, 200, 300, 500, 750 and 1000 lux	Title 24, Part 6, Appendix 5.4 A	The Appendices were a guideline for typical applicable lighting levels.
Control type	See Figure 3	Title 24, Part 6, Table 130.1-A	
Control placement	Centrally located relative to window, 2.5' above the floor. Primary control: One head height Secondary control: Two head heights	Judgment, Title 24, Part 6 Section 130.1(d)1	
Schedule	See Figure 4	Title 24, Part 6 Appendix 5.4 B, Office Occupancy	

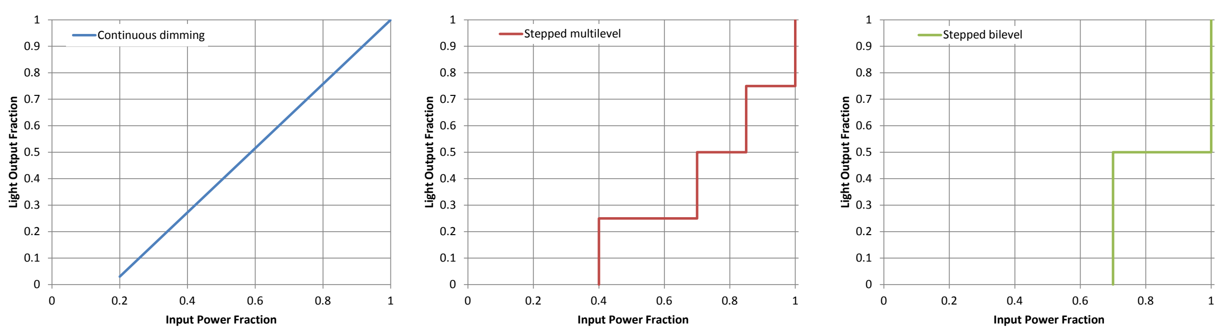


Figure 3: Power fraction by control type

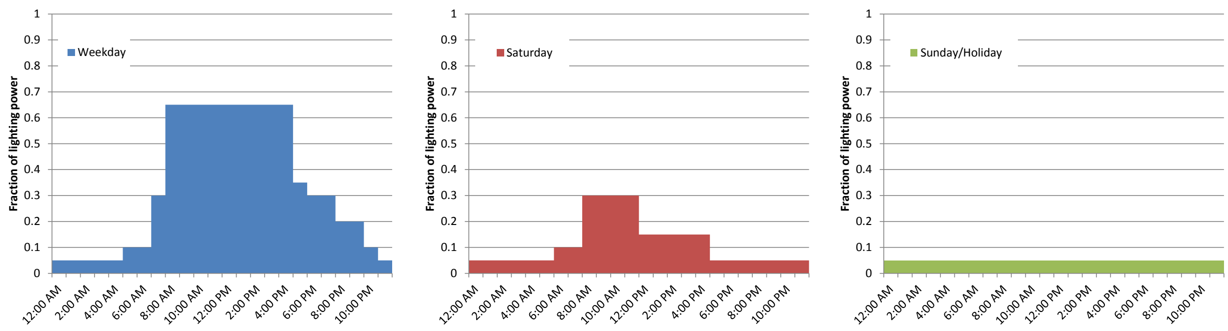


Figure 4: Lighting power schedules

The effect of the technologies on HVAC systems was not analyzed. In general HVAC systems during unoccupied hours are either off or have wide setpoint bands. This means that during unoccupied hours HVAC energy use is either zero or very low. Unoccupied hours are also generally characterized by low lighting. This implies that a slightly increased lighting energy from a PAF is expected to have either no or very little effect on the HVAC system energy during unoccupied hours.

Occupied hours approximately overlap daylighting hours. During occupied/daylighting hours the lighting energy with the use of the proposed measures would be lower than the lighting energy without the proposed measure. This is the entire basis for creating PAFs for the proposed measures. If there was no daylighting energy savings there would be no PAF. If the lighting energy during daylighting with a proposed measure is less than the lighting energy without the measure, then the HVAC energy use will be lower with the proposed measure. In addition, lower HVAC energy use often implies higher HVAC system efficiency, implying that the cooling energy provided by the HVAC with the proposed measures would be reduced even further compared to the HVAC energy use without the proposed measures.

Although the situation is complex, and the above discussion does not explain every possibility, it is considered a reasonable enough rationale to make the statement that in general HVAC energy will be reduced with the introduction of the proposed measures.

4.2.1.1 Fixed Slats

Fixed slats were analyzed in the study. Fixed slats block direct beam sunlight and provide some daylight redirection. They may be mounted on the exterior to mitigate solar gain, or they may be mounted on the interior to avoid wind loads, vandalism, thermal bridging or to allow passive solar heating of the space. Figure 5 illustrates an example of an installation.

Figure 5: Fixed slats

Source: Airolite

When designing fixed slats, one of the key parameters to model is cutoff angle. Cutoff angle is the minimum solar elevation which a slat blocks. For all elevations above this angle, the sun is blocked.

If horizontal slats are configured to block direct sunlight for seated occupants, then the energy savings associated with a particular horizontal cutoff angle is related to the seated height of the occupant. This seated height is quite consistent regardless of other building parameters or occupant stature. In summary, since seated height is a very predictable range, the savings associated with a particular horizontal cutoff angle are also predictable.

For vertical slats (i.e., fins), the energy savings associated with a particular vertical cutoff angle is related to the position of the occupant along the wall where the window is mounted. This position is not a predictable variable since occupants may be seated anywhere along the wall where the window is mounted. If the specific design of the space is known beforehand, then the positions might be more predictable. However, in specifying a statewide standard, the specific design is unknown. In summary, since occupant position relative to window width is unpredictable, the savings associated with a particular vertical cutoff angle is also unpredictable.

Due to the better predictability of savings from horizontal cutoff angles, only horizontal fixed slats were analyzed for inclusion in the proposed measures.

For this analysis, the following parameters were considered in the modeling of horizontal cutoff angle:

- A representative set of cutoff angles to analyze the effect of this parameter.
- Frequency of solar elevation above the cutoff angles.

The first step used in determining cutoff angles was to use NREL's SOLPOS algorithm to determine all the true solar positions within California.[5] The data in Figure 6 comes from the SOLPOS data. The column heights represent the frequency that the sun is above a particular elevation for the given orientation considering all latitudes and longitudes within the state of California. For example, looking at all hours of the year in all locations in California, for east-facing orientations, the sun is ten degrees above the horizon about 77 percent of the time.

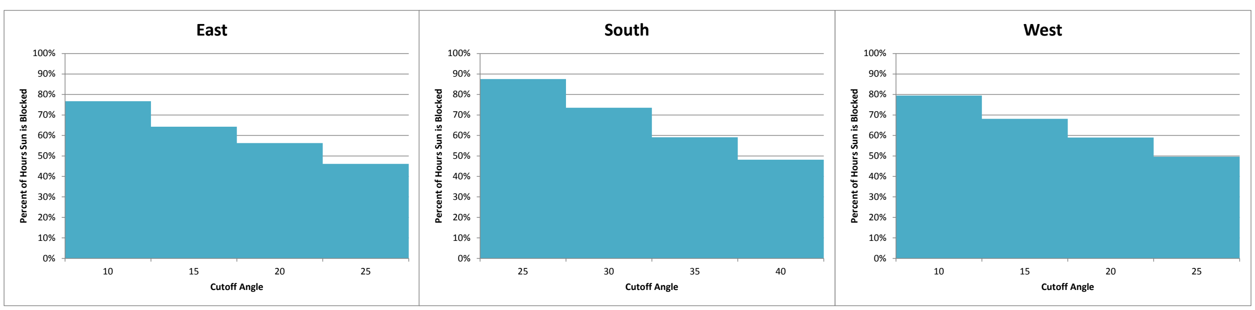


Figure 6: Cutoff angles in California

Representative cutoff angles were selected based on regular intervals of solar occlusion and regular intervals of cutoff angle. Specifically, cutoff angles were selected where the sun would be blocked approximately 80, 70, 60, and 50 percent of the time while still maintaining a regular five-degree interval between cutoff angles. The final selections of cutoff angles for modeling are given on the horizontal axes in Figure 6.

Analyzing various slat angles was also important. For a given cutoff angle and slat profile width, as slat angle increases, slat spacing increases. The situation is illustrated in Figure 7. But occupant view also

[5] Many software algorithms use approximations of solar position which are efficient in calculation and sufficient for their purpose. However actual solar position is a result of many parameters that are not included in these approximations.

decreases as slat angle increases, and, because daylight reflects off the surfaces of the slat, the slat angle affects the slat inter-reflections. This implies that the magnitude and direction of reflected daylight into the space are also a function of the slat angle, and therefore daylighting energy savings is also a function of angle and may have a maximum effectiveness at a certain angle.

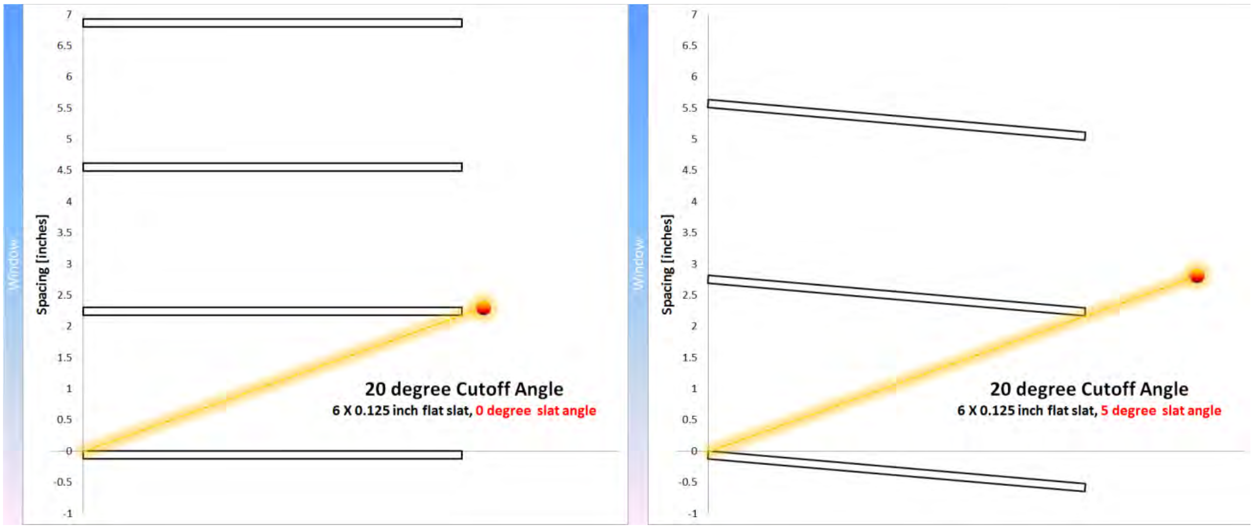


Figure 7: Slat angles and spacing for a given cutoff

In selecting slat angles to analyze, two criteria were considered:

- A representative set of slat angles to analyze the effect of this parameter.
- Reasonable availability of the slat configuration.

Any desired angle or spacing may be specified when purchasing fixed slats. This variability in angle and spacing means any cutoff angle is achievable by any slat profile width, as long as the correct angle and spacing are calculated. That is, for a given slat profile width to spacing ratio (WSR), there is only one slat angle that will achieve the desired cutoff angle.

If it is assumed that the profile of the slat is designed such that it's transmission of daylight is at least as good as a flat slat, then the only further consideration for profile is the relative thickness of the front edge of the slat versus the slat spacing. This is because any thickness of the front edge of the slat self-shades the slat assembly, which blocks light that would have otherwise been redirected to daylight the space.

Table 5 lists slat dimensions. Airfoil profiles are available with edge thicknesses of less than 0.1 inches. Flat rectangular profiles are available with edge thicknesses of 1/8 of an inch. For the purposes of the analysis an edge thickness to slat spacing ratio of 0.125:1 (1/8:1) was assumed for developing the PAF.

Table 5: Typical Slat Dimensions

Sun Control Model	Blade Type	Blade Material	Blade Material Thickness	Blade Widths
ASC4	Airfoil	Extruded Aluminum	0.081"	4"
ASC6	Airfoil	Extruded Aluminum	0.081"	6"
ASC8	Airfoil	Extruded Aluminum	0.081"	8"
FSC4	Fan	Extruded Aluminum	0.081"	4"
FSC6	Fan	Extruded Aluminum	0.081"	6"
TSC4	Rectangular Tube	Extruded Aluminum	0.125"	4"
TSC6	Rectangular Tube	Extruded Aluminum	0.125"	6"
TSC8	Rectanglular Tube	Extruded Aluminum	0.125"	8"
ZSC4	Louver	Extruded Aluminum	0.125"	4"

Source: Airolite

To analyze the effect of slat angle on savings, five degree intervals were modeled.

Reflectance of slat material and coating affects savings. Aluminum slats make up the bulk of mass-produced fixed slats and Kynar is a typical coating for these products.[6] The reflectance of Kynar was tested per ASTM E903 (Parker, et al. 2000). The reflectance of the various colors range from 0.742 to 0.052.

Aging is also a factor in reflectance. To estimate the effect of aging on materials and coatings two methods were investigated: the aged reflectance formula for cool roofs in Title 24, Part 6 and a dirt correction factor for horizontal windows (Mansfield 2008). The cool roof formula in Title 24, Part 6 includes decrease in reflectance of the material over time but is also intended to calculate the reflectance of the entire solar spectrum, not just visible light. The dirt correction factor accounts for the accumulation of dirt in the visible spectrum but does not account for material fading.

The cool roof aged reflectance formula was selected for coatings because Kynar is also used as a cool roof material. It was assumed that loss of reflectance in the visible spectrum was closely approximated by the cool roof aged reflectance formula.

The study that updated the aged reflectance formula was investigated (Levinson 2011). This study derived a soiling resistance factor, β, of 0.85 for factory-applied coatings. Using this factor with aged reflectance formula on the highest reflective Kynar coating yielded an aged reflectance of 0.66. This guided the upper bound for reflectivity for the analysis.

To find a reasonable lower bound, the darker coatings were not considered as they were assumed to not have a reasonable expectation of savings. Instead, uncoated aluminum used with the aforementioned dirt correction factor guided the lower bound for the analysis. Following the procedure for deriving the dirt correction factor for a horizontal window in an urban environment yielded a correction factor of 0.7. Combined with the initial reflectance of uncoated aluminum, this yielded an aged reflectance of 0.385.

Considering the above guidance for upper and lower bounds, the modeled upper and lower bounds were set to 0.7 and 0.3. A midpoint of 0.5 was also modeled to capture any curvature in savings versus slat visible reflectance. The parameters of the fixed slats for the analysis are summarized Table 6.

Table 6: Fixed Slat Parameters

Parameter	Value	Comments
Cutoff angles	East/West: 10°, 15°, 20°, 25° South: 25°, 30°, 35°, 40°	Blocks between ~80-50 percent of direct sun
Slat angles	5°, 10°, 15°, 20°	Greater than 20° considered to block too much view
Profile	Flat	Considered least efficient profile
Front edge thickness to spacing ratio	0.125:1	Conservative self-shading
Reflectance	Diffuse 0.3, 0.5, 0.7	

The fixed slat parameters above were entered into Window 7 to generate Bi-directional Scattering Distribution Function (BSDF) files. These BSDF files are used to model the direction and diffusion of transmitted visible light as a function of incident light angle.

[6] Airolite, Architectural Louvers, CS Sun Controls and others offer this as a standard coating.

Figure 8 illustrates an example of the visible transmittance of a slat that is 50 percent reflective and is 1.8 times as wide as its spacing (a WSR of 1.8) at an angle of 10 degrees. The yellow highlighted region on the left of the figure represents a chosen angle of incident light. The larger circle illustrates a heat map of the light level and direction from that incident light that is transmitted to the other side of the slat. Each incident light angle would result in a different heat map.

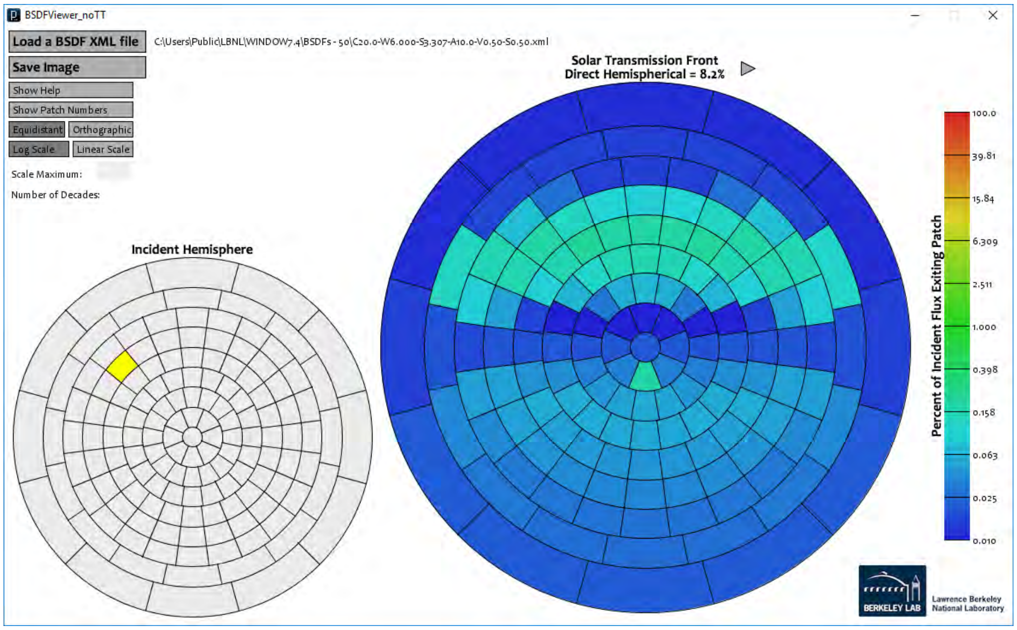


Figure 8: Example fixed slat BSDF – 50 percent reflective, 1.8 WSR, 10 degrees

4.2.1.2 Clerestories

Clerestories more efficiently distribute daylight as they take vertical fenestration higher, thereby increasing the depth of the daylit zones of a space. A one-foot-high clerestory was considered the minimum height for a viable clerestory. As can be seen in Figure 2, a ten-foot ceiling and four- to six-foot-high windows provided a reasonable gap above the view window for a clearstory while maintaining reasonable head and sill heights for the view window.

Defining clerestories as fenestration area above seven feet was considered. However, five-foot tall windows with 3-foot sills already reach eight feet and are common, especially at WWRs greater than 30 percent. Therefore, to avoid free-ridership, the threshold was set at eight-foot sills for clerestories.

WWR remained constant between the baseline window and the clerestory case. Window area was subtracted from the width of the view window to account for the additional area of the clerestory.

4.2.1.3 Light Shelves with Overhangs

Light shelves combine the characteristics of fixed slats with clerestories. They block and redirect direct beam and increase the daylit zone area. The cutoff angles and reflectance used to analyze fixed slats were considered analogous to light shelves. However, interior light shelves alone only block direct beam at the clerestory and do not block direct beam for any view window below the light shelf. Therefore, if there is view window below a light shelf, it must have an overhang to block direct beam sunlight. If a visible reflectance requirement is applied to the top of this overhang, then the overhang does two things: it blocks direct beam sunlight into the view window and increases the hours of direct beam sunlight redirection through the clerestory.

4.2.1.4 Daylight Redirecting Devices

Daylight redirecting devices (DRDs) have engineered optical properties such that incoming daylight is generally redirected to the ceiling of the space. This redirected daylight then bounces off the ceiling in a diffuse manner into the space. The daylight redirecting capabilities of these technologies far outperform those of fixed slats, but this redirection comes at the cost of view. However, these technologies are often mounted at the clerestory level so view is of lesser concern.

A schematic of the technology and examples of field installations are presented in Figure 9.

Figure 9: LightLouver profile and field installation

Source: LightLouver, Sacramento Municipal Utility District

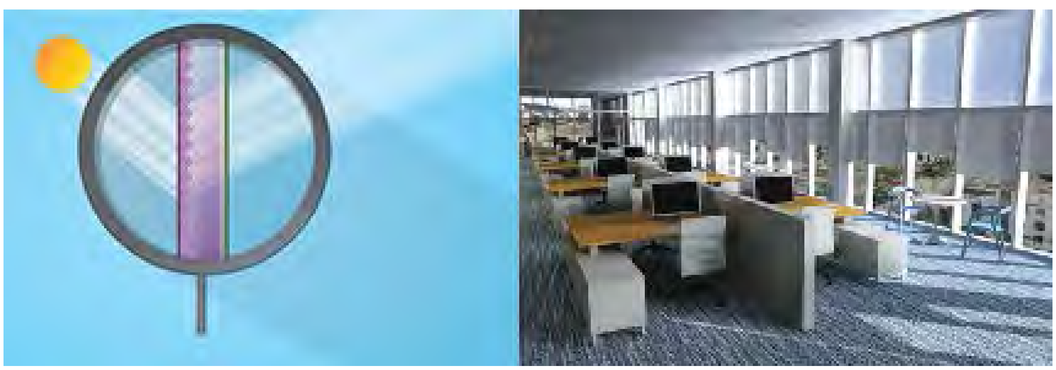


Figure 10: 3M daylight redirecting film profile and field installation

Source: 3M

DRDs are proprietary designs and therefore do not require the same determination of parameters as fixed slats. Instead, BSDF files were directly obtained from manufacturers. Figure 11 and Figure 12 show LightLouver and 3M daylight redirecting film (DRF) technology BSDFs.

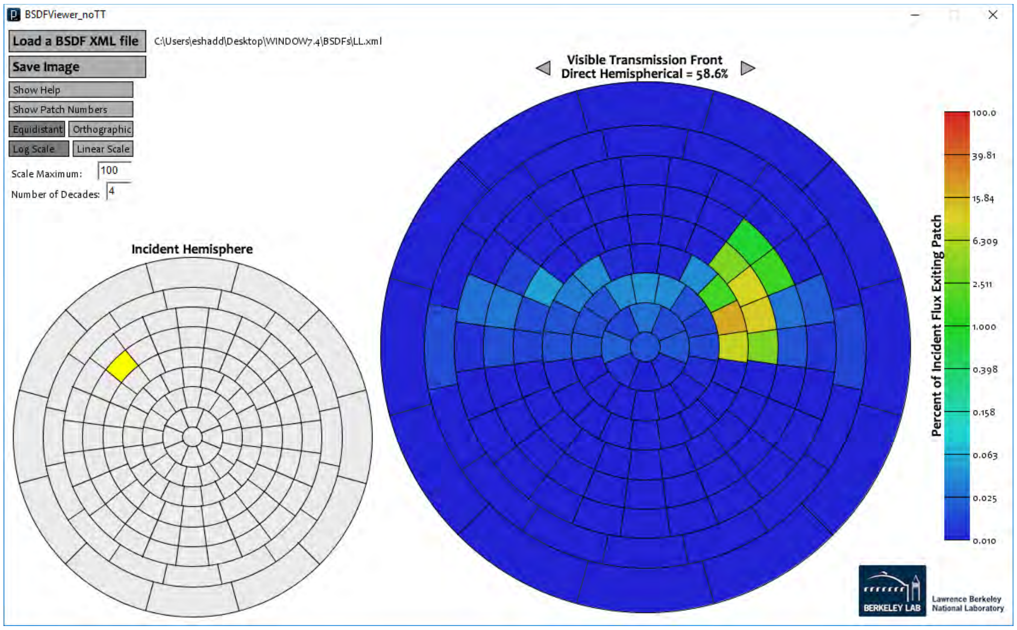


Figure 11: Example LightLouver BSDF

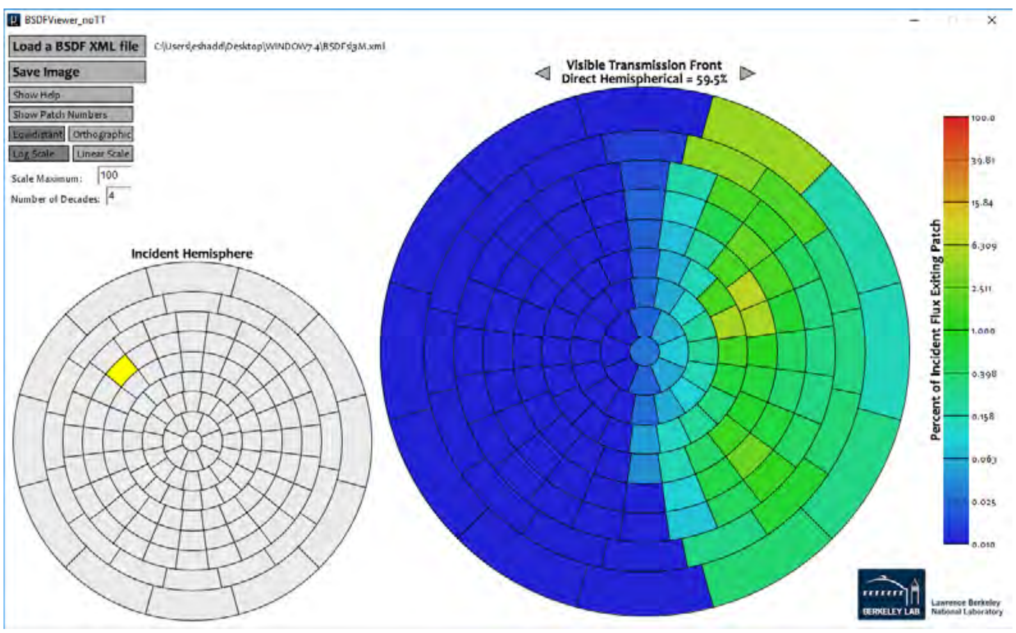


Figure 12: Example 3M DRF BSDF

In addition, two other manufacturers produce daylight redirecting films: Lucent and SerraGlaze. The important distinction for these products is that they are specularly transmissive. This means that high-intensity beam daylight can be transmitted directly through the film. This is an advantage for view but can be a disadvantage for glare (Lee 2017).

For this study, all DRDs will be categorized under the same PAF so an appropriate approach to quantify savings for all the technologies was needed.

Generally, these technologies recommend that manual interior shades are installed below the clerestory level so daylight is not blocked. LightLouver has a large profile projecting from the window and is opaque when viewed from below, so direct beam sunlight glare is very minimal. The study assumed it was likely that no blinds were installed at the clerestory level for LightLouver. However, DRF technologies do not project out from the window and are transparent or translucent when viewed from below, so direct beam sunlight glare may occur. Film technologies are also relatively new in the market making it difficult to determine that blinds will not be installed over them. The Statewide CASE Team assumed that during glare events in the model, LightLouver would not be covered with blinds, but the 3M DRF would be.

4.2.1.5 Manual Shade Behavior

The assumed operation of manual shades is critical to the quantification of the proposed measures. The operation of a manual shade determines how much daylight enters the space, thereby determining the level that electric lights may be lowered. The less a shade is closed, the more it lets in daylight.

A University of Idaho study (Van Den Wymelenberg 2012) reviewed the existing literature in the United States, Canada, and Europe, which covered buildings of various orientations and types. This study concluded that there was no meaningful consensus among these studies as to the manner or motivation for typical manual shade behavior.

Given this apparent gap in knowledge the question remained how to characterize the operation of blinds to quantify savings for the proposed measure's technologies. Although there was no meaningful consensus among studies as to the manner or motivation for typical manual shade behavior, there was some agreement among the existing literature regarding the extremes of manual shade behavior.

To make use of this feature of the data, in lieu of assuming a typical manual shade behavior, a bounded statistical approach whereby the extremes of behavior are used to analyze the energy impact of all manual shade behaviors was pursued. This bounded statistical approach set limits on the energy impact of behaviors, then used statistical methods to arrive at an overall probability-weighted average use. This approach is described in more detail in Appendix B. The conclusion is that averaging the energy impact of a low daylighting potential behavior ("Worst Case" for daylighting) and a high daylighting potential behavior ("Best Case" for daylighting) is considered a reasonable approach to calculate an approximate overall energy impact of all manual shade behaviors.

However, the Worst Case would be a completely sensitive occupant who could tolerate no glare and always had shades closed. The Best Case would be a completely insensitive occupant who could tolerate all glare and never closed their shades. Analyzing these two cases would give no information about the differences between technologies. Therefore, a reasonable "Bad Case" and "Good Case" was needed.

The Bad Case occupant was assumed to be somewhat sensitive to glare. When they sensed discomfort glare, they closed dark manual shades and very rarely checked if they could reopen blinds if there was no glare. The Good Case occupant was assumed to be somewhat insensitive to glare. When they sensed discomfort glare, they closed light manual shades but checked fairly often to see if they could reopen blinds if there was no glare. A discussion of the derivation of the specific levels of these parameters is given in Appendix D. All occupant parameters, including the manual shade behavior parameters, are listed in Table 7.

Table 7: Occupancy Parameters

Parameter	Value		Source
Occupant location	Left edge (interior facing) of window. See Figure 13 for additional details.		Height: mean 50th percentile adult male/female popliteal + seated eye height (U.S. Department of Transportation n.d.). Distance from window: Judgment.
Schedule	Monday – Friday, 8 am to 5 pm.		Title 24, Part 6 ACM Office Occupancy.
Occupant case	**Bad Case**	**Good Case**	
DGP glare threshold	0.4	0.6	See Appendix D.
Re-open check times	8 am after at least 3 weeks of closure.	8 am, 1 pm after at least 1 hour of closure.	See Appendix D.
Shade type	Fully lowered, fully closed venetian blinds.	Fully lowered, 1% transmittance diffusing shade.	See Appendix D.

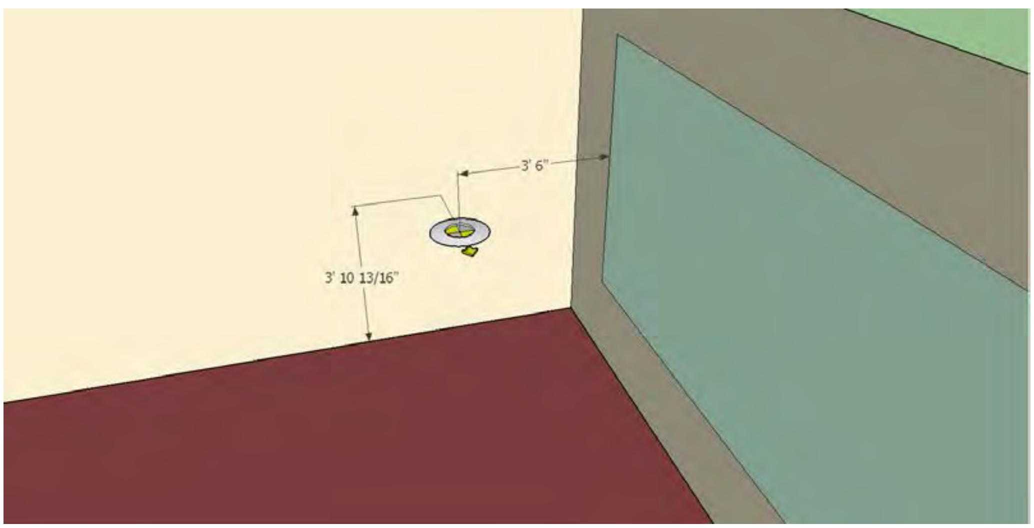


Figure 13: Occupant location

Energy savings were calculated using a TDV (Time Dependent Valuation) methodology.

4.2.2 Proposal B: Min VT Interpretation for TDDs

As described in Section 4.1.2, to interpret the 'Min VT for skylights' for TDDs, the Statewide CASE Team's analysis plan was to:

a. Find testing data on traditional plastic skylights that includes a standard VT (VTnormal) and visible transmittance at various solar altitude angles.
b. Use this data to calculate each skylight's VTannual rating using the methodology described in NFRC 203.
c. Compare VTannual against each skylight's rated VTnormal rating, to determine a relationship between the two ratings. Based on this relationship determine the equivalent VTannual rating for a VTnormal rating of 0.64 – the current Min VT for plastic, curb mounted skylights in Section 140.3.

4.2.2.1 PIER Skylight Testing Data

The Energy Commission PIER study on 'Skylight Photometric and Thermal Reports' (HMG 2003) provided detailed data from testing of eight commonly used skylights to generate photometric files for skylights. The data included solar-angle specific visible transmittance.

The PIER study conducted photometric testing for the eight skylights using a Skylight Goniophotometer (Figure 14). A goniophotometer measures luminous flux at various angles from the luminous source. The skylights were tested at 10º increments of solar altitude angles (location Scottsdale, AZ 33º N lat.). The data provided VT of traditional skylights at different solar angles.

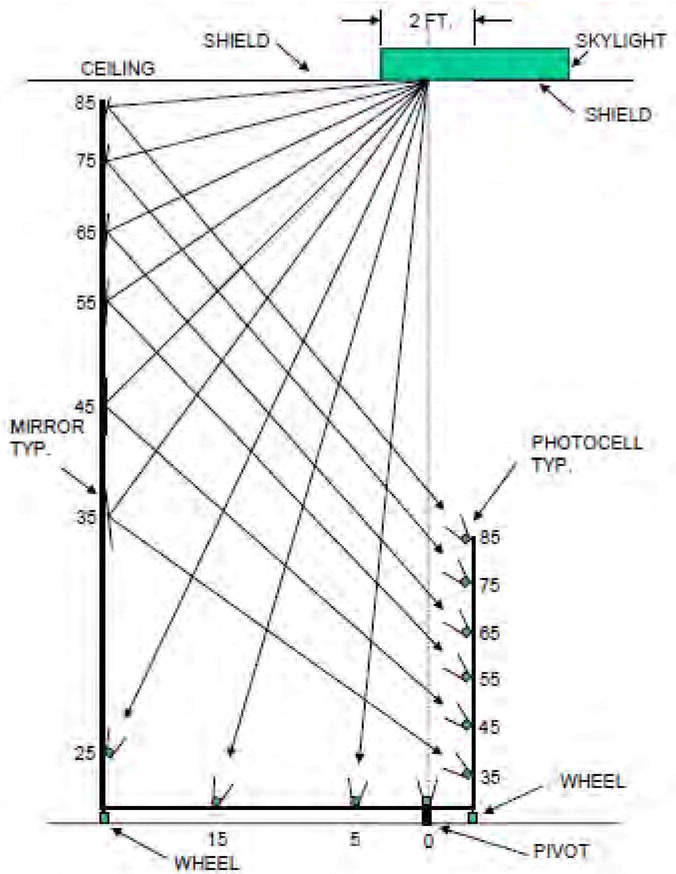


Figure 14: PIER skylight photometric testing using a goniophotometer

The eight skylights tested are described in the table in Table 8 and pictures in Figure 15.

Table 8: PIER Skylight Photometric Study - Test Skylights

Type	Dimension	Material	Color	Shape
A	4' x 4'	Double-glazed Low-E glass	Clear	Flat - horizontal
B	31" x 39"	Double-glazed Low-E glass	Clear	Flat - 20° slope
C	4' x 4'	Single-glazed Acrylic	Medium-white (color 2447)	Dome
D	4' x 4'	Double-glazed Acrylic	Outer – clear Inner – medium white (color 2447)	Dome
E	4' x 4'	Double-glazed Prismatic Acrylic	Clear, with 12 prismatic pattern on the inside surfaces.	Catenary Arch Dome
F	4' x 4'	Fiberglass insulating panel, crystal over crystal glazing sheets with no fiberglass batt filling between sheets		Pyramid
G	4' x 4'	Structured Polycarbonate "Twinwall" Glazing	Clear	Pyramid
H	4' x 4'	Non-diffusing Acrylic Sheets	Bronze	Pyramid

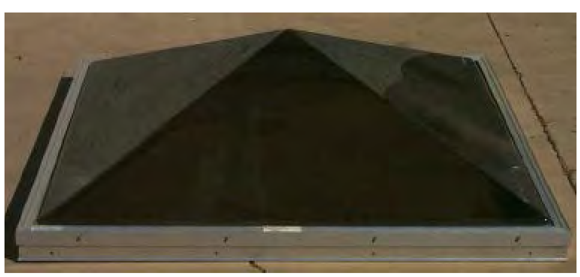
 Double-Glazed Low-E Flat Skylight - Type A	 Single-Glazed White Acrylic Dome Skylight – Type C
 Double-Glazed White Acrylic Dome Skylight - Type D.	 Double-Glazed Prismatic Acrylic Arch Skylight – Type E
 Fiberglass Pyramidal Skylight – Type F	 Twinwall Polycarbonate Pyramidal Skylight - Type G
 Bronze Acrylic Pyramidal Skylight – Type H	

Figure 15: PIER skylight photometric study test skylight pictures

4.2.2.2 NFRC 203 Testing Method

Tubular daylighting devices are different from traditional skylights due to two distinctive features:

1. A specular tubular light well (or light guide) that can be bent at various points;

2. Complex optics at the dome that are designed to specifically admit and reject certain sun angles to optimize performance.

Due to these features, the traditional testing procedures for VT prescribed by NFRC 200 or ASTM E972 fail to capture the performance of TDDs. These procedures test the product (NFRC 200) or a sample of the product material (ASRM E972) for only one angle – at normal angle (90º).

Figure 16: Tubular daylighting devices

Source: Solatube and Sunoptics

In 2014 NFRC developed a new Procedure for Determining Visible Transmittance of optically complex TDDs called NFRC 203-2014. Under this method, products are rated under 18 different angles of incidence and time-weighted averaged to develop a single VTannual number. The angles used to develop the VTannual rating represents the sun's actual movement through the sky for Middle America - 40˚ North Latitude.

Figure 17 shows the testing apparatus and a schematic representation of the 18 angles used in the calculation of VTannual. Note that TDDs are tested with a three-foot light well (light guide).

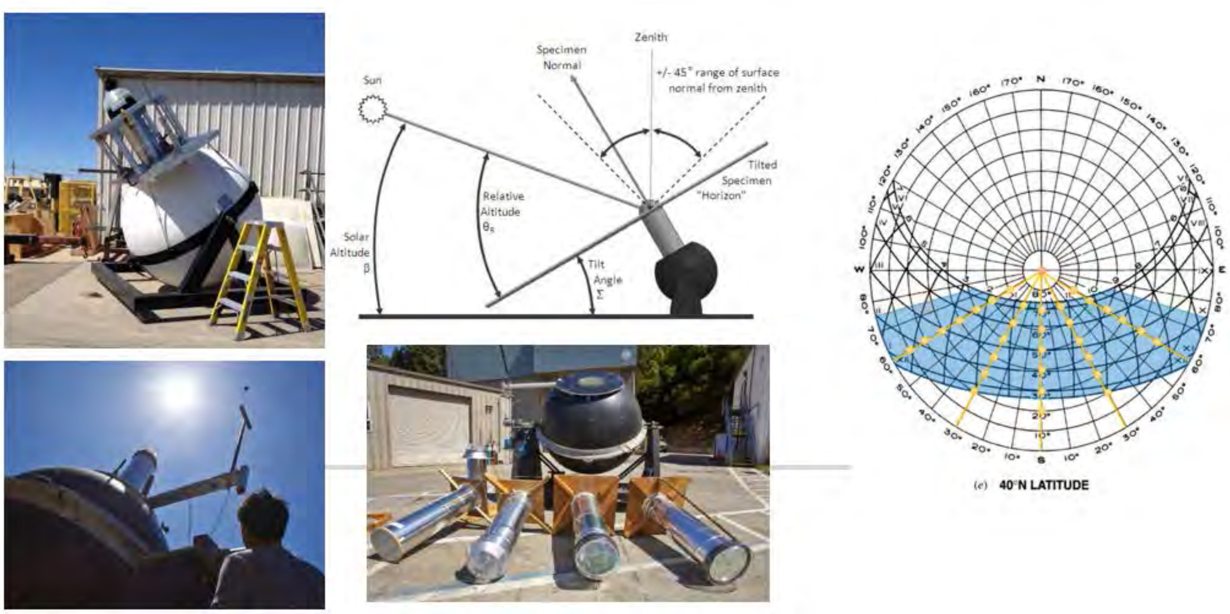


Figure 17: NFRC 203 testing procedure

Visible transmittance from the 18 different angles are then used to create the VTannual rating based on the procedure described in Figure 18.

Table 8-1 Zonal Time (ZT) Factors

		Surface-Solar Azimuth Angle, γ		
		0°	30°	60°
Relative Solar Altitude Angle (RSALT), θ_R	20°	0	0.106	0.084
	30°	0.074	0.097	0.072
	40°	0.034	0.064	0.068
	50°	0.026	0.053	0.078
	60°	0.023	0.051	0.074
	70°	0.029	0.055	0.012

Equation 8-3:

$$VT_{annual} = (VT_{20,0}*ZT_{20,0}) + (VT_{30,0}*ZT_{30,0}) + (VT_{40,0}*ZT_{40,0}) + (VT_{50,0}*ZT_{50,0}) + (VT_{60,0}*ZT_{60,0}) + VT_{70,0}*ZT_{70,0}) + (VT_{20,30}*ZT_{20,30}) + (VT_{30,30}*ZT_{30,30}) + (VT_{40,30}*ZT_{40,30}) + (VT_{50,30}*ZT_{50,30}) + (VT_{60,30}*ZT_{60,30}) + (VT_{70,30}*ZT_{70,30}) + (VT_{20,60}*ZT_{20,60}) + (VT_{30,60}*ZT_{30,60}) + (VT_{40,60}*ZT_{40,60}) + (VT_{50,60}*ZT_{50,60}) + (VT_{60,60}*ZT_{60,60}) + (VT_{70,60}*ZT_{70,60});$$

Where:

VT_{annual} = Total Annual Visible Transmittance of TDD

$VT(\theta_R, \gamma)$ = Visible transmittance at one RSALT angle and one surface-solar azimuth angle

ZT = Zonal Time Factor

Figure 18: Calculation procedure for VTannual (NFRC 203-2014)

4.2.2.3 PIER Data Analysis

Data from PIER Photometric testing of six plastic skylights for different solar altitude angles (10^o to 60^o) was processed to develop a VTannual rating for each skylight.

This rating was compared to the skylight's glazing material Visible Transmittance (VTnormal) for each skylight, obtained using ASTM E972 method. This method rates the visible transmittance of a sample of the glazing material and is currently the only accepted method for rating visible transmittance of projecting skylights.

Skylight Type	VT normal	VT annual
Crystal over crystal Fiberglass ins panel pyramid	0.292	0.180
Double glazed clear prismatic acrylic compound arch	0.628	0.408
Double glazed white acrylic dome	0.587	0.398
Single glazed bronze acrylic pyramid	0.282	0.065
Single glazed white acrylic dome	0.626	0.442
Single glazed white PET compound arch	0.488	0.294

Table 9: VTannual and VTnormal Ratings for Six Skylights – from PIER Data

This data was plotted to determine a relationship between the VTannual and VTnormal. The graph in Figure 19 shows the data plotted on an X-Y Scatter plot. The horizontal line (orange) represents the current Min VT rating of 0.64 for plastic skylights.

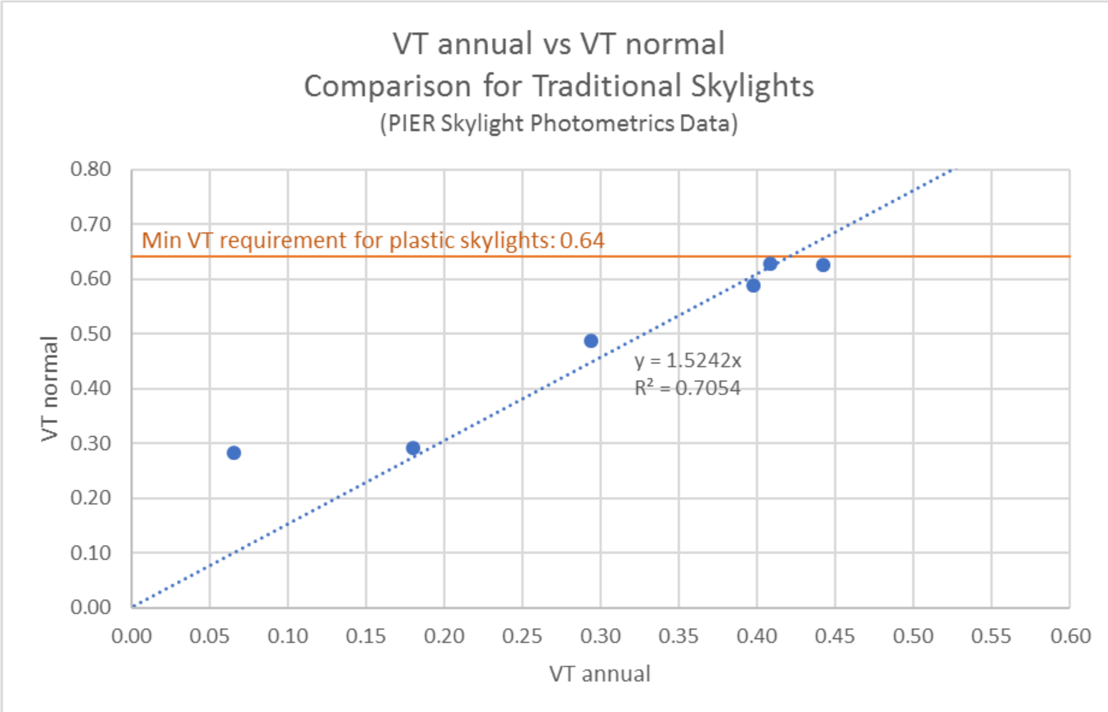


Figure 19: VTannual vs VTnormal relationship

The plot shows a strong linear relationship between VTannual and VTnormal ($r^2 = 0.7054$). The following equation represents the linear relationship:

$$VT_{normal} = 1.5242 \times VT_{annual}$$

Using this equation, the Statewide CASE Team derived an equivalent to a VTnormal of 0.64 as VTannual = 0.42

To develop a comparative value to a TDD tested with NFRC 203 test procedure, a correction is applied to this value to account for the three-foot light well used for TDDs that was not provided in the PIER test procedure. The skylights in the PIER study had one-foot light wells.

TDD light wells are highly specular and designed to lose minimal light. Table 10 (from 2008 Title 24, Part 6) provides calculated well efficiencies for specular tubular light wells. The well efficiency of a three-foot length (L) light well, for a 21 inch diameter (D) TDD with a 97 percent reflectance is about 0.9.

Table 10: Well Efficiencies for Specular Light Wells

TABLE 146-B WELL EFFICIENCY FOR SPECULAR TUBULAR LIGHT WELLS

	Light Well Reflectance (ρ)						
L/D	ρ = 99%	ρ = 97%	ρ = 95%	ρ = 92%	ρ = 90%	ρ = 85%	ρ = 80%
0.5	0.99	0.97	0.95	0.91	0.89	0.84	0.78
1.0	0.98	0.94	0.89	0.83	0.79	0.70	0.61
1.5	0.97	0.90	0.84	0.76	0.71	0.58	0.48
2.0	0.96	0.87	0.80	0.69	0.63	0.49	0.37
2.5	0.95	0.85	0.75	0.63	0.56	0.41	0.29
3.0	0.94	0.82	0.71	0.58	0.50	0.34	0.23
3.5	0.93	0.79	0.67	0.53	0.44	0.29	0.18
4.0	0.92	0.76	0.64	0.48	0.39	0.24	0.14
4.5	0.91	0.74	0.60	0.44	0.35	0.20	0.11
5.0	0.90	0.71	0.57	0.40	0.31	0.17	0.09
5.5	0.88	0.68	0.52	0.35	0.26	0.13	0.06
6.0	0.87	0.65	0.48	0.30	0.22	0.10	0.04

Applying this correction to the equivalent value derived from equation from Figure 19:

$$VT_{annual} = 0.42 \times 0.9 \ = \mathbf{0.38}$$

A VTannual of 0.38 is proposed as an equivalent interpretation of the current Min VT requirement for skylights.

See Section 7 for exact code language proposed under Table 140.3-B.

4.2.3 Proposal C: Update to Daylit Zones Definitions

4.2.3.1 Skylit Daylit Zones in Atriums

To develop the analysis for Skylit Daylight Zone definition in Atrium spaces, a Radiance model of a building with six floors and a central atrium was developed and simulations were run to understand the daylight distribution in the space.

Table 11: Assumptions for the Building Model

Floor to ceiling height	10'
No. of floors	6
Floor dimensions	100' x 100'
Atrium dimensions	31' x 61'
Skylight dimensions	30' x 50' (Skylight option a) 20' x 50' (Skylight option b) 10' x 50' (Skylight option c)
Skylight properties	40% VT (translucent)
Floor, wall, ceiling reflectance	75%, 50%, 25%
Location	Sacramento, CA

4.2.3.2 Atrium - Radiance Simulation Runs

Figure 20, Figure 21, and Figure 22 show output from Radiance simulations for three skylight sizes (noted in table above). The image on the left is a photorealistic rendering showing illuminance for Sept 21st at 12 noon, while two images to the right show Continuous Daylight Autonomy (cDA300) for a sensor grind on the top and bottom floors. The cDA300 results can be interpreted as percent energy savings from a photocontrol Dimming plus OFF system. Each sensor is represented with a circle and percent energy savings are shown inside the circle. The circles with greater than 50 percent savings are shaded white, while those with less than 50 percent savings are shaded from gray to black.

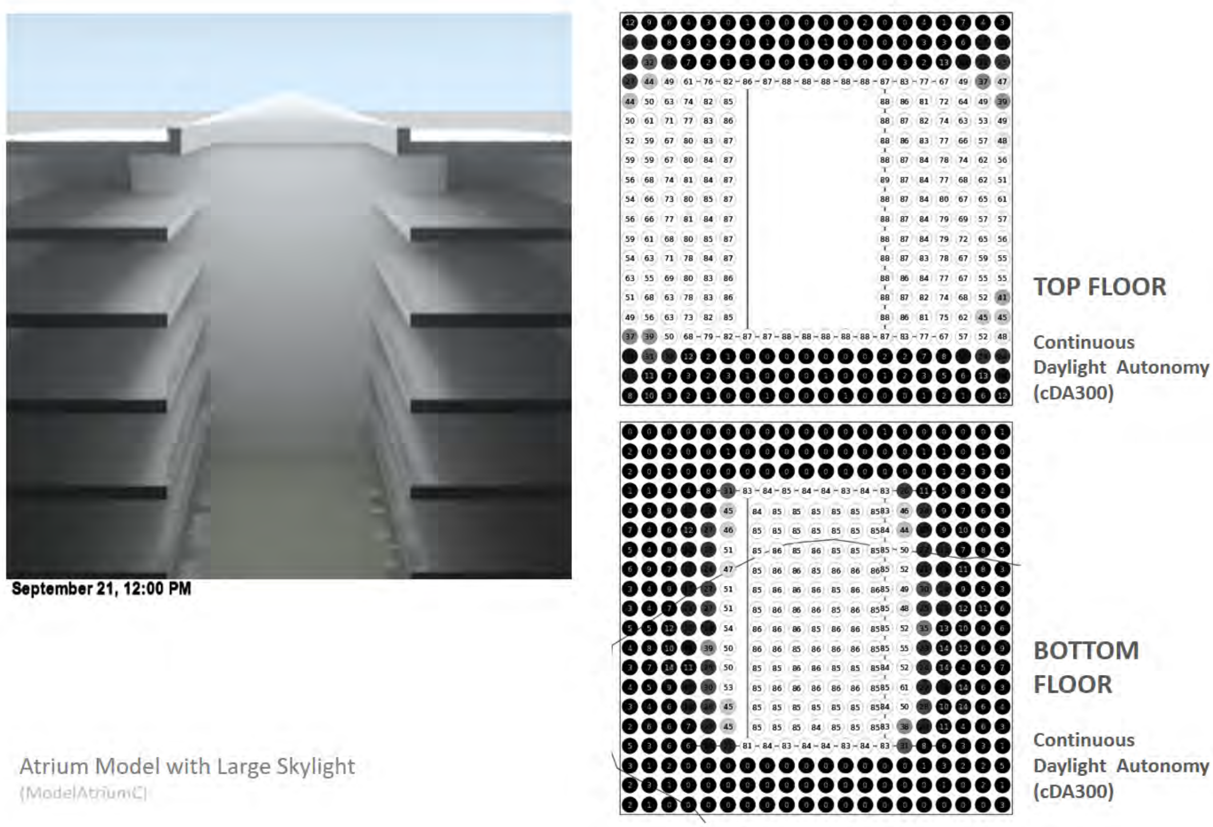


Figure 20: Skylight option (a) 30' x 50' Radiance simulation results

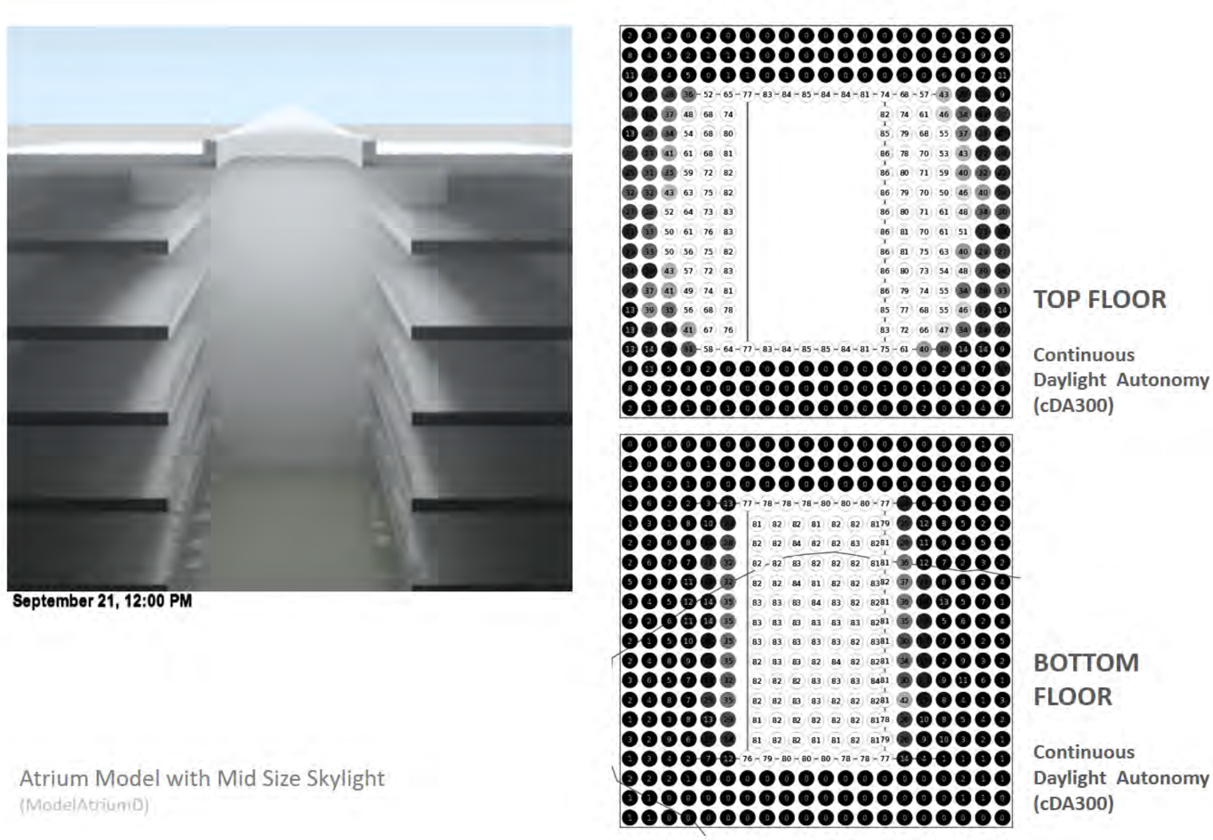


Figure 21: Skylight option (b): 20’ x 50’ Radiance simulation results

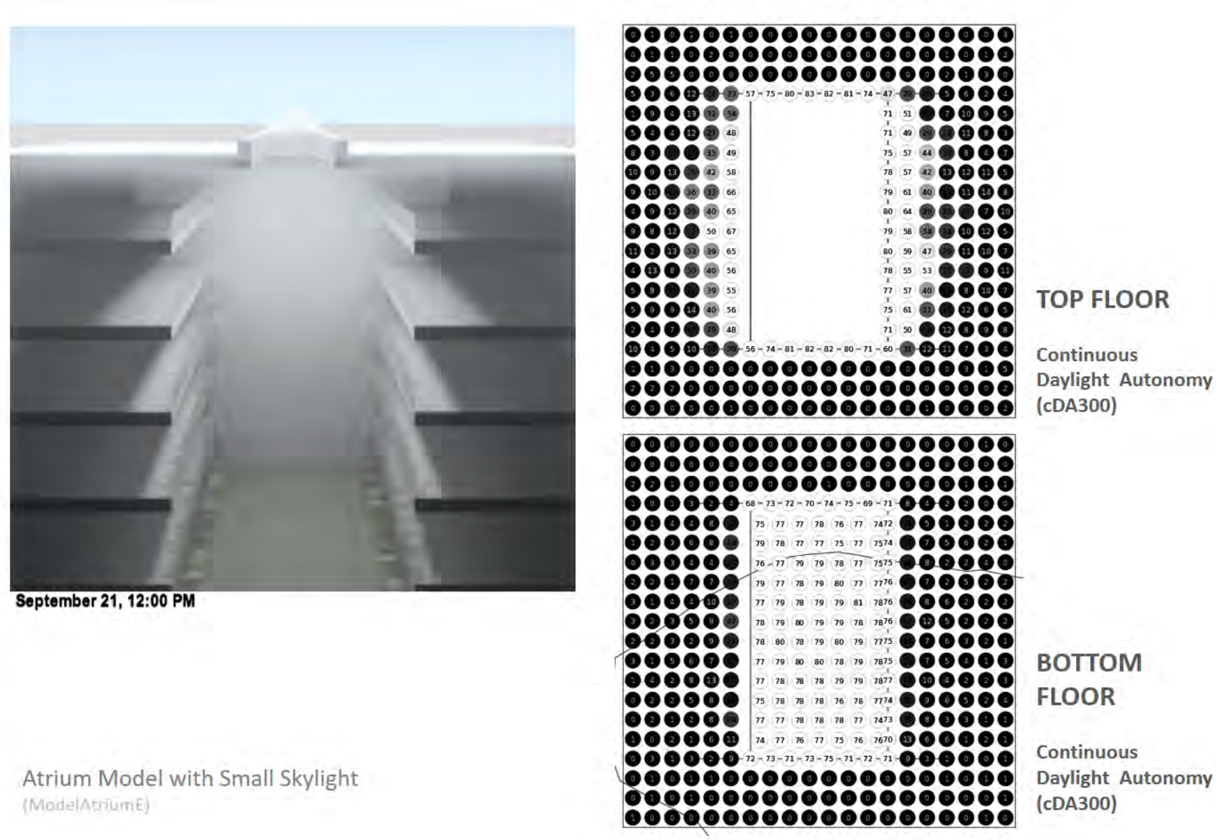


Figure 22: Skylight option (c): 10’ x 50’ Radiance simulation results

4.2.3.3 Atrium – Analysis and Conclusion

Analysis of Figure 20, Figure 21, and Figure 22 show the following:

1. In the option with the largest skylight (a), the top floor is the most well-daylit floor area (i.e., area with >50% energy savings),
2. In options (b) and (c), as the width of the skylight decreases, the well-daylit floor area (i.e., area with > 50% energy savings) on the top floor progressively becomes smaller.
3. In all cases, the well-daylit floor area (i.e., are with > 50% energy savings) progressively decreases towards the lower floors. The decrease in daylit floor area in lower floors is dependent on the geometry of the skylight and by extension, the geometry of the atrium and surface reflectance.
4. In all cases, the area below the skylight, on the bottom floor is always well-daylit (i.e., has >50% energy savings).

Per the analysis for cost-effectiveness of photocontrols (California Utilities Statewide Codes and Standards Team 2011), photocontrols were found to be cost-effective where annual lighting energy savings from daylighting were greater than 50 percent. Thus, the floor area with greater than 50 percent energy savings in the building model represents the area where photocontrols can be cost-effective.

To further understand these results, the Statewide CASE Team applied the Skylit Daylit Zone definition to the three cases, as shown in Figure 23. The definition is interpreted as creating a Skylit Daylit Zone on the floor where the line representing 0.7 x CH for a floor is unobstructed.

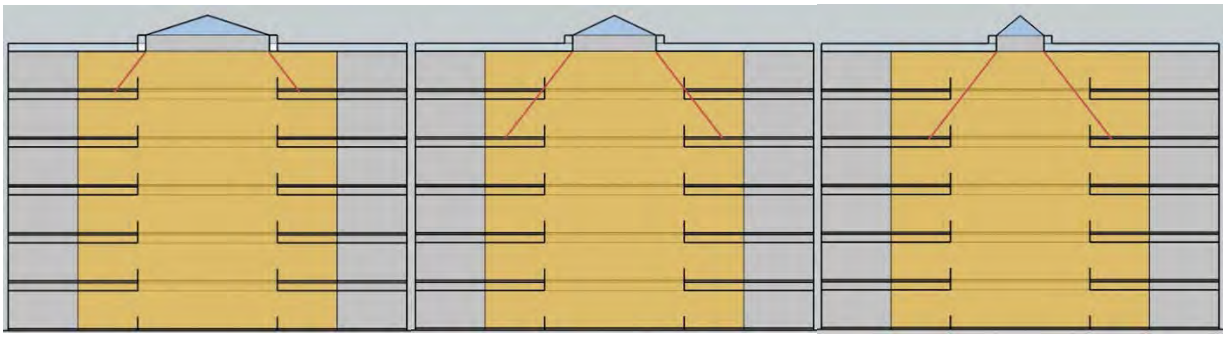


Figure 23: Skylit daylit zone analysis for atrium cases (a), (b), and (c)

Figure 23 shows that in case (a), the Skylit Daylit Zone is on the top floor, where as in cases (b) and (c), the Skylit Daylit Zone is on the floor below the top floor. This interpretation of the Skylit Daylit Zone definition roughly matches the results from Radiance simulations for the three cases. Daylight on the top floor was least influenced by the geometry of the space and reflectance of surfaces.

Based on the observation of areas where energy savings is greater than 50%, the Statewide CASE Team concluded that the daylit zone on the floor area directly below the skylight could be interpreted using the existing skylit daylit zone definition. Since the area directly below the skylight (on the bottom floor) is consistently and reliably daylit, it can also be considered part of the skylit daylit zone. The floors below the top floor, may or may not have sufficient daylight depending on many factors, such as atrium geometry and reflectance of various surfaces.

Based on these conclusions, the Statewide CASE Team has proposed code language to interpret skylight daylit zones in Atrium spaces that conservatively include only the top floor and the area directly below the skylight. See Section 7 for exact code language proposed under Section 130.1(d)1A.

Figure 24 through Figure 26 show three cases where the proposed code language is interpreted for a symmetrical atrium, asymmetrical atrium, and a case with small skylights.

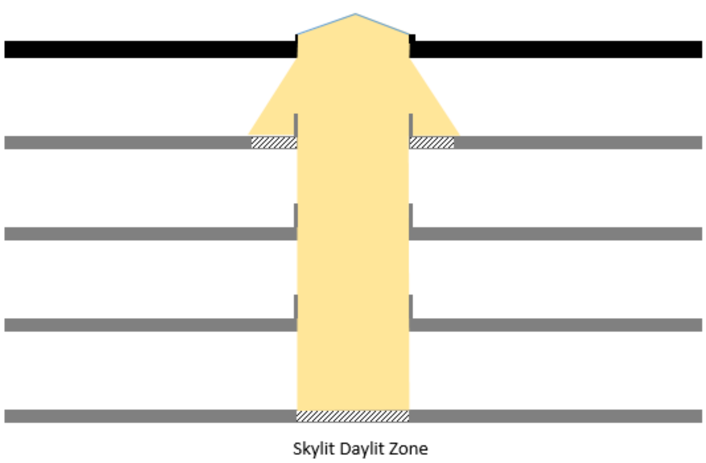


Figure 24: Skylit daylit zone interpretation – case 1 symmetrical atrium

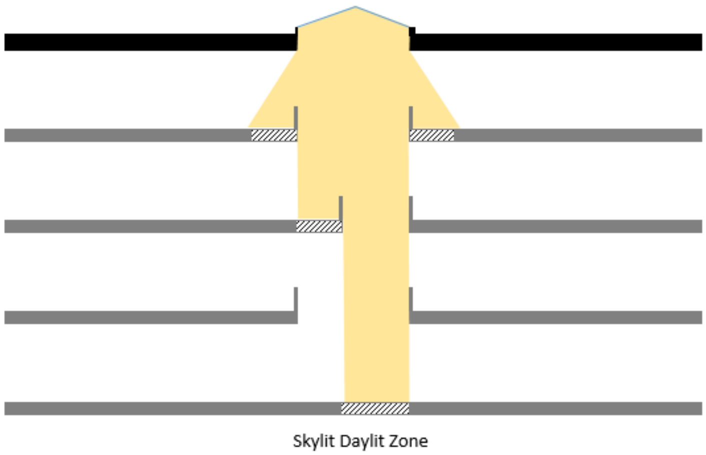


Figure 25: Skylit daylit zone interpretation – case 2 asymmetrical atrium

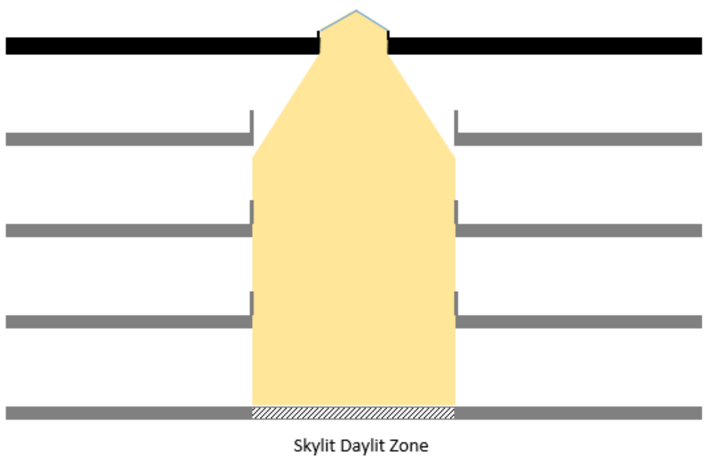


Figure 26: Skylit daylit zone interpretation – case 3 small skylight

4.2.3.4 Sidelit Daylit Zones Definitions – Large Overhangs

A Radiance model of a simple room with a window was used for the analysis of large overhangs. An overhang with incrementally changing dimensions was applied to the model room to develop multiple study cases. Table 12 provides the various building model assumptions, and Figure 27 shows a view of the building model.

Table 12: Assumptions for the Building Model

Floor to ceiling height	12’
Window Head Height	10’
Window Sill Height	3’
Room dimensions	40’ x 40’
Window dimensions	20’ x 7’ (located on center of wall)
Overhang dimensions	(20’ – 40’) x (2’ – 20’)
Overhang offset	(0’ – 6’)
Window properties	45% VLT Roller shades (3% openness) Operated hourly using sDA trigger (IES LM-83)
Window Orientation	South East (same as West) North
Floor, wall, ceiling reflectance	25%, 50%, 75%
Ground Reflectance	10%
Location	Sacramento, CA

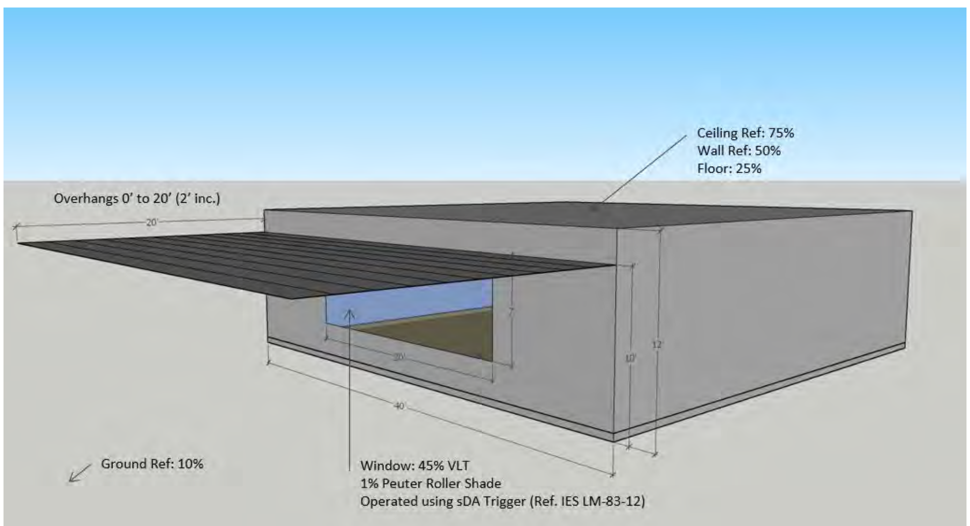


Figure 27: Large overhangs – Radiance model

Description of Terms

Various terms related to overhangs that are used in this section are defined here. Figure 28 provides a visual representation of these terms on the building model.

- Overhang Projection: 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.
- Overhang Rise: the vertical distance between the bottom of the front edge of an overhang and the sill of the vertical fenestration onto which it is mounted.
- Overhang Offset: the vertical distance from the edge of exposed exterior glazing at the head of a window to the overhang.
- Overhang Height: the vertical distance from the floor to the bottom of the front edge of an overhang.

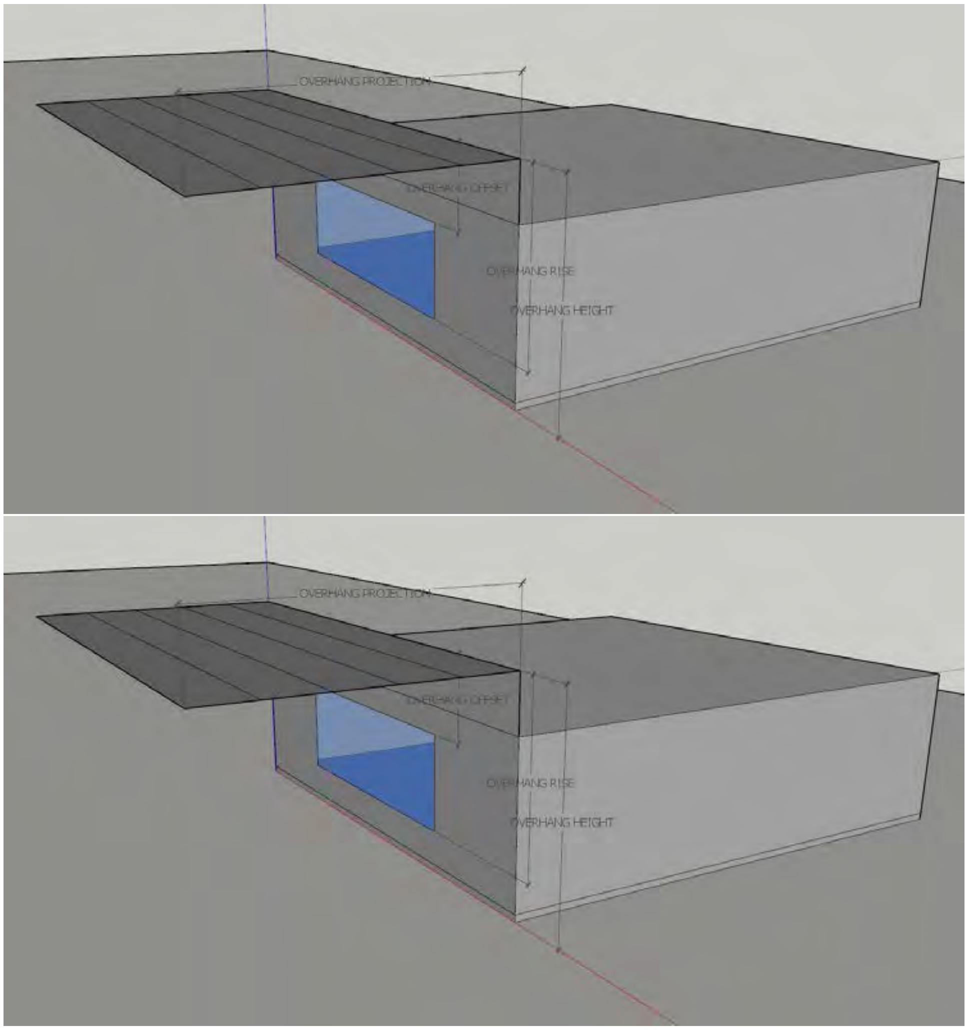


Figure 28: Overhang terms

4.2.3.5 Large Overhangs – Radiance Simulation Runs

Annual Radiance simulations runs were conducted for various overhang dimensions and offsets in three analysis sets.

- Analysis Set 1: Overhang Projection length was incrementally increased from 0 ft. to 20 ft. (in 2 ft. increments) with the Overhang Offset at 0 ft. These runs were conducted for three orientations (South, North, and East). The study cases considered are shown in Figure 29.
- Analysis Set 2: Overhang Projection length was incrementally increased from 0 ft. to 20 ft. (in 4 ft. increments) with the Overhang Offset at 2 ft., 4 ft., and 6ft. above the window. These runs were conducted for South orientation only. The study cases considered are shown in Figure 30.
- Analysis Set 3: Overhang Projection length was incrementally increased from 0 ft. to 20 ft. (in 4 ft. increments) with the Overhang Offset at 0 ft., and the lateral dimension of the overhang incrementally decreased from 40 ft. to 30 ft. to 20 ft. These runs were conducted for three orientations (South, North, and East). The study cases considered are shown in Figure 31.

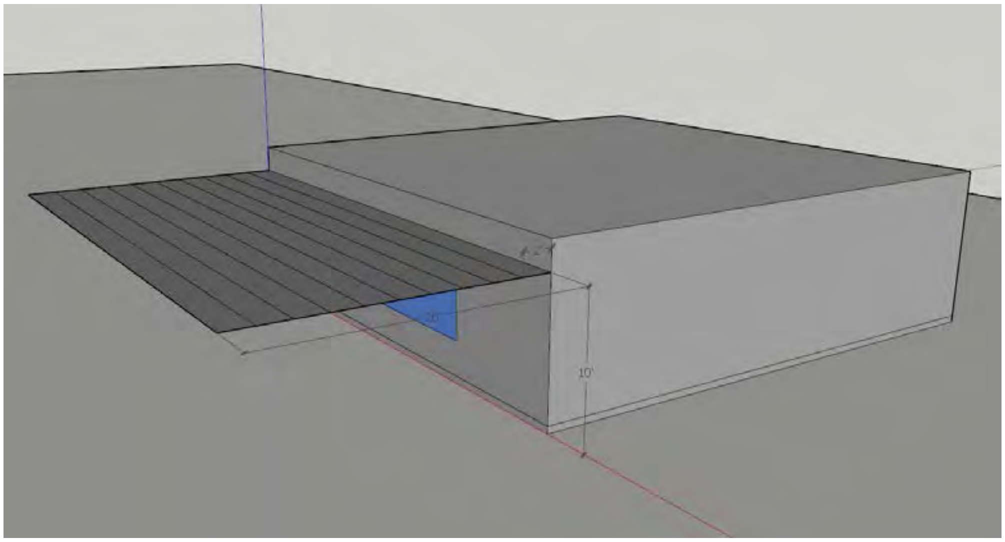


Figure 29: Analysis Set 1 Study Cases – incrementally changing Overhang Projection

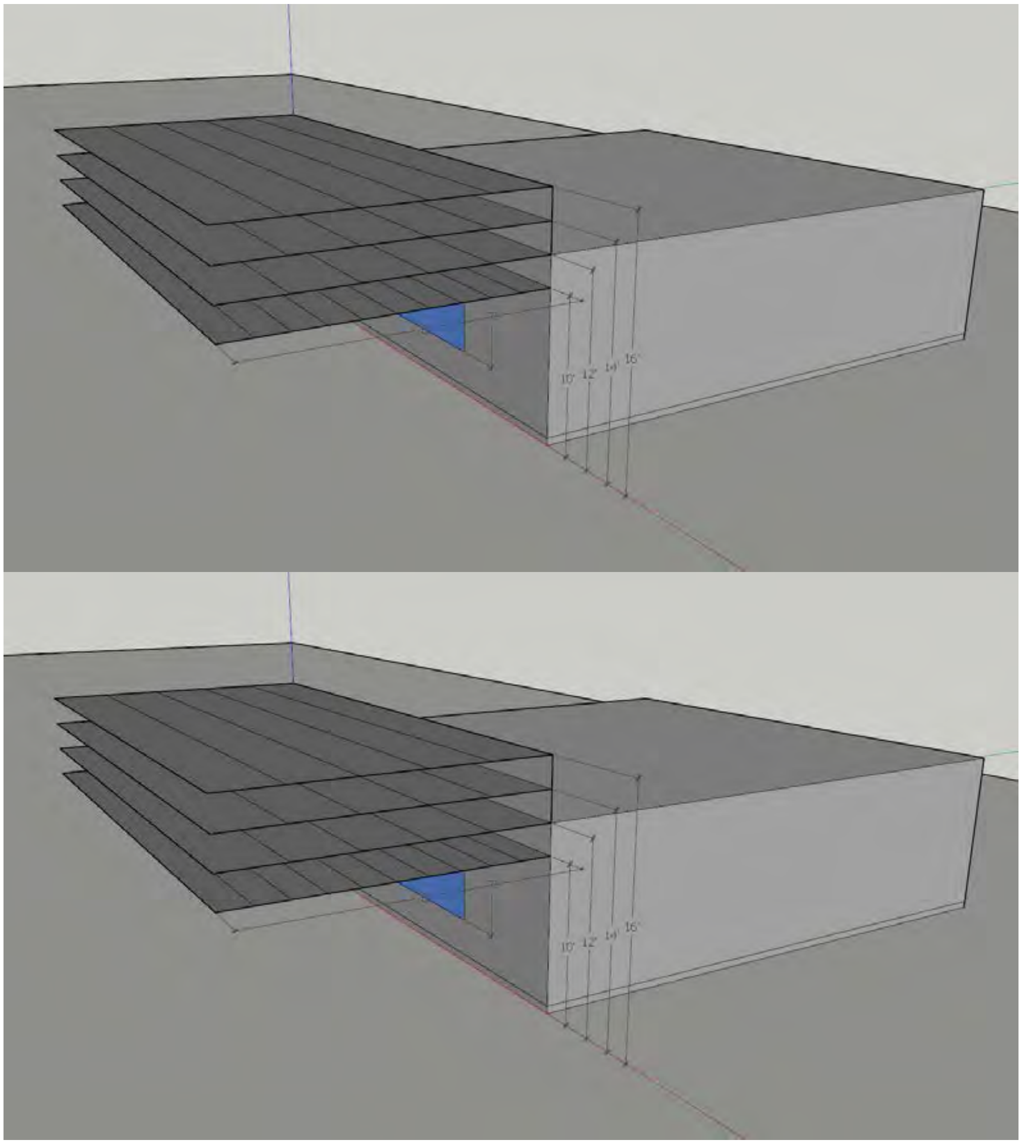


Figure 30: Analysis Set 2 Study Cases – incrementally changing overhang offsets

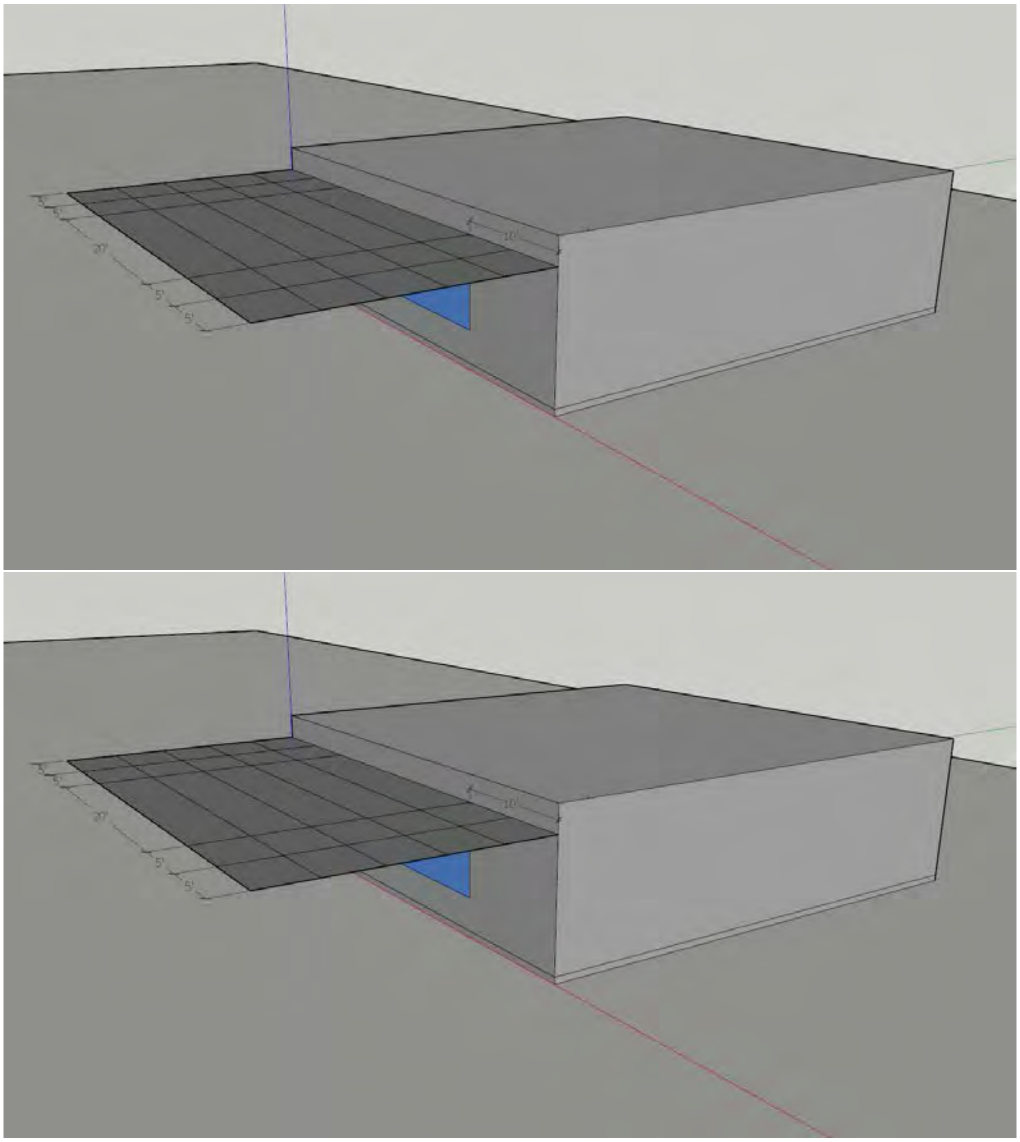


Figure 31: Analysis Set 3 Study Cases – incrementally changing overhang lateral dimensions

Annual simulation results from a sensor in the back of the primary and secondary daylit zones were converted to lighting energy savings from a dimming lighting control system plus OFF. Figure 32 shows lighting energy savings calculated as continuous daylight autonomy (cDA300) over the sensor grid inside the room – with 0 ft. Overhang Projection. The dashed lines represent primary and secondary daylit zones, and the sensors that are circled represent the sensors used to determine energy savings for each daylit zone.

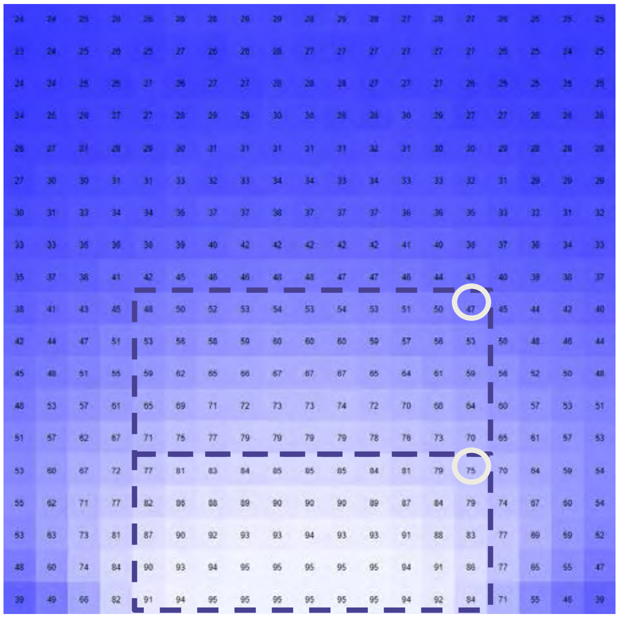


Figure 32: cDA300 plot for 0 ft. Overhang Projection

4.2.3.6 Large Overhangs – Analysis and Conclusions

Lighting energy savings from primary and secondary daylit zones were calculated for a dimming lighting control system plus OFF and combined for each study case. Savings are calculated against a base case where lighting remains on between 8:00 am and 5:00 pm. Per the analysis of cost-effectiveness of photocontrols (California Utilities Statewide Codes and Standards Team 2011), photocontrols were found to be cost-effective where annual lighting energy savings from daylighting were greater than 50 percent. Thus, area below 50 percent savings on the graph is shaded grey to represent the point below which photocontrols are no longer cost-effective.

In the graphs that follow, each point represents a single study case.

Analysis Set 1

Lighting energy savings from primary plus secondary daylight zones for each study case in Analysis Set 1 are show in Figure 33. Area below 50 percent savings on the graph is shaded grey to represent the point below which photocontrols are no longer cost-effective.

Since roller shades (called blinds hereon) are operated to close for all hours where more than two percent of the sensors in the room are in direct sunlight, also known as sDA Trigger per IES LM-83-12, the South orientation window first shows a characteristic increase in energy savings as Overhang Projection increases – and then decrease. East and North orientation show reduced savings as Overhang Projection increases.

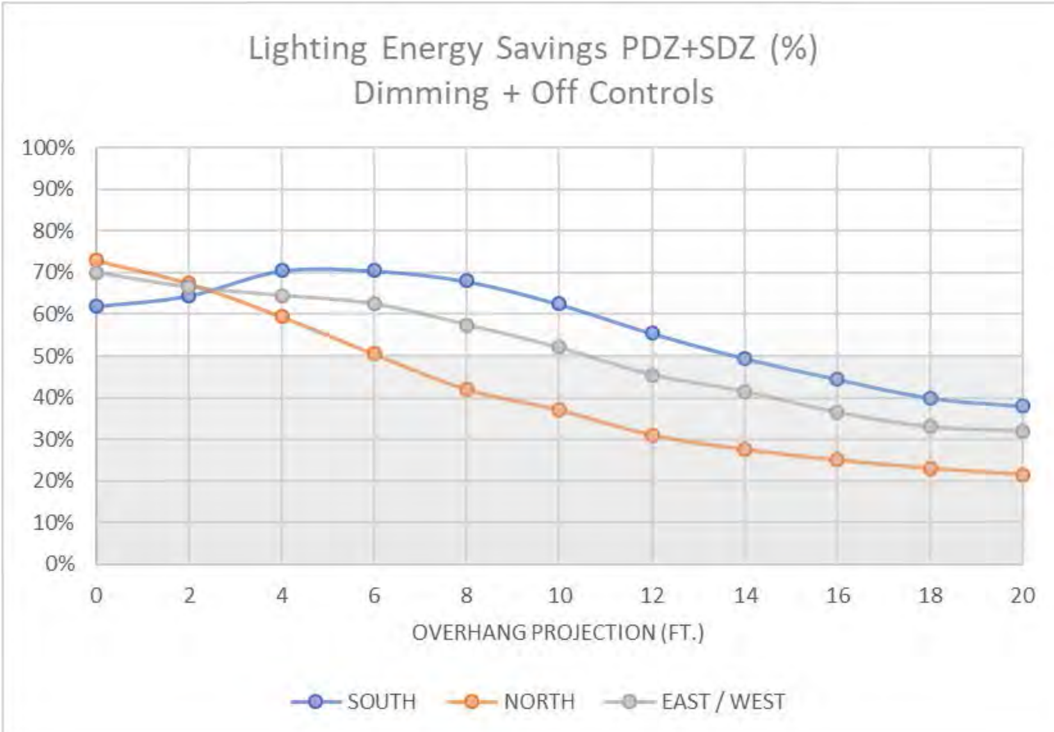


Figure 33: Analysis Set 1 - lighting energy savings plotted against Overhang Projection

In Figure 34, the same energy savings data is plotted against Overhang Projection Factor on the X-Axis:

$$Overhang\ Projection\ Factor = \frac{Overhang\ Projection}{Overhang\ Rise}$$

Here:

- 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.
- Overhang Rise – is the vertical distance between the bottom of the front edge of an overhang and the sill of the vertical fenestration onto which it is mounted.

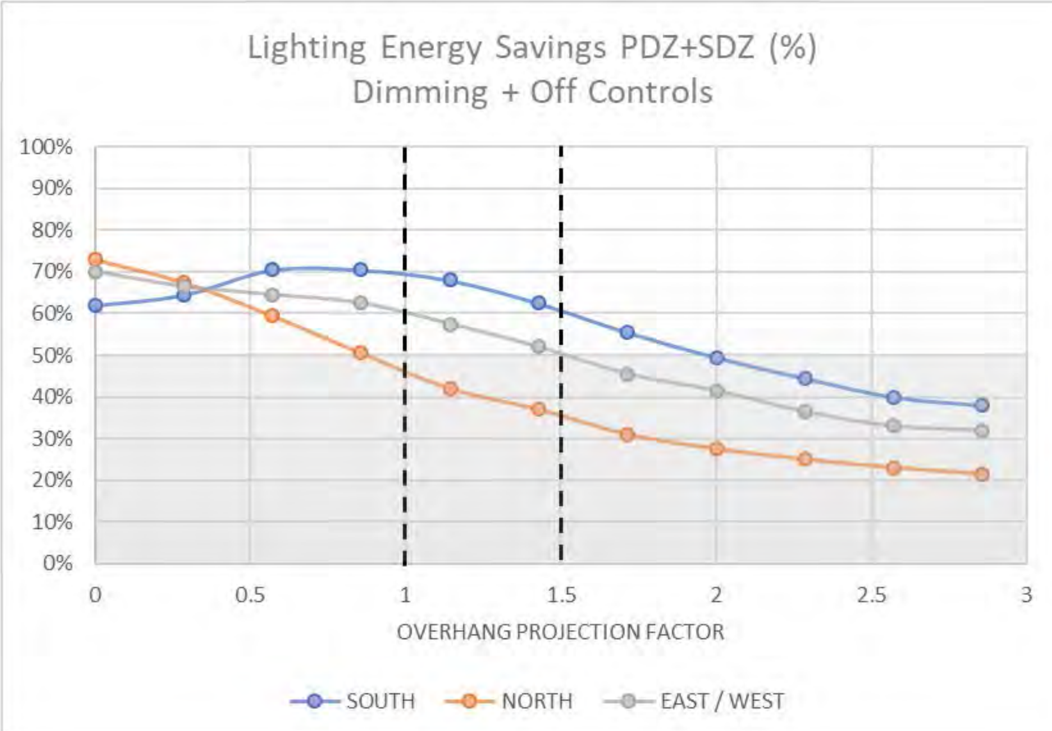


Figure 34: Analysis Set 1 - lighting energy savings plotted against Overhang Projection Factor

In Figure 34, South and East/West orientation go below 50% savings after Overhang Projection Factor of 1.5, while for North orientation, that point is reached around the Overhang Projection Factor of 1. Based on this, the code proposal exempting photocontrols has been developed where overhangs with Overhang Projection Factors greater than 1 for North orientation windows and greater than 1.5 for all other orientation windows are exempted from requiring photocontrols. See Section 7 for exact code language proposed under Section 130.1(d)1B and 130.1(d)1C.

Analysis Set 2

Lighting energy savings from primary plus secondary daylight zones for each study case in Analysis Set 2 are show in Figure 35 plotted against Overhang Projection. Area below 50 percent savings on the graph is shaded grey to represent the point below which photocontrols are no longer cost-effective.

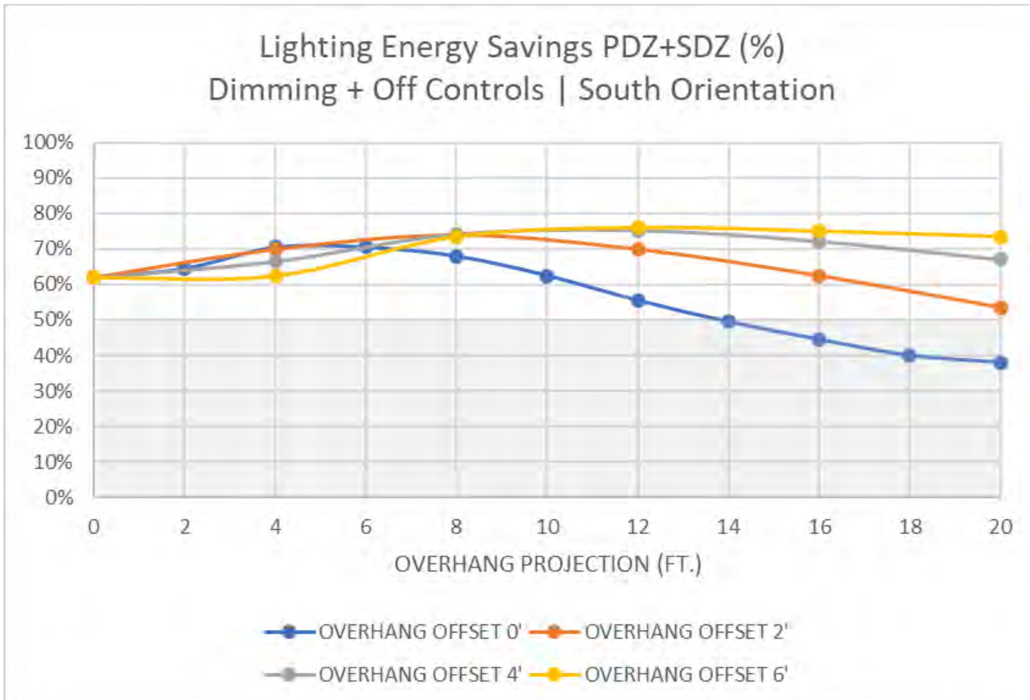


Figure 35: Analysis Set 2 - lighting energy savings plotted against Overhang Projection

Figure 35 shows that as Overhang Offset increases from 0 ft. to 6 ft., the characteristic curve for a south orientation window moves towards the right to higher Overhang Projection lengths.

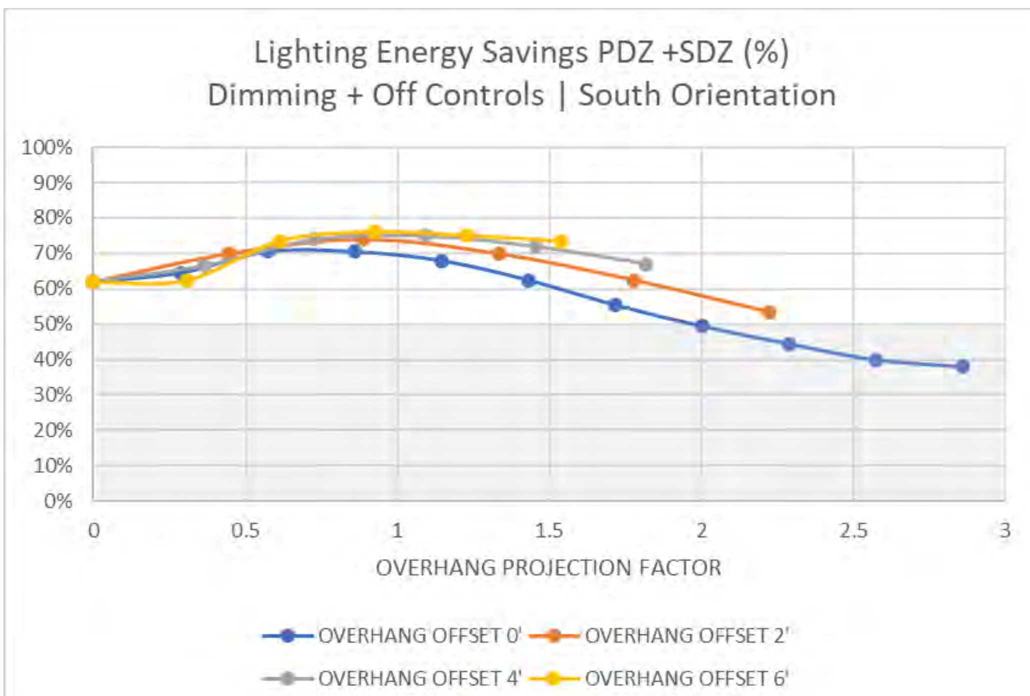


Figure 36: Analysis Set 2 - lighting energy savings plotted against Overhang Projection Factor

In Figure 36, the same energy savings data is plotted against Overhang Projection Factor on the X-Axis. Here, the characteristic curve moves to the left to coincide with the curve over the 0 ft. Overhang Offset case. This shows that Overhang Projection Factor appropriately accounts for Overhang Offsets, and is thus used in the proposed code language for the overhang exception. (See Section 7 for exact code language proposed under Section 130.1(d)1B and 130.1(d)1C)

Analysis Set 3

Lighting energy savings from primary plus secondary daylight zones for each study case in Analysis Set 2 are show in Figure 37, Figure 38, and Figure 39 plotted against Overhang Projection Factor. Area below 50 percent savings on the graph is shaded grey to represent the point below which photocontrols are no longer cost-effective. The dotted line on each graph represents the Overhang Projection Factor for each orientation that was determined as the point beyond which photocontrols were no longer cost-effective from Analysis Set 1.

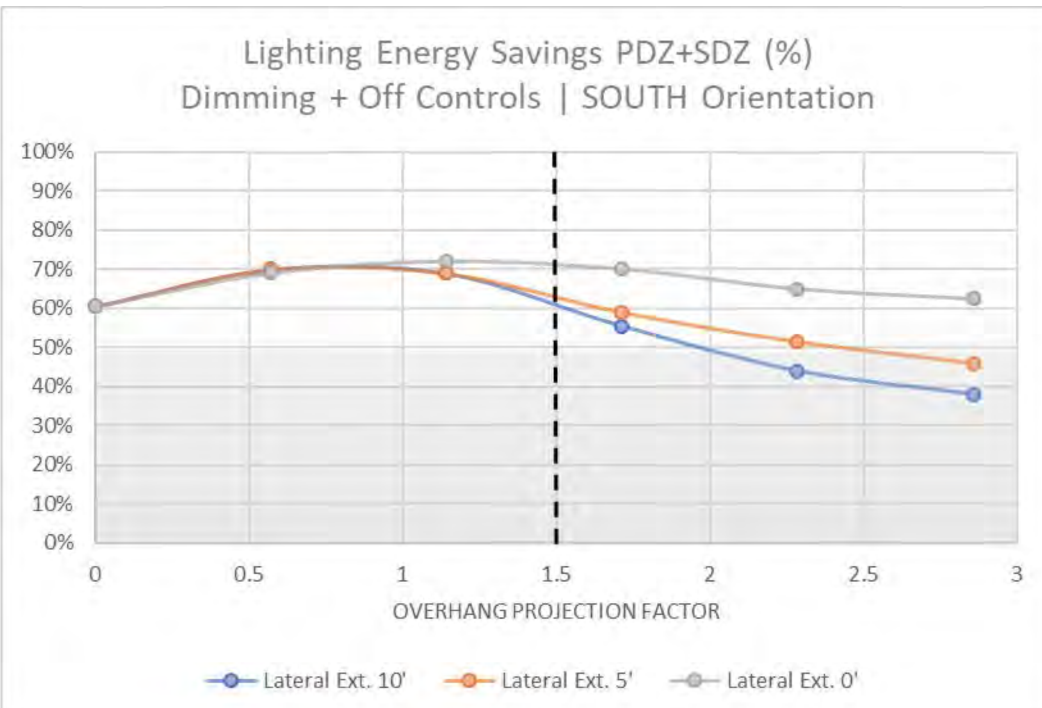


Figure 37: Analysis Set 3 – south window lighting energy savings

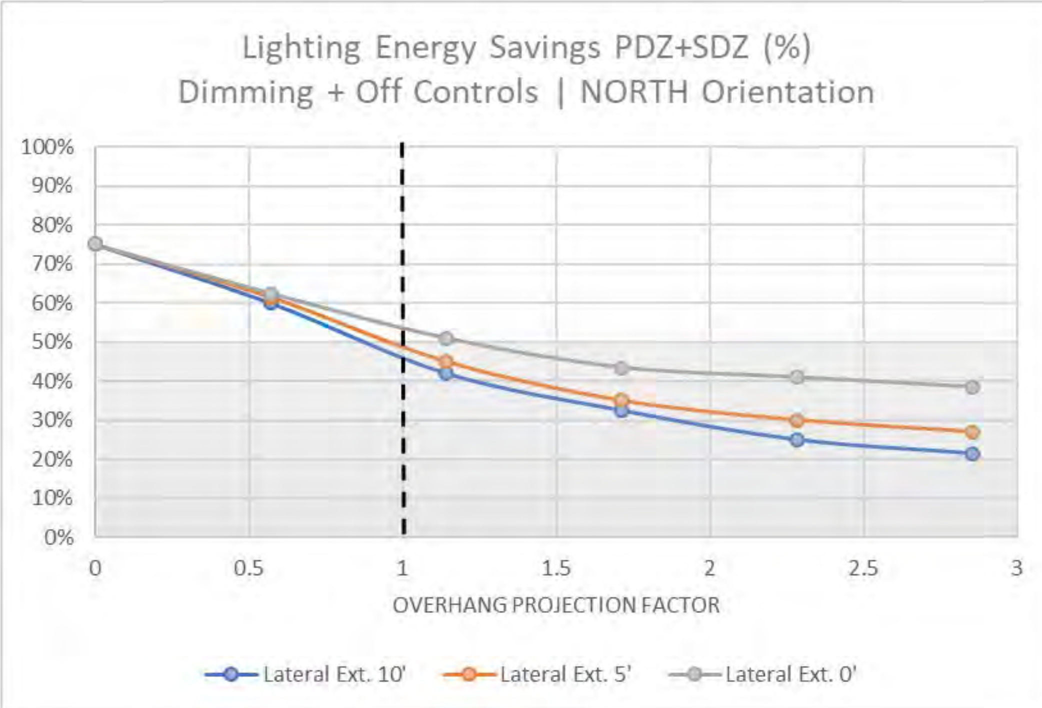


Figure 38: Analysis Set 3 – north window lighting energy savings

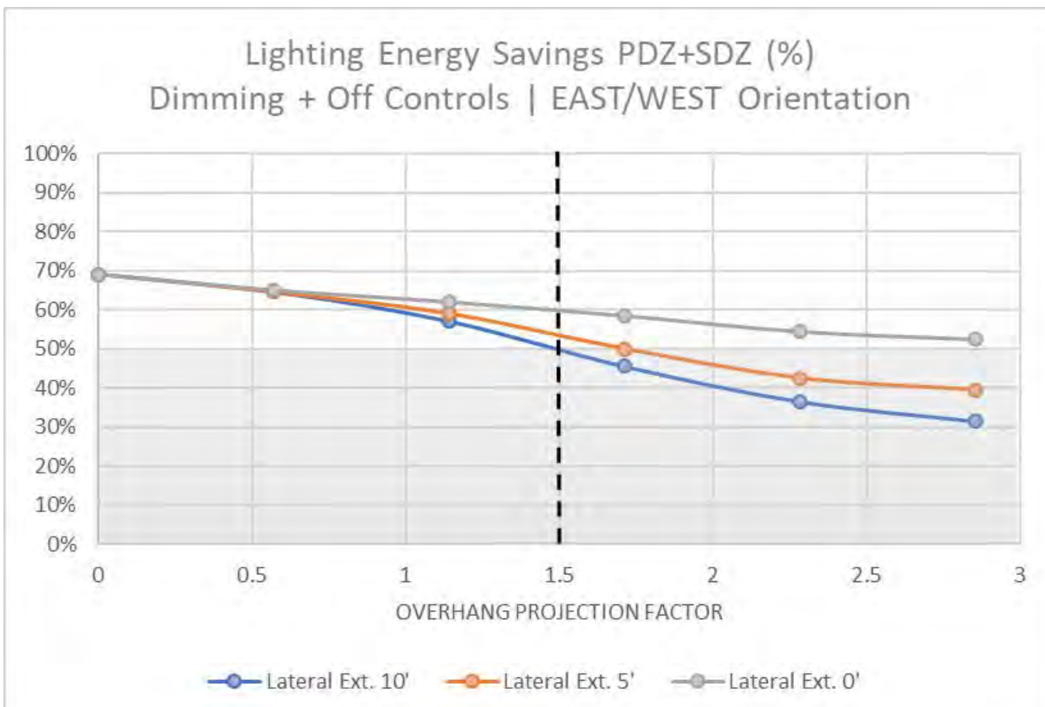


Figure 39: Analysis Set 3 – east/west window lighting energy savings

The analysis shows that for Overhang Projection Factors less than 1 for North orientation windows, and less than 1.5 for South, East/West orientation windows, the impact of changing the lateral dimension of the overhang has very little impact on the savings. It is typically when the Overhang Projection Factors are higher than 1.5 that the differences in savings are more discernable.

Based on this analysis, it was decided that the proposed code change language will not need to address the lateral dimension of the overhangs. (See Section 7 for exact code language proposed under Section 130.1(d)1B and 130.1(d)1C.

4.3 Per-Unit Energy Impacts Results

TDV energy savings per unit for new construction and alterations are presented below. As stated earlier, to create PAFs the analysis required examining all the varieties of installations where the PAF may be used. This is different from a statewide energy and cost savings analysis where a technology is modeled in specific prototypes deemed by the state to represent the majority of forecasted construction. With a prototype for each combination of three orientations, four WWRs, three technologies, three control types, and six setpoints, a very large number of prototypes were examined. As such, the prototype results are placed in a format that is conducive to presenting the essential results of the analysis.

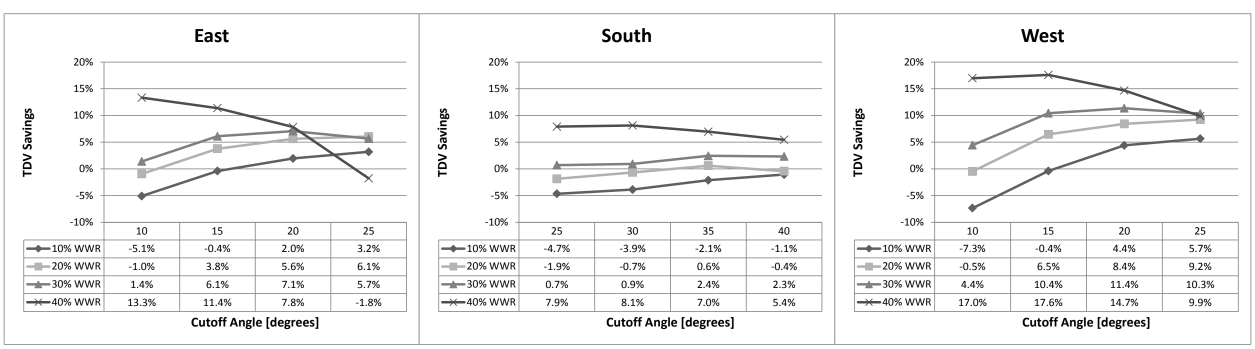
PAFs have traditionally not been given on a per climate zone basis. Therefore, the energy savings results have been weighted by forecasted construction per climate zone to give a statewide energy savings estimate.

The per-unit energy savings estimates do not take naturally occurring market adoption or compliance rates into account.

4.3.1 Fixed Slats

The TDV energy use for slats was compared to a window without slats on a percent difference basis. Results[7] characterizing the energy savings by cutoff angle are presented in Figure 40. These savings are for continuous dimming controlling the primary and secondary sidelit daylit zone at a setpoint of 300 lux and a 0.5 reflectance slat at a ten-degree slat angle.[8]

On the east and west a minimum 5 percent savings can be seen for WWRs between 20 and 30 percent at cutoff angles between 20 and 25 degrees. At higher WWRs on the east and west, glare affects savings. There is not much light redirection on the south, so there is not much benefit from slats. The west experiences direct beam sunlight during peak TDV periods, so it benefits greatly from slats.



East

Cutoff Angle [degrees]	10	15	20	25
10% WWR	-5.1%	-0.4%	2.0%	3.2%
20% WWR	-1.0%	3.8%	5.6%	6.1%
30% WWR	1.4%	6.1%	7.1%	5.7%
40% WWR	13.3%	11.4%	7.8%	-1.8%

South

Cutoff Angle [degrees]	25	30	35	40
10% WWR	-4.7%	-3.9%	-2.1%	-1.1%
20% WWR	-1.9%	-0.7%	0.6%	-0.4%
30% WWR	0.7%	0.9%	2.4%	2.3%
40% WWR	7.9%	8.1%	7.0%	5.4%

West

Cutoff Angle [degrees]	10	15	20	25
10% WWR	-7.3%	-0.4%	4.4%	5.7%
20% WWR	-0.5%	6.5%	8.4%	9.2%
30% WWR	4.4%	10.4%	11.4%	10.3%
40% WWR	17.0%	17.6%	14.7%	9.9%

Figure 40: Slat TDV energy savings by cutoff angle

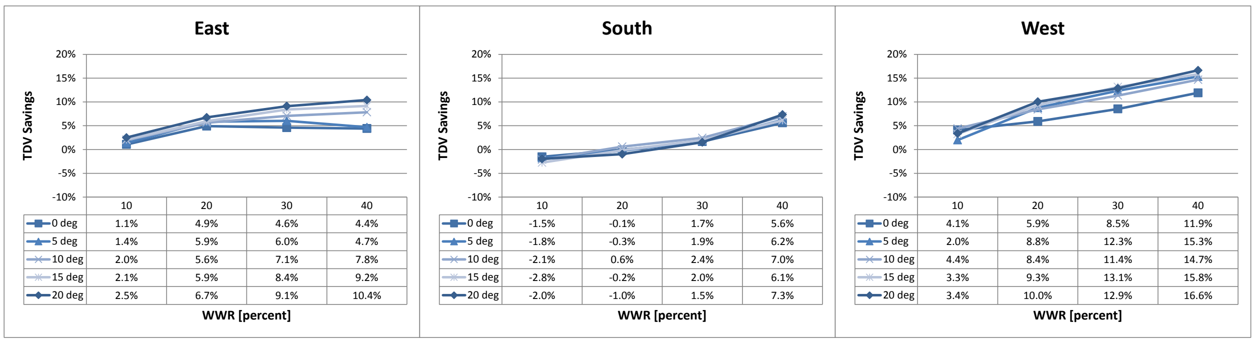
[7] Results are the average of the Good Case and Bad Case results per the discussion in 4.2.1.3.

[8] Recall from Figure 7 that any angle can meet a particular cutoff angle if the slat profile width and spacing are selected correctly.

Results characterizing the energy savings by WWR for various slat angles (not cutoff angles) are presented in Figure 41. These savings are for continuous dimming controlling the primary and secondary sidelit daylit zone at a setpoint of 300 lux and a 0.5 reflectance slat with cutoff angles for the east, south, and west of 20, 35, and 20 degrees, respectively. Savings increased with increased WWR as slats tended to mitigate the increase of glare with larger WWRs.

For a constant cutoff angle, as is the case in Figure 41, the number of hours that direct beam sunlight is blocked is the same regardless of the slat angle. This means that the change in savings seen across slat angles is due to the redirection of daylight into the space.

For the east and west, generally, the higher the slat angle, the higher the savings, implying that light redirection from higher slat angles increases savings. For the south, savings remained steady regardless of slat angle, implying that redirection is not significant at this orientation. This is due to the high angle of the sun in the south. This high angle makes light redirection for slats less effective.



East:

	10	20	30	40
0 deg	1.1%	4.9%	4.6%	4.4%
5 deg	1.4%	5.9%	6.0%	4.7%
10 deg	2.0%	5.6%	7.1%	7.8%
15 deg	2.1%	5.9%	8.4%	9.2%
20 deg	2.5%	6.7%	9.1%	10.4%

South:

	10	20	30	40
0 deg	-1.5%	-0.1%	1.7%	5.6%
5 deg	-1.8%	-0.3%	1.9%	6.2%
10 deg	-2.1%	0.6%	2.4%	7.0%
15 deg	-2.8%	-0.2%	2.0%	6.1%
20 deg	-2.0%	-1.0%	1.5%	7.3%

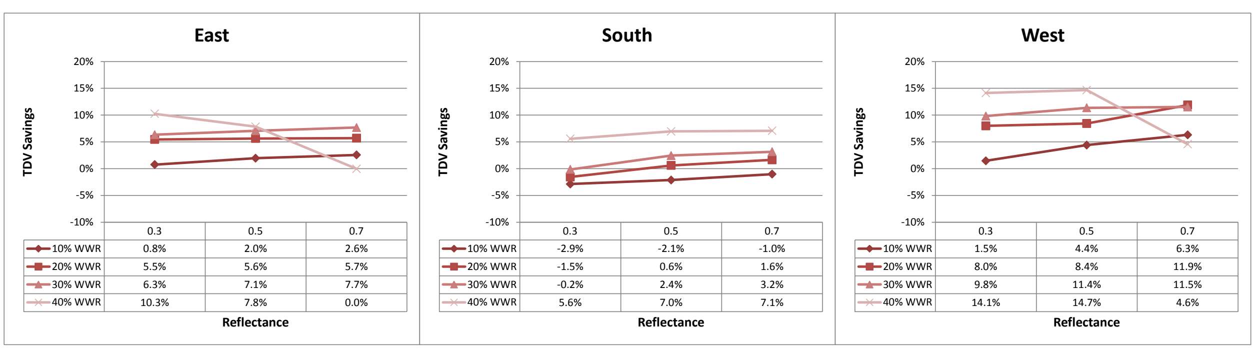
West:

	10	20	30	40
0 deg	4.1%	5.9%	8.5%	11.9%
5 deg	2.0%	8.8%	12.3%	15.3%
10 deg	4.4%	8.4%	11.4%	14.7%
15 deg	3.3%	9.3%	13.1%	15.8%
20 deg	3.4%	10.0%	12.9%	16.6%

Figure 41: Slat TDV energy savings by WWR and slat angle

Results characterizing the energy savings by slat visible reflectance are presented in Figure 42. These savings are for continuous dimming controlling the primary and secondary sidelit daylit zone at a setpoint of 300 lux with cutoff angles for the east, south, and west of 20, 35, and 20 degrees, respectively at slat angles of ten degrees.

Increasing reflectance led to increased savings as daylight is redirected more efficiently for higher visible reflectance. In general, the trend leveled off above 0.5 reflectance, except that at the upper limit of WWR 40 percent, and at the upper limit of reflectance 0.7, glare on the east and west caused a decrease in savings.



East:

	0.3	0.5	0.7
10% WWR	0.8%	2.0%	2.6%
20% WWR	5.5%	5.6%	5.7%
30% WWR	6.3%	7.1%	7.7%
40% WWR	10.3%	7.8%	0.0%

South:

	0.3	0.5	0.7
10% WWR	-2.9%	-2.1%	-1.0%
20% WWR	-1.5%	0.6%	1.6%
30% WWR	-0.2%	2.4%	3.2%
40% WWR	5.6%	7.0%	7.1%

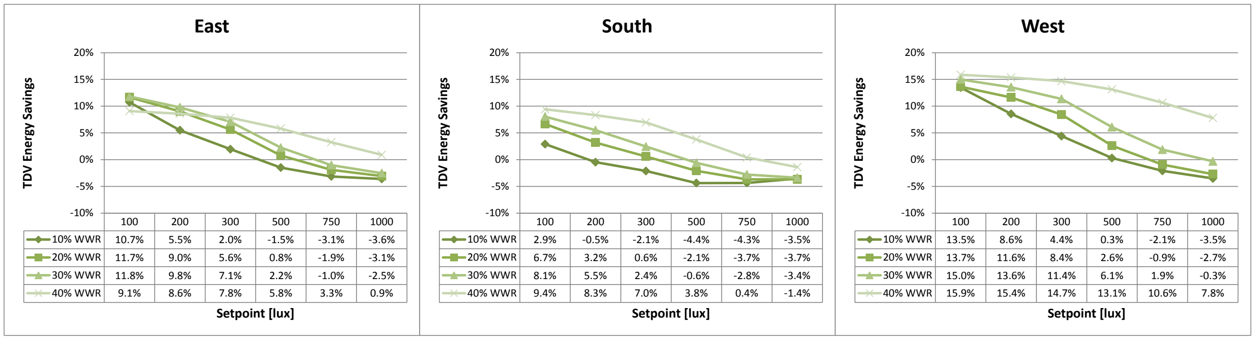
West:

	0.3	0.5	0.7
10% WWR	1.5%	4.4%	6.3%
20% WWR	8.0%	8.4%	11.9%
30% WWR	9.8%	11.4%	11.5%
40% WWR	14.1%	14.7%	4.6%

Figure 42: Slat TDV energy savings by slat visible reflectance

Results characterizing the energy savings by lighting control setpoint are presented in Figure 43. These savings are for continuous dimming controls in the primary sidelit daylit zone with a 0.5 reflectance slat with cutoff angles for the east, south, and west of 20, 35, and 20 degrees, respectively at slat angles of ten degrees.

The savings drop off with higher setpoints as expected.



East

Setpoint [lux]	100	200	300	500	750	1000
10% WWR	10.7%	5.5%	2.0%	-1.5%	-3.1%	-3.6%
20% WWR	11.7%	9.0%	5.6%	0.8%	-1.9%	-3.1%
30% WWR	11.8%	9.8%	7.1%	2.2%	-1.0%	-2.5%
40% WWR	9.1%	8.6%	7.8%	5.8%	3.3%	0.9%

South

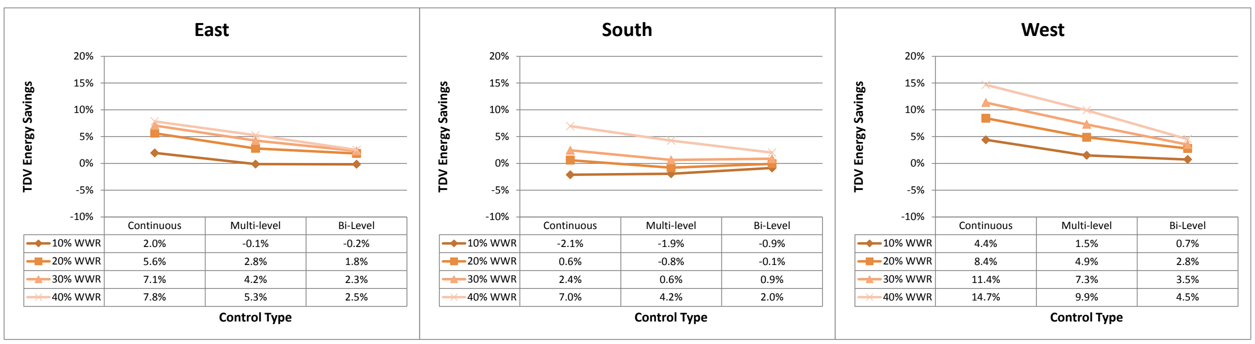
Setpoint [lux]	100	200	300	500	750	1000
10% WWR	2.9%	-0.5%	-2.1%	-4.4%	-4.3%	-3.5%
20% WWR	6.7%	3.2%	0.6%	-2.1%	-3.7%	-3.7%
30% WWR	8.1%	5.5%	2.4%	-0.6%	-2.8%	-3.4%
40% WWR	9.4%	8.3%	7.0%	3.8%	0.4%	-1.4%

West

Setpoint [lux]	100	200	300	500	750	1000
10% WWR	13.5%	8.6%	4.4%	0.3%	-2.1%	-3.5%
20% WWR	13.7%	11.6%	8.4%	2.6%	-0.9%	-2.7%
30% WWR	15.0%	13.6%	11.4%	6.1%	1.9%	-0.3%
40% WWR	15.9%	15.4%	14.7%	13.1%	10.6%	7.8%

Figure 43: Slat TDV energy savings by lighting control setpoint

Results characterizing the energy savings by lighting control type are presented in Figure 44. These savings are for controlling the primary and secondary sidelit daylit zone at a setpoint of 300 lux with a 0.5 reflectance slat with cutoff angles for the east, south, and west of 20, 35, and 20 degrees, respectively at slat angles of ten degrees. Daylighting controls are the same for the base case and the slat case. Savings decrease with fewer control steps as expected.



East

Control Type	Continuous	Multi-level	Bi-Level
10% WWR	2.0%	-0.1%	-0.2%
20% WWR	5.6%	2.8%	1.8%
30% WWR	7.1%	4.2%	2.3%
40% WWR	7.8%	5.3%	2.5%

South

Control Type	Continuous	Multi-level	Bi-Level
10% WWR	-2.1%	-1.9%	-0.9%
20% WWR	0.6%	-0.8%	-0.1%
30% WWR	2.4%	0.6%	0.9%
40% WWR	7.0%	4.2%	2.0%

West

Control Type	Continuous	Multi-level	Bi-Level
10% WWR	4.4%	1.5%	0.7%
20% WWR	8.4%	4.9%	2.8%
30% WWR	11.4%	7.3%	3.5%
40% WWR	14.7%	9.9%	4.5%

Figure 44: Slat TDV energy savings by lighting control type

Results characterizing the energy savings by number of zones controlled are presented in Figure 45. These savings are for continuous dimming controls at a setpoint of 300 lux with a 0.5 reflectance slat with cutoff angles for the east, south, and west of 20, 35, and 20 degrees, respectively at slat angles of ten degrees.

Often with fixed slats, the secondary zone savings dropped from the base case. However, the net savings for primary with secondary was often significant. This feature is important to consider because any daylit areas which include both primary and secondary controls should not use this technology (or the PAF) if there are no energy savings for the “Primary & Secondary” case.

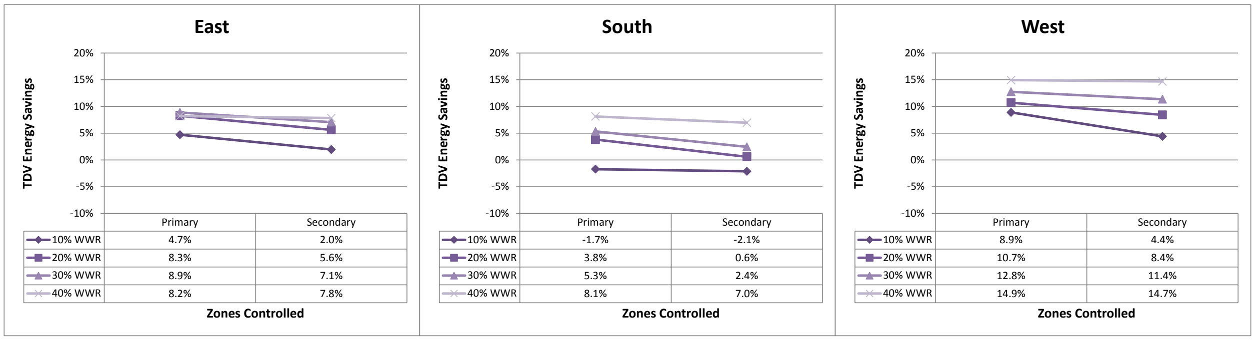


Figure 45: Slat TDV energy savings by zones controlled

4.3.2 Clerestories

The Statewide CASE Team compared TDV energy of clerestories to the view-window-only case presented in the assumption section in Figure 1 on a percent difference basis. Clerestory savings include the increase in area of the daylit zone corresponding to the increase in head height when installing a clerestory.

Specifically, the clerestory case's daylit zone increased in depth and width per the geometries in Figure 1 and Figure 2 and per the daylit zone definitions in Title 24, Part 6 section 130.1(d). This resulted in a net increase in daylit zone area for the clerestory case. For the view-window-only case, this increased area was modeled as not having daylight controls, thereby running at power levels per the schedule in Figure 4 without any reduction from daylighting.

Results characterizing the energy savings by WWR are presented in Figure 46. These savings are for continuous dimming controlling the primary and secondary sidelit daylit zone at a setpoint of 300 lux.

Lower WWRs had a larger benefit. At larger WWRs there was still significant benefit but since the non-clerestory case already had significant daylight, the benefit was lower. Savings on the south are slightly less compared to the east and west due to the higher solar elevations in the south.

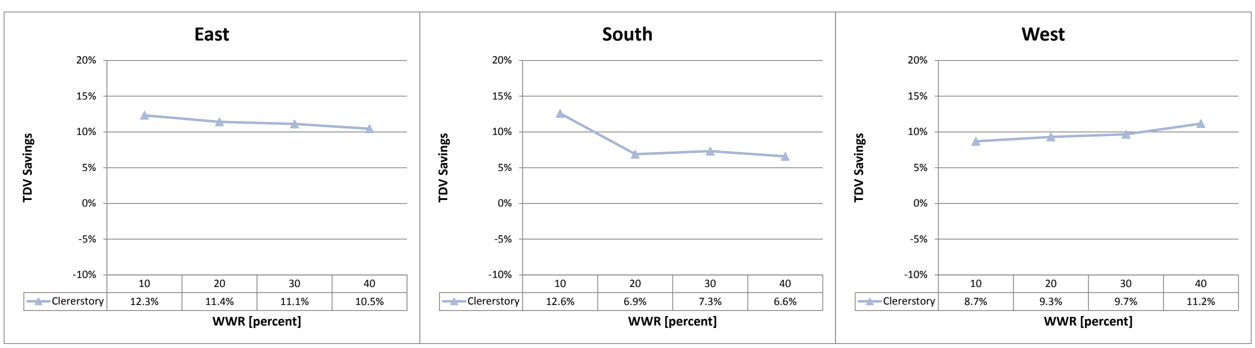
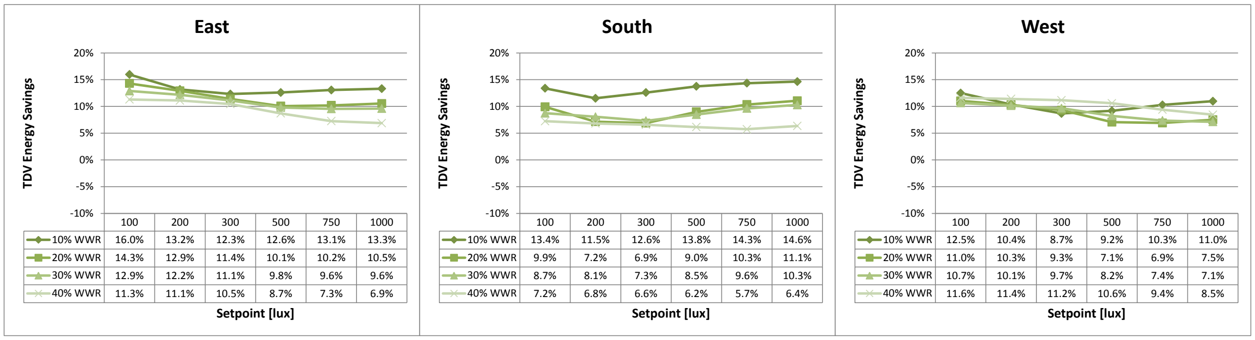


Figure 46: Clerestory TDV energy savings by WWR

Results characterizing the energy savings by lighting control setpoint are presented in Figure 47. These savings are for continuous dimming controlling the primary and secondary sidelit daylit zone.

An interesting trend in energy savings can be seen. For lower setpoints as setpoint increased the energy savings decrease as expected. However, for higher setpoints the view-window-only base case could not provide enough hours of adequate daylight at higher setpoints compared to the clerestory case. Clerestories can provide more hours of adequate daylight deeper in the space than can a view window.

Therefore, instead of decreasing, savings leveled off or even increased for higher setpoints for clerestories.



East	100	200	300	500	750	1000
10% WWR	16.0%	13.2%	12.3%	12.6%	13.1%	13.3%
20% WWR	14.3%	12.9%	11.4%	10.1%	10.2%	10.5%
30% WWR	12.9%	12.2%	11.1%	9.8%	9.6%	9.6%
40% WWR	11.3%	11.1%	10.5%	8.7%	7.3%	6.9%

South	100	200	300	500	750	1000
10% WWR	13.4%	11.5%	12.6%	13.8%	14.3%	14.6%
20% WWR	9.9%	7.2%	6.9%	9.0%	10.3%	11.1%
30% WWR	8.7%	8.1%	7.3%	8.5%	9.6%	10.3%
40% WWR	7.2%	6.8%	6.6%	6.2%	5.7%	6.4%

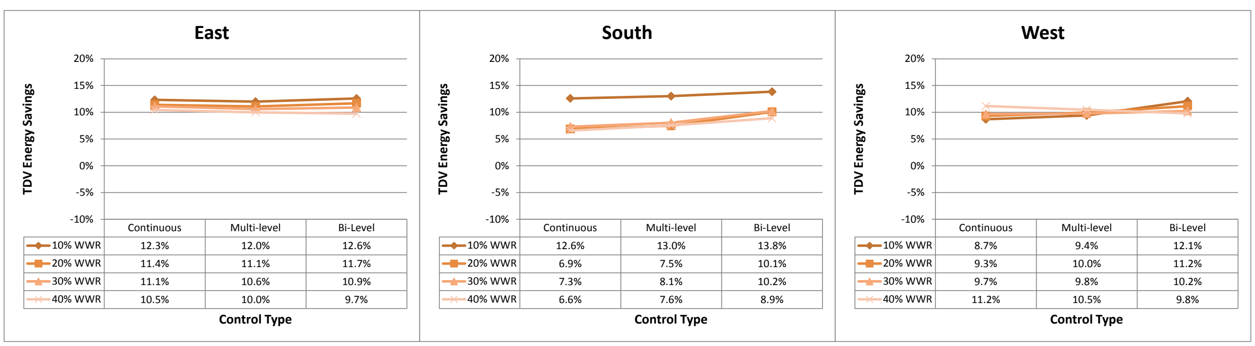
West	100	200	300	500	750	1000
10% WWR	12.5%	10.4%	8.7%	9.2%	10.3%	11.0%
20% WWR	11.0%	10.3%	9.3%	7.1%	6.9%	7.5%
30% WWR	10.7%	10.1%	9.7%	8.2%	7.4%	7.1%
40% WWR	11.6%	11.4%	11.2%	10.6%	9.4%	8.5%

Figure 47: Clerestory TDV energy savings by lighting control setpoint

Results characterizing the energy savings by lighting control type are presented in Figure 48 and Figure 49. These savings are for continuous dimming controlling the primary and secondary sidelit daylit zone at a setpoint of 300 lux.

Deciding which lighting controls to use in the base case is not straightforward. Figure 48 represents the clerestory energy savings for a base case with the same controls as the clerestory case. As can be seen, energy savings increase as controls decrease in granularity. This is because the clerestory case can meet the switching threshold for multi and bi-level controls in the secondary zone more often than the base case can. However, this apparently incentivizes less granular controls.

It makes more sense to compare the clerestory energy use to a base case of continuous dimming. Continuous dimming for the primary and secondary sidelit daylit zones is currently prescriptively required for most spaces in Title 24, Part 6. Results for this comparison are shown in Figure 49. For this comparison, energy savings decreased with decreasing granularity in controls. It is recommended that these energy savings results be used when comparing the impact of controls on clerestory savings.



East	Continuous	Multi-level	Bi-Level
10% WWR	12.3%	12.0%	12.6%
20% WWR	11.4%	11.1%	11.7%
30% WWR	11.1%	10.6%	10.9%
40% WWR	10.5%	10.0%	9.7%

South	Continuous	Multi-level	Bi-Level
10% WWR	12.6%	13.0%	13.8%
20% WWR	6.9%	7.5%	10.1%
30% WWR	7.3%	8.1%	10.2%
40% WWR	6.6%	7.6%	8.9%

West	Continuous	Multi-level	Bi-Level
10% WWR	8.7%	9.4%	12.1%
20% WWR	9.3%	10.0%	11.2%
30% WWR	9.7%	9.8%	10.2%
40% WWR	11.2%	10.5%	9.8%

Figure 48: Clerestory TDV energy savings by lighting control type, same controls in base case

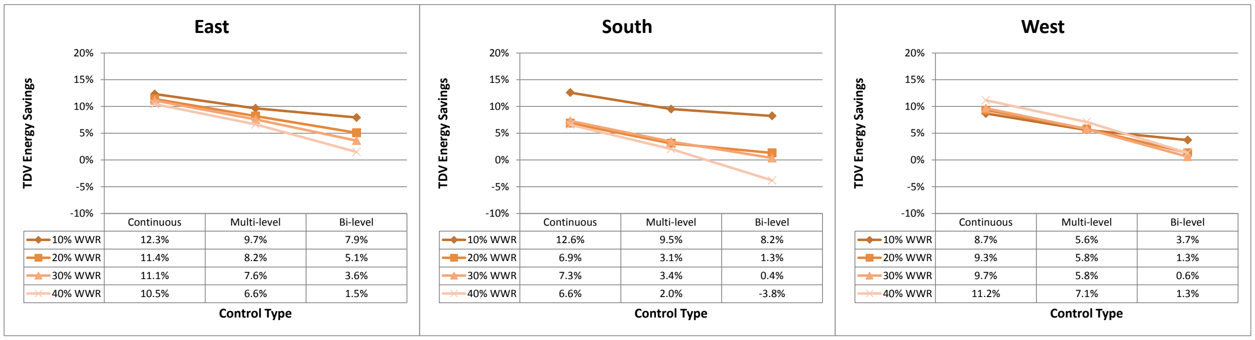


Figure 49: Clerestory TDV energy savings by lighting control type, base case of continuous dimming

Results characterizing the energy savings by the number of zones controlled are presented in Figure 50. These savings are for continuous dimming at a setpoint of 300 lux. High solar elevations on the south resulted in secondary zone savings on the south being less significant compared to east and west.

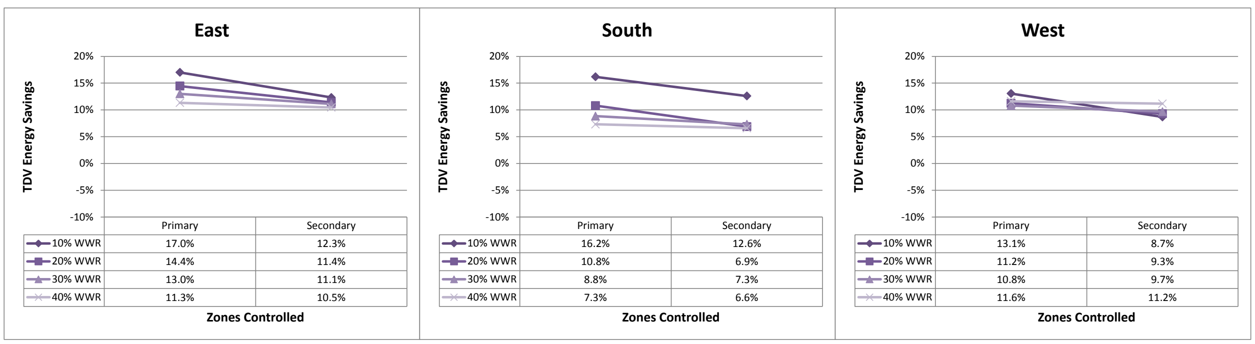


Figure 50: Clerestory TDV energy savings by zones controlled

4.3.3 Daylight Redirecting Devices

The TDV energy of DRDs was compared to the view-window-only case presented in Figure 1 on a percent difference basis. DRD savings also include the increase in area of the daylit zone corresponding to the increase in head height when installing a clerestory as was discussed in 4.3.2.

Results characterizing the energy savings by WWR are presented in Figure 51 and Figure 52. These savings are for continuous dimming controlling the primary and secondary sidelit daylit zone at a setpoint of 300 lux.

For lower WWRs, DRDs had a larger benefit. At larger WWRs there was still significant benefit but since the view-window-only case already had significant daylight, the benefit is lower. Savings on the south are slightly less compared to the east and west due to the higher solar elevations in the south. However, the south-facing orientation outperformed the clerestory case as the DRD countered the disadvantage of high solar elevations on the south, bringing daylight deeper into the space than a clerestory only.

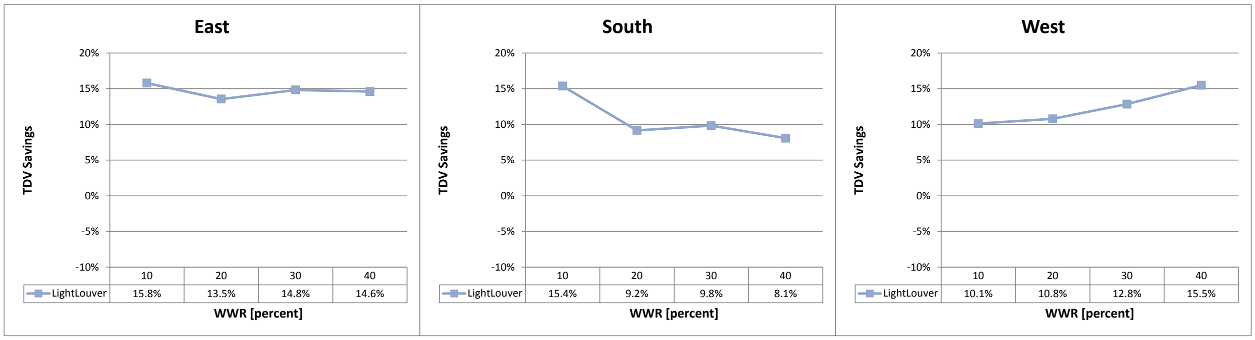


Figure 51: LightLouver TDV energy savings by WWR

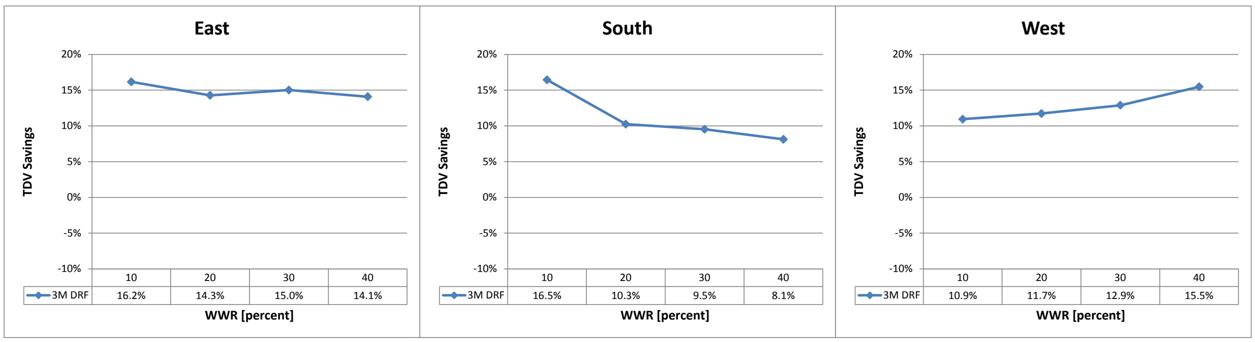


Figure 52: 3M DRF TDV energy savings by WWR

Results characterizing the energy savings by lighting control setpoint are presented in Figure 53 for LightLouver and Figure 54 for the 3M DRF. These savings are for continuous dimming controlling the primary and secondary sidelit daylit zone. The dip in energy savings with setpoint is similar to the clerestory case and is explained in Section 4.3.2.

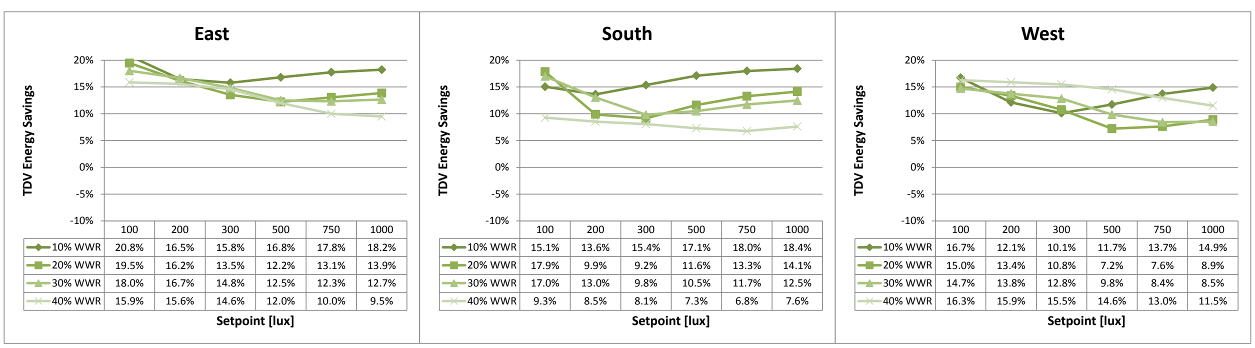


Figure 53: LightLouver TDV energy savings by lighting control setpoint

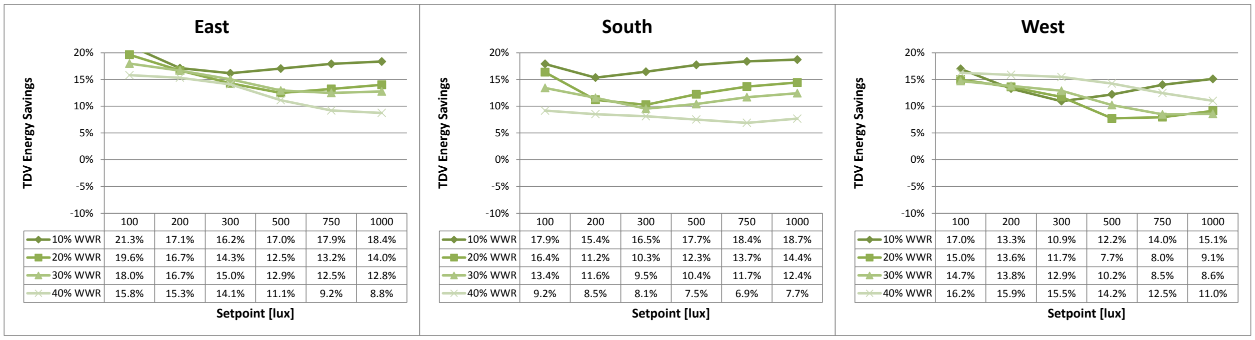


Figure 54: 3M DRF TDV energy savings by lighting control setpoint

Results characterizing the energy savings by lighting control type are presented in Figure 55 through Figure 58. These savings are for controlling the primary and secondary sidelit daylit zone at a setpoint of 300 lux.

As with the clerestory case, when comparing like controls between the base case and the DRD case, decreasing granularity resulted in increasing savings. As with clerestories, it is recommended that continuous dimming controls be considered the base case when analyzing the effect of controls on DRD daylighting energy savings. For more discussion see Section 4.3.2.

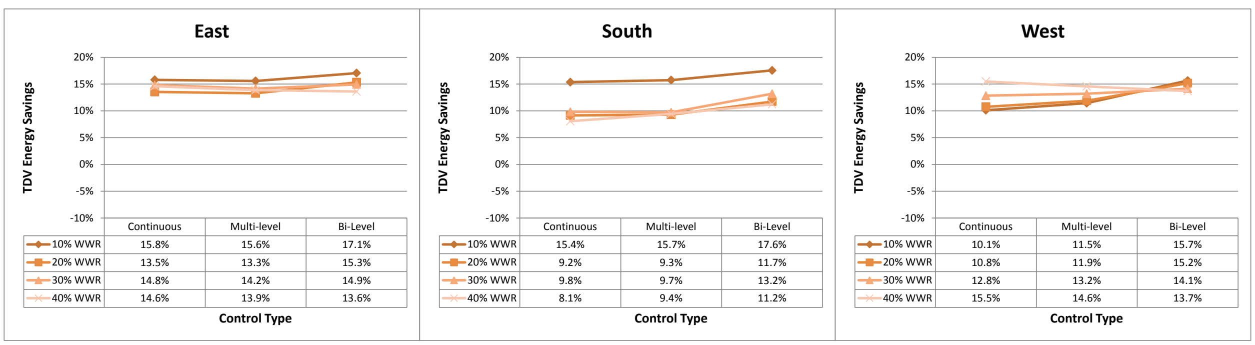


Figure 55: LightLouver TDV energy savings by lighting control type, same controls in base case

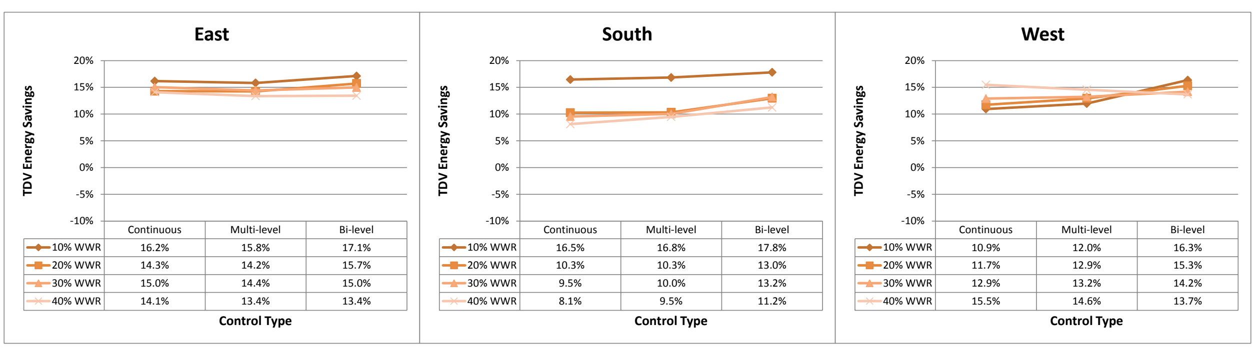


Figure 56: 3M DRF TDV energy savings by lighting control type, same controls in base case

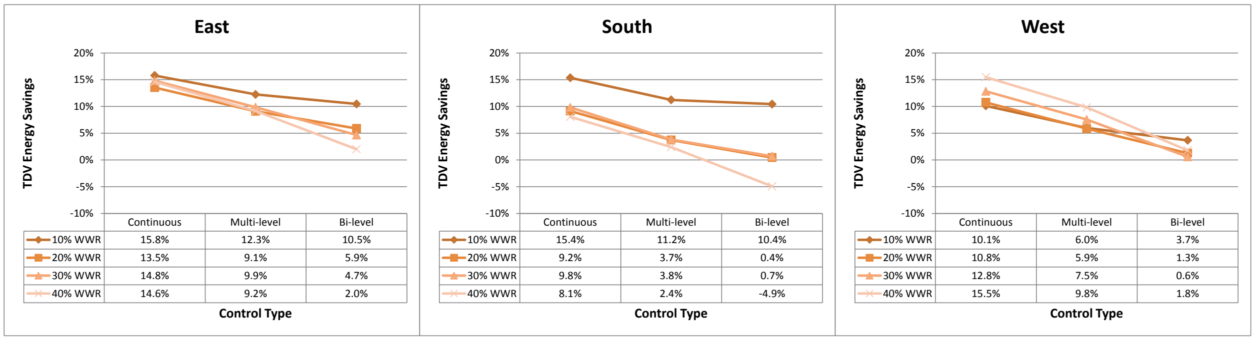


Figure 57: LightLouver TDV energy savings by lighting control type, continuous dimming base case

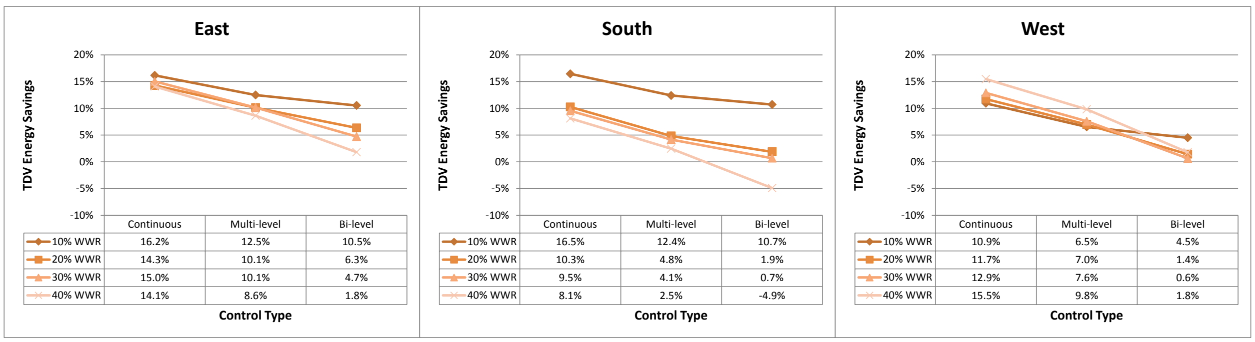


Figure 58: 3M DRF TDV energy savings by lighting control type, continuous dimming base case

Results characterizing the energy savings by number of zones controlled are presented in Figure 59 and Figure 60. These savings are for continuous dimming controls at a setpoint of 300 lux. As expected, savings decrease deeper in the space.

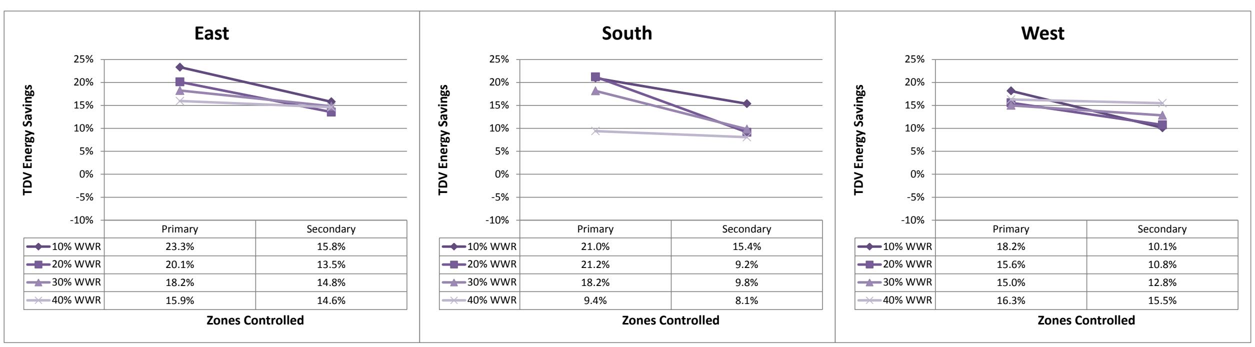


Figure 59: LightLouver TDV energy savings by zones controlled

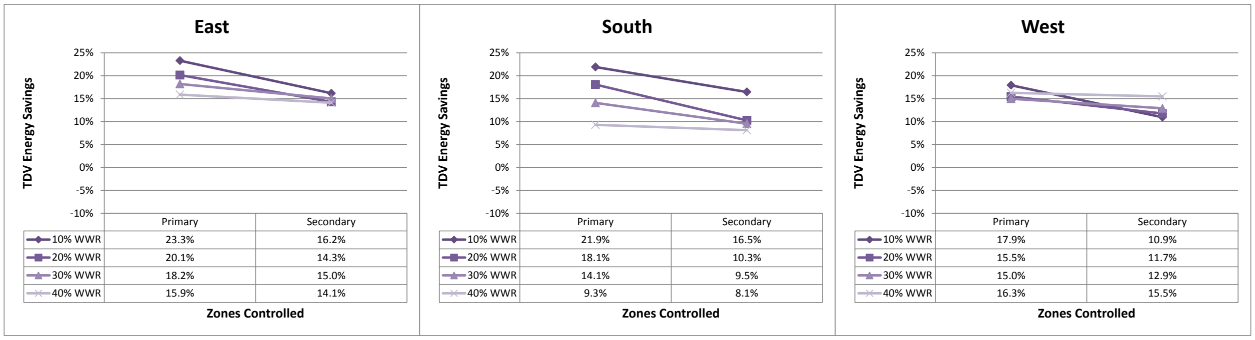


Figure 60: 3M DRF TDV energy savings by zones controlled

4.3.4 Light Shelves with Overhangs

Light Shelves are similar to DRDs; they are mounted on clerestories to block and redirect light, but are not as highly engineered as DRDs. For this study, the savings from light shelves were considered to be similar to a combination of the savings from fixed slats and clerestories, especially given that in most cases the light shelf with overhang, which extends from interior to exterior, would provide a longer redirecting surface than the equivalent fixed slats. This extended surface will extend the hours and amount of redirected direct beam sunlight.

Results characterizing the energy savings by WWR for various slat angles (not cutoff angles) are presented in Figure 61. These savings are a sum of the slat savings and clerestory savings for continuous dimming controls at a setpoint of 300 lux and a 0.5 reflectance slat with cutoff angles for the east, south, and west of 20, 35, and 20 degrees, respectively.

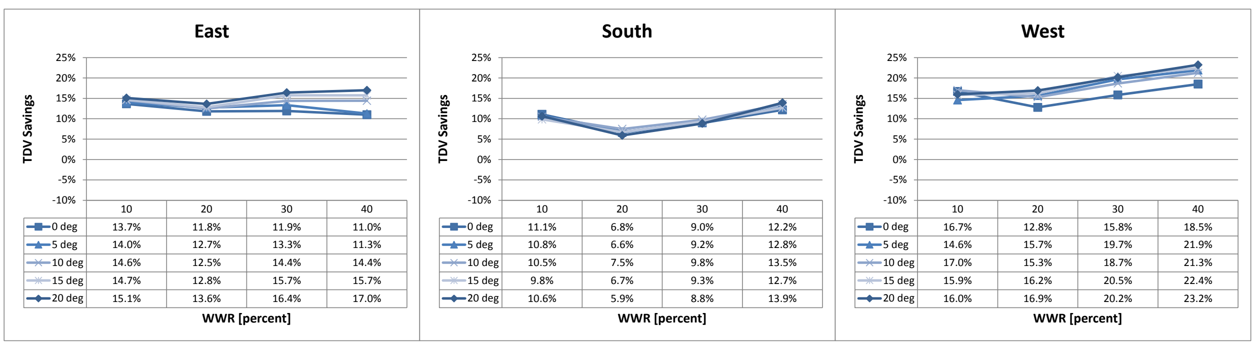


Figure 61: Light shelf with overhang TDV energy savings by WWR

5. LIFECYCLE COST AND COST-EFFECTIVENESS

5.1 Energy Cost Savings Methodology

TDV energy is a normalized format for comparing electricity and natural gas cost savings that takes into account the cost of electricity and natural gas consumed during each hour of the year. The TDV values are based on long term discounted costs (30 years for all residential measures and nonresidential envelope measures and 15 years for all other nonresidential measures).

5.1.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

PAFs are not requirements of Title 24, Part 6, but are options for projects to use to tradeoff one building feature for another with an equal or greater energy savings outcome. Therefore, no cost savings analysis is required to justify their inclusion in Title 24, Part 6.

PCOs use energy modeling to calculate the net TDV energy savings therefore no cost savings analysis is required to justify their inclusion in Title 24, Part 6.

5.1.2 Proposal B: Min VT Interpretation for TDDs

The proposed code change interprets the already established 'Min VT threshold for skylights' for TDDs. Since this interpretation does not change the already established threshold for Min VT, but adds an interpretation of it for TDDs, lifecycle cost and cost-effectiveness calculations are not required.

5.1.3 Proposal C: Update to Daylit Zones Definitions

The proposed code changes provide a clarification for users on the Daylit Zone definitions, for specific use cases of skylights in atriums and windows with large overhangs, which does not require lifecycle cost and cost-effectiveness calculations.

5.2 Energy Cost Savings Results

5.2.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

PAFs and PCOs are not requirements of Title 24, Part 6, so an energy cost savings analysis is not necessary.

5.2.2 Proposal B: Min VT Interpretation for TDDs

Since the proposal interprets the already established 'Min VT threshold for skylights' for TDDs, energy cost savings analysis is not necessary.

5.2.3 Proposal C: Update to Daylit Zones Definitions

Since the proposal provides clarification on Daylit Zone definitions for specific use cases, energy cost savings analysis is not necessary.

5.3 Incremental First Cost

5.3.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

PAFs and PCOs are not requirements of Title 24, Part 6, so investigating incremental first cost is not necessary.

5.3.2 Proposal B: Min VT Interpretation for TDDs

Since the proposal interprets the already established 'Min VT threshold for skylights' for TDDs, incremental first cost analysis is not necessary.

5.3.3 Proposal C: Update to Daylit Zones Definitions

Since the proposal provides clarification on Daylit Zone definitions for specific use cases, incremental first cost analysis is not necessary

5.4 Lifetime Incremental Maintenance Costs

5.4.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

PAFs and PCOs are not requirements of Title 24, Part 6, so investigating maintenance costs is not necessary.

5.4.2 Proposal B: Min VT Interpretation for TDDs

Since the proposal interprets the already established 'Min VT threshold for skylights' for TDDs, lifetime incremental maintenance cost analysis is not necessary.

5.4.3 Proposal C: Update to Daylit Zones Definitions

Since the proposal provides clarification on Daylit Zone definitions for specific use cases, lifetime incremental maintenance analysis is not necessary.

5.5 Lifecycle Cost-Effectiveness

5.5.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

PAFs and PCOs are not requirements of Title 24, Part 6, so calculating lifecycle cost-effectiveness is not necessary.

5.5.2 Proposal B: Min VT Interpretation for TDDs

Since the proposal interprets the already established 'Min VT threshold for skylights' for TDDs, lifecycle cost-effectiveness is not necessary.

5.5.3 Proposal C: Update to Daylit Zones Definitions

Since the proposal provides clarification on Daylit Zone definitions for specific use cases, lifecycle cost-effectiveness is not necessary.

6. FIRST-YEAR STATEWIDE IMPACTS

6.1 Statewide Energy Savings and Lifecycle Energy Cost Savings

6.1.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

PAFs and PCOs are not requirements of Title 24, Part 6, but are options for projects to use to tradeoff one building feature for another with an equal or greater energy savings outcome. Therefore, neither statewide energy savings nor statewide lifecycle energy cost savings analysis is required to justify their inclusion in Title 24, Part 6.

6.1.2 Proposal B: Min VT Interpretation for TDDs

Since the proposal interprets the already established 'Min VT threshold for skylights' for TDDs, lifecycle statewide energy savings and lifecycle energy cost savings is not necessary.

6.1.3 Proposal C: Update to Daylit Zones Definitions

Since the proposal provides clarification on Daylit Zone definitions for specific use cases, lifecycle statewide energy savings and lifecycle energy cost savings is not necessary.

6.2 Statewide Water Use Impacts

The proposed code change will not result in water savings.

6.3 Statewide Material Impacts

6.3.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

Many manufactured fixed slats are constructed from aluminum. Aside from large doses for which any metal can become toxic, aluminum is not considered a hazardous material and appears in many household and ingestible items (Bernardo 2015). The production of aluminum has three significant waste products: bauxite, mercury and spent pot lining (SPT). The focus of mitigating the material impact of bauxite is storage efficiency although there is ongoing research into reuse as construction material, treating it to make it more benign, and rehabilitation of storage areas for reuse. Mercury is produced at 0.17 grams per metric ton as of 2015 with goals to reach 0.02 grams per metric ton by 2030. SPL is currently being explored as a mineral product and fuel (Alumina Limited 2015).

Even though aluminum production and its associated byproducts may increase, the low implementation rate are expected to minimize the effects.

Current DRDs are constructed of aluminum or plastic. Plastic is an inert substance, and therefore its material impacts are considered acceptable.

Similarly, the material impact of slats and daylight redirecting devices is expected to be negligible.

Clerestories are windows, so their material impact is not expected to be significant.

6.3.2 Proposal B: Min VT Interpretation for TDDs

Since the proposal interprets the already established 'Min VT threshold for skylights' it has no statewide materials impact.

6.3.3 Proposal C: Update to Daylit Zones Definitions

Since the proposal provides clarification on Daylit Zone definitions for specific use cases, it has no statewide materials impact.

6.4 Other Non-Energy Impacts

6.4.1 Proposal A: Power Adjustment Factors and Performance Compliance Options

The proposed measures block direct beam sunlight and brighten spaces with more natural daylight. These features are expected to increase occupant comfort and productivity.

6.4.2 Proposal B: Min VT Interpretation for TDDs

Providing an interpretation of the Min VT code for TDDs may result in more buildings with daylighting, which has been shown to have a positive impact on health and productivity.

6.4.3 Proposal C: Update to Daylit Zones Definitions

Since the proposal provides clarification on Daylit Zone definitions for specific use cases, it has no non-energy impacts.

7. PROPOSED REVISIONS TO CODE LANGUAGE

The proposed changes to the Standards, Reference Appendices, and the ACM Reference Manuals are provided below. Changes to the 2016 documents are marked with <u>underlining</u> (new language) and ~~strikethroughs~~ (deletions).

When writing code language, considerations aside from energy savings must also be made. A discussion on analysis to account for practical implementation of the code or to assure energy benefits is given in Appendix E.

The Statewide CASE Team recognizes that DRDs is the most complicated of the proposed PAFs. The proposed language for DRDs appears in blue font to help simplify review of the language.

7.1 Standards

10-102 – DEFINITIONS

NFRC 203 is the National Fenestration Rating Council document titled "NFRC 203: Procedure for Determining Visible Transmittance of Tubular Daylighting Devices." ~~(2012)~~ (2014)

SECTION 100.1 – DEFINITIONS AND RULES OF CONSTRUCTION

CLERESTORY is any portion of exterior vertical fenestration area greater than eight feet above the finished floor of a space.

LIGHT SHELF, INTERIOR is a contiguous opaque surface located at the sill of a clerestory, oriented horizontally and projecting inward horizontally from an interior vertical surface.

LIGHT SHELF DROP is the vertical distance between the projected edge of an interior light shelf and the head of the clerestory above the light shelf.

LIGHT SHELF PROJECTION is the horizontal distance from the projected edge of an interior light shelf to the base edge of the interior light shelf.

LIGHT SHELF PROJECTION FACTOR is ratio of the light shelf projection to the light shelf drop.

OVERHANG RISE is the vertical distance between the projected edge of an overhang and the sill of the vertical fenestration below it.

OVERHANG PROJECTION FACTOR is ratio of the overhang projection to the overhang rise.

SLAT, HORIZONTAL is a surface located adjacent to vertical fenestration, oriented horizontally and projecting inward horizontally from an interior vertical surface for an interior slat or projecting outward horizontally from an exterior surface for an exterior slat.

PROJECTION BASE EDGE is the edge of a slat, light shelf or overhang that is adjacent to the vertical fenestration.

PROJECTION PROJECTED EDGE is the inward edge of an interior slat or light shelf or the outward edge of an exterior slat, light shelf or overhang.

SLAT PROJECTION is the horizontal distance between the projected edge of a slat to the base edge of the slat.

SLAT RISE is the vertical distance between the projected edge of a given slat and the base edge of the slat below.

SLAT PROJECTION FACTOR is ratio of the slat projection to the slat rise.

DAYLIGHT REDIRECTING DEVICE, UPPER TRANSMISSION QUARTERSPHERE. If the YB and ZB direction as defined in ASTM E2387 are considered the upward and outward installation direction of the daylight redirecting device, respectively, then the upper transmittance quartersphere is the set of all scatter directions bounded by scatter polar angles between 90 degrees and 180 degrees and scatter azimuth angles between 0 degrees and 180 degrees.

DAYLIGHT REDIRECTING DEVICE, LOWER TRANSMISSION QUARTERSPHERE. If the YB and ZB direction as defined in ASTM E2387 are considered the upward and outward installation direction of the daylight redirecting device, respectively, then the lower transmission quartersphere is the set of all scatter directions bounded by scatter polar angles between 90 degrees and 180 degrees and scatter azimuth angles between 180 degrees and 360 degrees.

DAYLIGHT REDIRECTING DEVICE, UPPER QUARTERSPHERICAL TRANSMITTANCE is the ratio of the incident luminous flux of visible light at a specified source angle of incidence, to the sum of the luminous flux of visible light over all specified transmitted scattered directions of the upper transmission quartersphere. Scattered luminous flux measured at 0 and 180 scatter azimuth angles shall be excluded when summing the scattered luminous flux of the upper transmission quartersphere.

DAYLIGHT REDIRECTING DEVICE, LOWER QUARTERSPHERICAL TRANSMITTANCE is the ratio of the incident luminous flux of visible light at a specified source angle of incidence, to the sum of the luminous flux of visible light over all specified transmitted scattered directions of the lower transmission quartersphere. Scattered luminous flux measured at 0 and 180 scatter azimuth angles shall be excluded when summing the scattered luminous flux of the lower transmission quartersphere.

NFRC 203 is the National Fenestration Rating Council document titled "NFRC 203: Procedure for Determining Visible Transmittance of Tubular Daylighting Devices." ~~(2012)~~ (2014)

WINDOW WALL RATIO (WWR) is the ratio of the window area to the gross exterior wall area

SECTION 110.6 – MANDATORY REQUIREMENTS FOR FENESTRATION PRODUCTS AND EXTERIOR DOORS

(a) Certification of Fenestration Products and Exterior Doors other than Field-fabricated.

4. **Visible Transmittance (VT).** The fenestration product's VT shall be rated in accordance with NFRC 200 or ASTM E972, for tubular ~~skylights~~ daylighting devices VT shall be rated using NFRC 203.

SECTION 130.1 – MANDATORY INDOOR LIGHTING CONTROLS

(d) Automatic Daylighting Controls.

1. Daylit Zones shall be defined as follows:

   A. **SKYLIT DAYLIT ZONE** is the rough area in plan view under each skylight, plus 0.7 times the average ceiling height in each direction from the edge of the rough opening of the skylight, minus any area on a plan beyond a permanent obstruction that is taller than ~~the following: A permanent obstruction that is taller than~~ one-half the distance from the floor to the bottom of the skylight. The bottom of the skylight is measured from the bottom of the skylight well for skylights having wells, or the bottom of the skylight if no skylight well exists.

   For the purpose of determining the skylit daylit zone, the geometric shape of the skylit daylit zone shall be identical to the plan view geometric shape of the rough opening of the skylight; for example, for a rectangular skylight the skylit daylit zone plan area shall be rectangular, and for a circular skylight the skylit daylit zone plan area shall be circular.

   For skylight(s) located in an atrium, the skylit daylit zone shall include the floor area directly under the atrium, and the area of the top floor that is directly under the skylight, plus 0.7 times the average ceiling height of the top floor, in each direction from the edge of the rough opening of the skylight, minus any area on a plan beyond a permanent obstruction that is taller than one-half the distance from the top floor to the bottom of the skylight.

EXCEPTION 1 to 130.1(d)1A: Areas under skylights where it is documented that existing adjacent structures or natural objects block direct sunlight for more than 1,500 daytime hours per year between 8 a.m. and 4 p.m.

B. **PRIMARY SIDELIT DAYLIT ZONE** is the area in plan view and is directly adjacent to each vertical glazing in an exterior wall, one window head height deep into the area, and ~~window~~ vertical fenestration width plus 0.5 times window head height wide on each side of the rough opening of the ~~window~~ vertical fenestration, minus any area on a plan beyond a permanent vertical obstruction that is 6 feet or taller as measured from the floor and minus any area that is in a skylit daylit zone.

C. **SECONDARY SIDELIT DAYLIT ZONE** is the area in plan view ~~and is~~ directly adjacent to the primary sidelit daylit zone ~~each vertical glazing~~, and extends two window head heights deep from the vertical fenestration into the area, and is the ~~window~~ vertical fenestration width plus 0.5 times window head height wide on each side of the rough opening of the ~~window~~ vertical fenestration, minus any area on a plan beyond a permanent vertical obstruction that is 6 feet or taller as measured from the floor and minus any area that is in a skylit daylit zone or in a primary sidelit zone.

Note: Modular furniture walls shall not be considered a permanent obstruction.

EXCEPTION to 130.1(d)1B&C: Areas adjacent to vertical glazing and no vertical glazing above the overhang, where Overhang Projection Factor > 1.5 for South, East and West orientations, or where Overhang Projection Factor > 1 for North orientations.

2. Luminaires providing general lighting that are in or are partially in the Skylit Daylit Zones or the Primary Sidelit Daylit Zones shall be controlled independently by fully functional automatic daylighting controls that meet the applicable requirements of Section 110.9, and the applicable requirements below:

…

EXCEPTION 1 to Section 130.1(d)2: ~~Rooms~~ Luminaires in Skylit Daylit Zone(s) in an enclosed space, in which the combined total installed general lighting power in the Skylit Daylit Zone(s) ~~and Primary Sidelit Daylit Zone~~ is less than 120 Watts.

EXCEPTION 2 to Section 130.1(d)2: Luminaires in Primary Sidelit Daylit Zone(s) in an enclosed space, in which the combined total installed general lighting power in the Primary Daylit Zone(s) is less than 120 Watts.

EXCEPTION ~~2~~3 to Section 130.1(d)2: ~~Rooms~~ Enclosed spaces that have a total glazing area of less than 24 square feet.

EXCEPTION ~~3~~4 to Section 130.1(d)2: Parking garages complying with Section 130.1(d)3.

SECTION 140.3 – PRESCRIPTIVE REQUIREMENTS FOR BUILDING ENVELOPES

(d) Daylighting design strategies for Power Adjustment Factors. Daylighting design strategies that comply with the following requirements shall qualify for a Power Adjustment Factors in Table 140.6-A.

1. Lighting and lighting controls shall comply with Section 140.6(a)2L

2. Where specified as required in Sections 140.3(d)3 and 140.3(d)4, the requirements below shall apply to the following projections: horizontal slats, light shelves and overhangs.

    A. Projections shall be permanently mounted.

    B. Projections shall extend beyond each side of the window jamb by a distance equal to or greater than their horizontal projection.

       EXCEPTION to 140.3(d)2B Where the projection is located entirely within the vertical fenestration's rough opening or a fin is located at the window jamb and extends vertically the entire height of the window jamb and extends horizontally the entire depth of the projection.

    C. Exterior projections shall be horizontal or slope downwards from vertical fenestration. Interior projections shall be horizontal or slope upwards from vertical fenestration.

    D. For south-facing projections, the projection factor shall be between 1.0 and 2.0. The projection factor for east- and west-facing projections shall be between 2.0 and 3.0. The projection factor shall be permanently fixed and not adjustable.

    E. The distance from the vertical fenestration to any existing structures or natural objects within view of the vertical fenestration divided by the structure or object's height above the vertical fenestration's sill shall be greater than or equal to 0.3 times the design projection factor.

       EXCEPTION to 140.3(d)2E Where it is documented that existing adjacent structures or natural objects within view of the vertical fenestration block direct sunlight onto the vertical fenestration between 8 a.m. and 5 p.m. for less than 500 daytime hours per year for east- and west-facing fenestration or less than 750 daytime hours per year for south-facing fenestration.

3. Interior or exterior Horizontal Slats

    A. Shall meet all the requirements of Section 140.3(d)2.

    B. Shall be adjacent to vertical fenestration and extend the entire height of the vertical fenestration.

    C. The visible reflectance shall be equal to or greater than 0.50 when tested in accordance with ASTM E903.

    D. The slat surface material shall be entirely opaque and free of perforations.

       EXCEPTION to 140.3(d)3D Slats with a visible transmittance less than or equal to 0.03 when tested in accordance with ASTM E1175.

    E. The dimensions for the slat projection and slat rise shall appear on the building plans.

4. Interior Light Shelves with Overhangs

    A. Interior light shelves shall meet all the requirements of Section 140.3(d)2.

    B. Interior light shelves shall be installed on a clerestory that meets the requirements of Section 140.3(d)5 and has a head height less than or equal to one foot below a finished ceiling.

    C. The top surface of interior light shelves shall have a visible reflectance equal to or greater than 0.50 when tested in accordance with ASTM E903.

    D. If there is vertical fenestration area below the light shelf, that fenestration area shall have an overhang.

i. The overhang shall meet the requirements of Sections 140.3(d)2A through 140.3(d)2C.

ii. The overhang projection factor shall be between 0.25 and 1.25.

iii. The top surface of the overhang shall have a visible reflectance equal to or greater than 0.50 when tested in accordance with ASTM E903.

EXCEPTION 140.3(d)4Diii When the overhang is installed greater than two feet below the clerestory sill.

iv. The dimensions for the overhang projection and overhang rise shall appear on the building plans.

EXCEPTION to 140.3(d)4D When horizontal slats which meet the requirements of Section 140.3(d)3 and are installed on the vertical fenestration area below the light shelf.

E. The dimensions for the light shelf projection and light shelf drop shall appear on the building plans.

5. Clerestories

A. Shall have a head height that is at least 10 feet above the finished floor.

B. Shall have a glazing height that is greater than or equal to 10 percent of the head height.

C. If operable shading is installed on the clerestory, then the clerestory shading shall be controlled separately from shading serving other vertical fenestration.

6. Daylight Redirecting Devices

A. Shall be mounted on a clerestory which meets the requirements of Section 140.3(d)5. The clerestory onto which the daylight redirecting device is mounted shall have a VT greater than or equal to 0.50.

B. Shall be permanently mounted on a clerestory that meets the requirements of Section 140.3(d)5 and has a head height less than or equal to one foot below a finished ceiling.

C. The distance from the clerestory to any existing structures or natural objects within view of the clerestory divided by the structure or object's height above the clerestory's sill shall be greater than or equal to 0.6.

EXCEPTION to 140.3(d)6C Where it is documented that existing adjacent structures or natural objects within view of the vertical fenestration block direct sunlight onto the vertical fenestration between 8 a.m. and 5 p.m. for less than 500 daytime hours per year for east- and west-facing clerestories or less than 1,000 daytime hours per year for south-facing clerestories.

D. The light scattering properties of the product shall be measured according to ASTM E2387.

E. The source angles of incidence as defined in ASTM E2387 shall be 30, 50 and 70 degrees, and the source incident azimuth angle shall be 90 degrees. The transmittance shall be measured at each scatter polar angle specified in Table 140.3-E for every increment of scatter azimuth angle specified in Table 140.3-E.

TABLE 140.3-E DAYLIGHT REDIRECTING DEVICE TRANSMITTANCE MEASUREMENT ANGLES

Scatter Polar Angle (degrees)	100	110	120	130	140	150	160	170	180

Scatter Azimuth Angle Increments (degrees)	Every 30	Every 22.5	Every 15	Every 15	Every 15	Every 18	Every 22.5	Every 45	One measurement

E. The minimum upper quarterspherical transmittance of the daylight redirecting device as defined in Section 100.1 shall be greater than or equal to 0.40. The minimum ratio of upper quarterspherical transmittance to lower quarterspherical transmittance shall be greater than or equal to 2.5.

7. Horizontal Slats and Daylight Redirecting Devices shall have a conspicuous factory installed label permanently affixed and prominently located on an attachment point of the device to the building envelope, stating the following: "NOTICE: Removal of this device will require re-submittal of compliance documentation to the enforcement agency responsible for compliance with the California Title 24, Part 6 Building Energy Efficiency Standards."

8. Acceptable manufacturers and models shall be listed in the building specifications.

SECTION 140.6 – PRESCRIPTIVE REQUIREMENTS FOR INDOOR LIGHTING

(a) Calculation of Actual Indoor Lighting Power.

2. Reduction of wattage through controls.

L. To qualify for the PAFs for Horizontal Slats, Light Shelves with Overhangs, Clerestories and Daylight Redirecting Devices, the daylight control and controlled luminaires shall comply with Section 130.1(d) and 130.4(a)3. Continuous dimming daylight controls shall be installed on all luminaires in the primary and secondary sidelit daylit zones. The PAF shall apply only to the controlled general lighting luminaires in the primary and secondary sidelit daylit zones where the fenestration that defines the daylit zones per Section 130.1(d) meets the pertinent requirements of Section 140.3(d) and Table 140.6-A.

TABLE 140.6-A LIGHTING POWER ADJUSTMENT FACTORS (PAF)

TYPE OF SYSTEM~~CONTROL~~	TYPE OF AREA		FACTOR
a. To qualify for any of the Power Adjustment Factors in this table, the installation shall comply with the applicable requirements in Section 140.6(a)2 b. Only one PAF may be used for each qualifying luminaire unless combined below. c. Lighting controls that are required for compliance with Part 6 shall not be eligible for a PAF			
1. Daylight Dimming plus OFF Control	Luminaires providing in skylit daylit zone or primary sidelit daylit zone.		0.10
2. Occupant Sensing Controls in Large Open Plan Offices	In open plan offices > 250 square feet: One sensor controlling an area that is:	No larger than 125 square feet	0.40
		From 126 to 250 square feet	0.30
		From 251 to 500 square feet	0.20
3. Institutional Tuning	Luminaires in non-daylit areas: Luminaires that qualify for ~~other~~ PAFs 1, 2 or 4 in this table may ~~also qualify for this tuning PAF.~~ add the associated PAF to this PAF.		0.10
	Luminaires in daylit areas: Luminaires that qualify for ~~other~~ PAFs 1, 2 or 4 in Table 140.6-A may ~~also qualify for this tuning PAF~~ add the associated PAF to this PAF.		0.05
4. Demand Responsive Control	All building types less than 10,000 square feet. Luminaires that qualify for ~~other~~ PAFs 1, 2 or 3 in this table may ~~also qualify for this demand responsive control PAF~~ add the associated PAF to this PAF.		0.05
5. Horizontal Slats	Luminaires with controls in daylit zones complying with all requirements of Section 140.6(a)2L. The daylit zones shall be for fenestration on east- or west-facing facades with WWR between 20 and 30 percent. Luminaires that qualify for PAFs 1, 7 or 8 in this table may add the associated PAF to this PAF.		0.05
6. Interior Light Shelves with Overhangs	Luminaires with controls in daylit zones complying with all requirements of Section 140.6(a)2L. The daylit zones shall be for fenestration south-facing facades with WWR greater than 30 percent. Luminaires that qualify for PAF 1 in this table may add the associated PAF to this PAF.		0.10
7. Clerestories	Luminaires with controls in daylit zones complying with all requirements of Section 140.6(a)2L. The daylit zones shall be for fenestration on east-, west- or south-facades. Luminaires that qualify for PAF 1 in this table may add the associated PAF to this PAF.		0.05
8. Daylight Redirecting Devices	Luminaires with controls in daylit zones complying with all requirements of Section 140.6(a)2L. The daylit zones shall be for fenestration on east-, west-, or south-facing facades. Luminaires that qualify for PAF 1 in this table may add the associated PAF to this PAF.		0.07

(d) Automatic Daylighting Controls in Secondary Daylit Zones. All luminaires providing general lighting that ~~is~~ are in, or partially in a Secondary Sidelit Daylit Zone as defined in Section 130.1(d)1C, and that ~~is~~ are not in a Primary Sidelit Daylit Zone shall:.

…

EXCEPTION 1 to Section 140.6(d): Luminaires in Secondary Sidelit Daylit Zone(s) in ~~areas where~~ an enclosed space in which the combined total general lighting power in Secondary Sidelit Daylit Zone(s) ~~the total wattage of general lighting~~ is less than 120 Watts, or where the combined total general lighting power in Primary and Secondary Sidelit Daylit Zone(s) is less than 240 Watts.

TABLE 140.3-B - 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)

Envelope	Fenestration				Fixed Window	Operable Window	Curtainwall or Storefront	Glazed Doors[2]
		Vertical	Area-Weighted Performance Rating	Max U-factor	0.36	0.46	0.41	0.45
				Max RSHGC	0.25	0.22	0.26	0.23
				Min VT	0.42	0.32	0.46	0.17
			Maximum WWR%	40%				
		Skylights			Glass, Curb Mounted	Glass, Deck Mounted	Plastic, Curb Mounted	Tubular Daylighting Devices (TDDs)
			Area-Weighted Performance Rating	Max U-factor	0.58	0.46	0.88	0.88
				Max RSHGC	0.25	0.25	NR	NR
				Min VT (Min VT_{annual} for TDDs)	0.49	0.49	0.64	0.38
			Maximum SRR%	5%				

SECTION 150.1 – PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES FOR LOW-RISE RESIDENTIAL BUILDINGS

(c) Prescriptive Standards/Component Package.

3. Fenestration.

A. **EXCEPTION 1 to Section 150.1(c)3A:** For each dwelling unit up to 3 square feet of new glazing area installed in doors and up to 3 square feet of new tubular ~~skylights~~ daylighting devices area with dual-pane diffusers shall not be required to meet the U-factor and SHGC requirements of TABLE 150.1-A.

7.2 Reference Appendices

Section NA7.4 will be revised to include acceptance testing for fenestration attachments in the proposed measure.

NA7.4.4 Horizontal Slats for PAF

NA7.4.4.1 Procedures

These procedures detail the installation and verification protocols necessary to meet acceptance requirements of horizontal slats that are used in conjunction with lighting controls to receive a PAF for qualifying installed luminaires. Each horizontal slat assembly shall be provided with documentation of visible reflectance testing per ASTM E903 and may come with documentation of visible transmittance testing per ASTM E1175. The documentation shall be located at the job site for verification by the enforcement agency. In addition, the responsible person shall fill out the Installation Certificate (NRCI-

ENV-01-E) and the Certificate of Acceptance (NRCA-ENV-02-F), Fenestration Acceptance Certificate. The responsible person shall verify 1) the horizontal slats to be installed matches the energy Certificate of Compliance (NRCC-ENV-05-E) documentation and building plans. A copy of the Installation and Acceptance Certificate shall be given to the building owner and the enforcement agency for their records.

For buildings with up to seven (7) horizontal slat assemblies claiming the Horizontal Slats PAF, all horizontal slat assemblies shall be tested. For buildings with more than seven (7) assemblies claiming this PAF, random sampling may be done on seven assemblies. If any of the assemblies in the sample group of seven assemblies fails the acceptance test, another group of seven assemblies must be tested.

NA7.4.4.2 The Responsible Person or Installer Shall Meet the Following Protocols before Installation:

a) Verify the horizontal (not diagonal or vertical) distance from the front edge of the slat to the back edge of the slat matches the building plans;
b) Verify the vertical (not diagonal or horizontal) distance from the lowest edge of the slat to the highest edge of the slat below it matches the building plans;
c) Verify the visible reflectance on the ASTM E903 test results matches the building plans;
d) If the horizontal slat surfaces are not opaque and free of perforations, verify that the horizontal slats ASTM E1175 test results matches the building plans;
e) Installation of horizontal slats shall meet the manufactures installation instructions; and
f) After the installation, the installer completes and signs the Declaration Statement on the Installation Certificate NRCI-ENV-01-E. A signed copy of the NRCI-ENV-01-E Certificate(s) shall remain at the job site for verification by the building inspector.

NA7.4.4.3 Field Technician or Responsible Person Shall Meet the Following Protocols After Installation:

a) Verify the Installation Certificate NRCI-ENV-01-E and the Declaration Statement is signed before inspection of the installation;
b) Verify that horizontal slats are permanently mounted;
c) If the horizontal slats extend beyond each side of the window jamb, then verify the extension matches the length shown on the building plans;
d) If the horizontal slats do not extend beyond each side of the window jamb, then verify that the light shelf and overhang are entirely within the window rough opening or that fins at the window jambs match the building plans;
e) Verify that horizontal slat assemblies extend the entire height of the window;
f) Verify that exterior horizontal slats are horizontal or slope downwards from the window and that interior horizontal slats are horizontal or slope upwards from the window;
g) After inspection is complete ensure the NRCA-ENV-02-F certificate form is completed and including the signature of the Declaration Statements; and
h) Provide certificates and additional copies to the builder, enforcement agency and building owner at occupancy.

NA7.4.4.4 Documentation at Occupancy:

The following documentation shall be made available to the responsible party of construction or building owner at occupancy:

a) A completed and signed NRCI-ENV-01-E and NRCA-ENV-02-F form(s);
   1. If supplied by the manufacturer, a copy of the manufacturer's warranty and user manual.

NA7.4.5 Interior Light Shelves with Overhangs for PAF

NA7.4.5.1 Procedures

These procedures detail the installation and verification protocols necessary to meet acceptance requirements of interior light shelves with overhangs that are used in conjunction with lighting controls to receive a PAF for qualifying installed luminaires. Each interior light shelf shall be provided with documentation of visible reflectance testing per ASTM E903. Overhangs may be provided with documentation of visible reflectance testing per ASTM E903. The documentation shall be located at the job site for verification by the enforcement agency. In addition, the responsible person shall fill out the Installation Certificate (NRCI-ENV-01-E) and the Certificate of Acceptance (NRCA-ENV-02-F), Fenestration Acceptance Certificate. The responsible person shall verify 1) the light shelves and overhangs to be installed match the energy Certificate of Compliance (NRCC-ENV-05-E) documentation and building plans. A copy of the Installation and Acceptance certificate shall be given to the building owner and the enforcement agency for their records.

For buildings with up to seven (7) light shelf units (and any accompanying overhangs if on the plans) claiming the Light Shelves with Overhangs PAF, all units shall be tested. For buildings with more than seven (7) units claiming this PAF, random sampling may be done on seven units. If any of the units in the sample group of seven units fails the acceptance test, another group of seven units must be tested.

NA7.4.5.2 The Responsible Person or Installer Shall Meet the Following Protocols before Installation:

a) Verify the horizontal (not diagonal or vertical) distance from the front edge of the light shelf to the back edge of the light shelf matches the building plans;
b) Verify the vertical (not diagonal or horizontal) distance from the highest edge of the light shelf to the top of the clerestory above it matches the building plans;
c) Verify that light shelves are installed at the height specified in the building plans;
d) Verify the visible reflectance on the ASTM E903 test results matches the building plans;
e) If there is an overhang, verify the horizontal (not diagonal or vertical) distance from the front edge of the overhang to the back edge of the overhang matches the building plans;
f) If there is an overhang, verify the vertical (not diagonal or horizontal) distance from the lowest edge of the overhang to the sill of the window below it matches the building plans;
g) If there is an overhang and the overhang is less than two feet below the clerestory sill, verify the visible reflectance on the ASTM E903 test results matches the building plans;
h) Installation of light shelves and overhangs shall meet the manufactures installation instructions; and
i) After the installation, the installer completes and signs the Declaration Statement on the Installation Certificate NRCI-ENV-01-E. A signed copy of the NRCI-ENV-01-E Certificate(s) shall remain at the job site for verification by the building inspector.

NA7.4.5.3 Field Technician or Responsible Person Shall Meet the Following Protocols After Installation:

a) Verify the Installation Certificate NRCI-ENV-01-E and the Declaration Statement is signed before inspection of the installation;
b) Verify that that light shelves are permanently mounted;
c) If the light shelf extends beyond each side of the window jamb, then verify the extension matches the length shown on the building plans;
d) If the light shelf does not extend beyond each side of the window jamb, then verify that the light shelf is entirely within the window rough opening or that fins at the window jambs match the building plans;
e) Verify that interior light shelves are horizontal or slopes upwards from the window;
f) If there is any window area below the light shelf on the same floor, then verify there is an overhang above that window area.

g) If there is an overhang and the overhang extends beyond each side of the window jamb, then verify the extension matches the length shown on the building plans;
h) If there is an overhang and the overhang does not extend beyond each side of the window jamb, then verify that the overhang is entirely within the window rough opening or that fins at the window jambs match the building plans;
i) If there is an overhang, verify that the overhang is horizontal or slopes downwards from the window;
j) If operable shading is installed on the clerestory, then verify the clerestory shading is controlled separately from shading serving other vertical fenestration;
k) After inspection is complete ensure the NRCA-ENV-02-F certificate form is completed and including the signature of the Declaration Statements; and
l) Provide certificates and additional copies to the builder, enforcement agency and building owner at occupancy.

NA7.4.5.4 Documentation at Occupancy:

The following documentation shall be made available to the responsible party of construction or building owner at occupancy:

a) A completed and signed NRCI-ENV-01-E and NRCA-ENV-02-F, form(s);
   1. If supplied by the manufacturer, a copy of the manufacturer's warranty and user manual.

NA7.4.6 Clerestories for PAF

NA7.4.6.1 Procedures

These procedures detail the installation and verification protocols necessary to meet acceptance requirements of clerestories that are used in conjunction with lighting controls to receive a PAF for qualifying installed luminaires. The responsible person shall fill out the Installation Certificate (NRCI-ENV-01-E) and the Certificate of Acceptance (NRCA-ENV-02-F), Fenestration Acceptance Certificate. The responsible person shall verify 1) the clerestory to be installed matches the energy Certificate of Compliance (NRCC-ENV-05-E) documentation and building plans. A copy of the Installation and Acceptance certificate shall be given to the building owner and the enforcement agency for their records.

For buildings with up to seven (7) clerestories units claiming the Clerestory PAF, all clerestories shall be tested. For buildings with more than seven (7) clerestories claiming this PAF, random sampling may be done on seven clerestories. If any of the clerestories in the sample group of seven clerestories fails the acceptance test, another group of seven clerestories must be tested.

NA7.4.6.2 The Responsible Person or Installer Shall Meet the Following Protocols before Installation:

a) Verify the height of the clerestory's sill and the height of the top of the clerestory match the building plans; and
b) After the installation, the installer completes and signs the Declaration Statement on the Installation Certificate NRCI-ENV-01-E. A signed copy of the NRCI-ENV-01-E Certificate(s) shall remain at the job site for verification by the building inspector.

NA7.4.6.3 Field Technician or Responsible Person Shall Meet the Following Protocols After Installation:

a) Verify the Installation Certificate NRCI-ENV-01-E and the Declaration Statement is signed before inspection of the installation;
b) If operable shading is installed on the clerestory, then verify the clerestory shading is controlled separately from shading serving other vertical fenestration;

c) After inspection is complete ensure the NRCA-ENV-02-F certificate form is completed and including the signature of the Declaration Statements; and
d) Provide certificates and additional copies to the builder, enforcement agency and building owner at occupancy.

NA7.4.6.4 Documentation at Occupancy:

The following documentation shall be made available to the responsible party of construction or building owner at occupancy:

a) A completed and signed NRCI-ENV-01-E and NRCA-ENV-02-F, form(s);
   1. If supplied by the manufacturer, a copy of the manufacturer's warranty and user manual.

NA7.4.7 Daylight Redirecting Devices for PAF

NA7.4.7.1 Procedures

These procedures detail the installation and verification protocols necessary to meet acceptance requirements of daylight redirecting devices (DRDs) that are used in conjunction with lighting controls to receive a PAF for qualifying installed luminaires. Each DRD shall be provided with documentation of testing per ASTM E2387. The documentation shall be located at the job site for verification by the enforcement agency. In addition, the responsible person shall fill out the Installation Certificate (NRCI-ENV-01-E) and the Certificate of Acceptance (NRCA-ENV-02-F), Fenestration Acceptance Certificate. The responsible person shall verify 1) the DRD to be installed matches the energy Certificate of Compliance (NRCC-ENV-05-E) documentation and building plans. A copy of the Installation and Acceptance certificate shall be given to the building owner and the enforcement agency for their records.

For buildings with up to seven (7) DRD units claiming the Daylight Redirecting Devices PAF, all units shall be tested. For buildings with more than seven (7) units claiming this PAF, random sampling may be done on seven units. If any of the units in the sample group of seven units fails the acceptance test, another group of seven units must be tested.

NA7.4.7.2 The Responsible Person or Installer Shall Meet the Following Protocols before Installation:

a) Verify the manufacturer and model matches the building plans;
b) Verify the dimensions and placement of the DRD match the building plans;
c) Installation of DRDs shall meet the manufactures installation instructions; and
d) After the installation, the installer completes and signs the Declaration Statement on the Installation Certificate NRCI-ENV-01-E. A signed copy of the NRCI-ENV-01-E Certificate(s) shall remain at the job site for verification by the building inspector.

NA7.4.7.3 Field Technician or Responsible Person Shall Meet the Following Protocols After Installation:

a) Verify the Installation Certificate NRCI-ENV-01-E and the Declaration Statement is signed before inspection of the installation;
b) Verify that DRDs are permanently mounted;
c) If operable shading is installed on the clerestory, then verify the clerestory shading is controlled separately from shading serving other vertical fenestration;
d) After inspection is complete ensure the NRCA-ENV-02-F certificate form is completed and including the signature of the Declaration Statements; and
e) Provide certificates and additional copies to the builder, enforcement agency and building owner at occupancy.

NA7.4.7.4 Documentation at Occupancy:

The following documentation shall be made available to the responsible party of construction or building owner at occupancy:

a) A completed and signed NRCI-ENV-01-E and NRCA-ENV-02-F, form(s);
   1. If supplied by the manufacturer, a copy of the manufacturer's warranty and user manual.

NA7.7.6.1 Construction Inspection for all PAFs except Institutional Tuning

Verify and document the following:

a) Separately list all requirements for each PAF that is claimed in accordance with Sections 110.9, and 140.6(a)2, and Table 140.6-A;
b) Verify the installation complies with all applicable requirements in accordance with Sections 110.9, and 140.6(a)2, and Table 140.6-A;
c) If all of the above in not true for a specific PAF, the installation fails, and that specific PAF cannot be used;
d) For lighting systems that are claiming a PAF for daylight dimming plus OFF control in accordance with Section 140.6(a)2H, the system must successfully complete the functional performance test in Section NA 7.6.1.2.1, and in addition during the Full Daylight Test the controls shall automatically turn OFF the luminaires that are receiving the daylight dimming plus OFF PAF credit; and
e) For lighting systems that are claiming a PAF for daylighting design strategies in accordance with Section 140.6(d), the system must successfully complete the functional performance test in Section NA 7.6.1.2.1, and in addition, the primary and secondary sidelit daylit zones for the lighting controls must be defined by fenestration that incorporates daylight design strategies that meet the acceptance requirements of the pertinent sections of Section NA 7.4.

7.3 ACM Reference Manual

The ACM Reference Manual will allow for more flexibility than the prescriptive PAFs. Specifically, the ACM shall include the following:

- A table of savings fractions corresponding to variations in lighting control type, lighting control setpoint, and fixed slat WSRs and angles.
- A table of adjustments to savings fractions corresponding to variations in window VT, and fixed slat visible reflectance.
- A table of adjustments to savings fractions corresponding to suspension of fixed slats from an overhang.
- The performance approach will allow slats that do not extend the entire height of the vertical fenestration, but will not allow the cutoff angle of this shorter extension to be less than the slat cutoff angle. Figure 67 is an illustration of this scenario.

7.4 Compliance Manuals

Chapter 5, subsection 5.6.5 of the Nonresidential Compliance Manual will need to be revised to reflect that PAFs are for more than just lighting controls now. This section will also include "buyer beware" language warning designers of the potential glare concerns for certain technologies. There will also be language explaining that removal of any of the proposed technologies triggers a re-check of Title 24, Part 6 compliance.

All other proposed code language will also have pertinent sections explaining how to comply.

7.5 Compliance Documents

No new compliance documents will need to be created.

NRCC-ENV-05-E, NRCI-ENV-01-E and NRCA-ENV-02-F – A section for fenestration attachments will be added to these compliance documents. This section will have subsections for the proposed PAFs and their requirements. These requirements include verifying the the following:

- Fixed slats, light shelves and overhangs: projection factor and surface material visible reflectance per ASTM E903, and if applicable, ASTM E1175.
- Clerestories: that fenestration area exists above eight foot, has an adequate head height and window height, and, if installed, that blinds are controlled separately between clerestory and view windows.
- Daylight redirecting devices: manufacturer and model and light redirecting performance per ASTM E2387.

NRCC-LTI-02-E – The compliance document language pertaining to PAFs will be modified from addressing daylighting controls only to addressing both daylighting controls and the proposed measures.

NRCC-PRF-01-E – The envelope and lighting sections of the performance method compliance documents will have language to accommodate the proposed measure.

NRCI-LTI-05-E (Power Adjustment Factors) will not need to be revised as its reference to PAFs is agnostic to which PAF is chosen.

NRCC-ENV-02-E – Under Section A the term VT will be changed to "VT / VTannual (for TDDs)"

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Appendix A: Discussion of Impacts of Compliance Process on Market Actors

This section discusses how the recommended compliance process (described in Section 2.5) could impact various market actors. The Statewide CASE Team asked stakeholders for feedback on how the measure will impact various market actors during public stakeholder meetings that were held on December 15th, 2016 and March 30th, 2017 (Statewide CASE Team 2016). The key results from feedback received during stakeholder meetings and other target outreach efforts are detailed below.

Table 13 identifies the market actors who will play a role in complying with the proposed change, the tasks for which they will be responsible, their objectives in completing the tasks, how the proposed code change could impact their existing work flow, and ways negative impacts could be mitigated.

Proposal A: Power Adjustment Factors and Performance Compliance Options

The inclusion of the proposed measure's technologies will add design time, consideration of lead time for delivery of materials to the site, and if daylight redirecting films are included, possibly new skills or the hiring of skilled labor for installation. The other technologies do not require specialized skill to install.

The envelope designer and lighting designer will need to coordinate to assure that the design will comply with the requirements to qualify for the PAF. This may not currently be a typical collaboration. As such energy consultants will need to be well-educated in the new PAFs and PCOs as they often educate design teams for new measures affecting compliance.

Inspectors will need to become familiar with the checks required to assure compliance with the requirements to qualify for the PAFs and PCOs. A new line item will be included on the existing forms that verify requirements for PAFs and PCOs.

Proposal B: Min VT Interpretation for TDDs

Because of this code change proposal, the Statewide CASE Team expects architects and building design professionals, such as Title 24 consultants, to have an additional option of using TDDs. They will need to be informed of this code change and assistance in properly understanding the proposed addition on Min VTannual to the code.

Code Officials, Plan Checkers and Field Inspector will need to be made aware of the new Min VTannual threshold, so they can perform their functions correctly of checking for compliance.

Proposal C: Update to Daylit Zones Definitions

This code change proposal adds a clarification to the Daylit Zone definitions for specific use cases with atriums and large overhangs.

Architects and building designer will need to be made aware of the updates to the definitions so they can properly use the code when they encounter these use cases.

Code Officials and Plan Checkers will need to be made aware of the updates to the definitions so they can properly review plans with these use cases.

Table 13: Roles of Market Actors in The Proposed Compliance Process

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Lighting Designer	• Provide a pleasing design • Identify relevant requirements and/or compliance path • Perform required calculations by space to confirm compliance • Coordinate design with other team members (HVAC & modeler) • Complete compliance document for permit application • Review submittals during construction • Coordinate with commissioning agent as necessary	• Quickly and easily determine requirements based on scope • Demonstrate compliance with calculations required for other design tasks • Streamlined coordination with other team members • Clearly communicate system requirements to constructors • Quickly complete compliance documents • Easily identify non-compliant substitutions • Minimize coordination during construction	• Will need to work more closely with Envelope Designer • Will need to perform additional calculations by space type to show compliance with PAF requirements • Will need to document compliance with new requirement, not currently being documented. • Will need to include new information in energy model to comply via performance path	• Provide several aesthetic alternatives • Revise compliance document to automate slat angle calculation • Proposed documentation methodology uses materials already produced as part of the design/construction process. No additional compliance documents necessary • Modeling software will need to be updated to include PAFs and PCOs • Software training updates.

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Envelope Designer	• Provide a pleasing design • Identify relevant requirements and/ or compliance path • Perform required calculations by space to confirm compliance • Coordinate design with other team members (HVAC & modeler) • Complete compliance document for permit application • Review submittals during construction • Coordinate with commissioning agent as necessary	• Quickly and easily determine requirements based on scope • Demonstrate compliance with calculations required for other design tasks • Streamlined coordination with other team members • Clearly communicate system requirements to constructors • Quickly complete compliance documents • Easily identify non-compliant substitutions • Minimize coordination during construction	• Will need to work more closely with Lighting Designer to ensure correct specification • Will need to spec the technology in either the prescriptive or performance approach	• Provide several aesthetic alternatives • Revise compliance document to automate compliance calculations • Proposed documentation methodology uses materials already produced as part of the design/ construction process. No additional documentation necessary • Software training updates
Manufacturers	• Manufacture products that meet the requirements of the Title 24, Part 6 • Test products per approved methodology	• Keep product available and in stock so they can be responsive to distributors • Ensure that distributors are aware of product availability	• Will need to tailor production to new demand for products	• Products are introduced as PAFs and PCOs so increase in demand will not be sudden
Distributors	• Sell products that meet the requirements of the Title 24, Part 6	• Keep product available and in stock so they can be responsive to installers • Ensure that installers are aware of product availability	• Will need to tailor stock to meet new demand for products	• Products are introduced as PAFs and PCOs so increase in demand will not be sudden
Installers	• Comply with the requirements of the Title 24, Part 6 when installing	• Quality installation • Timely installation	• Will need to understand proper installation or learn skill, in particular, installing films	• Most proposed products use standard installation practices • Installing films may be a new skill set but films are not an all new technology

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Plans Examiner	• Identify relevant requirements of compliance path • Confirm data on compliance documents is compliant • Confirm plans/ specifications match data on compliance documents • Provide correction comments if necessary	• Quickly and easily determine requirements based on scope • Quickly and easily determine if data in compliance documents meets requirements • Quickly and easily determine if plans/ specs match compliance documents • Quickly and easily provide correction comments that will resolve issue	• Will need to verify new calculations are compliant • Will need to verify calculations match plans	• Compliance document could auto-verify data is compliant with standards • Document compliance on compliance documents in a way easily compared to plans
Installer	• Install the technology per the building specifications and manufacturer's installation instructions	• Quickly and easily determine the requirements for installation.	• Will need to verify features of technology listed on building specifications match installation • Will need to fill out compliance documentation	• Provide the minimum steps and clear language to verify essentials of performance
Field Technician	• Verify the installation matches building specifications and manufacturer's installation instructions	• Quickly and easily determine the requirements for installation	• Will need to verify features of technology listed on building specifications match installation • Will need to fill out compliance documentation	• Provide the minimum steps and clear language to verify essentials of performance
Field Inspector	• Visit site • Confirm site installations match data on compliance documents, including testing • Provide correction comments if necessary	• Quickly and easily determine if site installations match compliance documents, including testing quickly • Quickly and easily provide correction comments that will resolve issue	• Will need to verify features of technology listed on compliance documents match installation	• Provide the minimum steps and clear language to verify essentials of performance

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Compliance Software Manufacturer	• Integrate performance approach requirements into the compliance software • Meet the test criteria for compliance software	• Minimize run times for compliance check	• Will need to add the PAFs and PCOs for the new technologies	• The technologies have been added as PAFs which are simple multipliers on the lighting power
Title 24 Consultants	• Identify relevant requirements of compliance path • Run prescriptive and performance calculations to confirm compliance with Title 24, Part 6 • Confirm data on compliance documents is compliant • Offer suggestions to design team if the building does not pass	• Have in-depth knowledge of Title 24, Part 6 requirements • Quickly and easily determine requirements based on scope • Quickly and easily determine if data in compliance documents meets requirements • Quickly and easily provide suggestions that will resolve any compliance issue	• Will need to learn about the new technologies and their requirements and how to document them properly.	• Learning new requirements at every code cycle is par for the course for these consultants
Building owners	• Provide a safe, functional, compliant and enjoyable building	• Understand and be available and aware of tenants' wants and needs • Be responsive to tenants' wants and needs	• Will need to be aware that new technologies are not optional attachments on window and that removal or adjustment is code-triggering	• Provide a permanent label on devices stating that their removal may be code-triggering
Tenant Improvements/Facility Managers	• Regularly maintain the building's systems • Install certain new systems as requested or required by the building owner	• Be skilled and knowledgeable of the building's systems	• Will need to be aware that new technologies are not optional attachments on window and that removal or adjustment is code-triggering	• Provide a permanent label on devices stating that their removal may be code-triggering
Attachment Energy Ratings Council	• Create test procedures to measure the performance of window attachments • Consolidate measurement results into a rating	• Create useful but usable ratings	• Will need to consider revising their timeline for the proposed technologies	• Provide information on the proposal so they can be informed of which technologies are included

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
IES Daylight Metrics Committee	• Provide standards for measuring the quality and amount of daylight in a space	• Account for all reasonable possible space • Create useful yet usable metrics	• No expected change to workflow	• Not expected to be impacted by compliance requirements per se

Appendix B: THE EFFECT OF FURNITURE

The position and dimensions of furniture within a space affects daylighting savings. In the 2013 Nonresidential Daylighting CASE Report (Saxena 2011), furniture factors were one of several factors used to predict daylighting energy savings. The values of the furniture factors used in this regression analysis are listed in Table 14.

Table 14: 2013 Nonresidential Daylighting CASE Regression Furniture Factors

Furniture height	South	North, East, West
30 inches or less	0.8	0.8
60 inches or higher	0.56	0.46

The Energy Commission forecasted construction includes many building types. These buildings contain different space types, which have different furniture heights. To calculate furniture factors for the proposed PAFs that would be consistent with the furniture heights of the Energy Commission's forecasted construction, a method similar to the method used in the 2013 Nonresidential Fenestration Update CASE Report (Shadd 2011) was used.

In that analysis, the Energy Commission forecasted construction by building type was combined with the features of the DOE reference building types to create statewide weighted average features. Using this same method with furniture factors, overall statewide weighted average furniture factors were developed. The detailed calculation steps of this method follow.

Perimeter area by building type

The square footage of perimeter area by DOE building type was first calculated per the following steps. The values at the calculation steps are listed in Table 15.

- The square footage of the DOE reference buildings was divided by the number of floors to get the floor area per floor.
- It was assumed that, on average, perimeter areas were evenly divided between all orientations. With this assumption, the statewide average façade length was the square root of the floor area per floor.
- Window heights were assumed to be between 7 and 8 feet on average. This results in daylit zones that are 15 feet deep on average. Using this depth, the perimeter floor area was calculated for each building type.
- For the office building types, it was assumed that 80% of the perimeter area contained cubicles and that 20% contained private offices.

Mapping to Forecasted Construction and Final Furniture Factors

The final, overall furniture factors were then calculated by mapping the above perimeter areas by DOE building types into the Energy Commission forecasted construction building types, and then using that area to area-weight an average furniture factor over the entire state. The steps of this process are given below. The values at the calculation steps are listed in Table 16. Table 16 includes an "Area ID" carried over from Table 15 to show the correspondence of building type areas between the two tables.

- The DOE reference building types were mapped into the Energy Commission forecasted construction building types. Under this method, the DOE categories were sometimes split into multiple categories within the Energy Commission building type. The percentage split comes from the 2013 Nonresidential Fenestration Update CASE Report. For example, as listed in the "CEC Type within DOE Type" column, "Full-Service Restaurant" and "Quick-Service

Restaurant” in the DOE building types were mapped 40 percent and 60 percent, respectively into the Energy Commission “REST” building type.

- From the mapping, the number of DOE reference building types that will be built was forecasted using the floor area by building type and the Energy Commission’s forecasted construction floor area.
- The number of floors by building type was then used to calculate each building types total perimeter area.
- It was then again assumed that façade lengths were on average equal on all orientations. With this assumption east- and west-facing façades comprised 2/3 of the perimeter area while south-facing facades comprised 1/3 of the perimeter area.
- The furniture factors corresponding to assumed furniture heights by area type was then multiplied by the corresponding building type’s forecasted perimeter floor area by orientation to create weighted furniture factors.
- The sum of these weighted furniture factors was then divided by the total forecasted perimeter floor area to calculate final, overall weighted average furniture factors by orientation.
- DRDs illuminate a space from above. Therefore, their savings are much less sensitive to furniture and orientation. Their furniture factor was always set to the higher level furniture factor from the 2013 Nonresidential Daylighting CASE Report.

Table 15: Perimeter Area by Building Type

Area ID	DOE Type	Number of Floors Per Bldg	Floor Area [sf]	Per Floor Area [sf]	Statewide Average Façade Length [ft]	Perimeter Area [sf]	Percentage Subtype	Perimeter Area per Floor by DOE Type [sf]
	Small Office	1	5,500	5,500	74	2,000		
1	Cubicle						80%	1,600
2	Private						20%	400
	Medium Office	3	53,628	17,876	134	3,786		
3	Cubicle						80%	3,029
4	Private						20%	757
	Large Office	12	498,588	41,549	204	5,890		
5	Cubicle						80%	4,712
6	Private						20%	1,178
7	Full-Service Restaurant	1	5,500	5,500	74	2,000	100%	2,000
8	Quick-Service Restaurant	1	2,500	2,500	50	1,275	100%	1,275
9	Stand-Alone Retail	1	24,962	24,962	158	4,515	100%	4,515
10	Strip Mall	1	22,500	22,500	150	4,275	100%	4,275
11	Supermarket	1	45,000	45,000	212	6,139	100%	6,139
12	Primary School	1	73,960	73,960	272	7,934	100%	7,934
13	Secondary School	2	210,887	105,444	325	9,517	100%	9,517
14	College	3	1,393,000	464,333	681	20,218	100%	20,218
15	Outpatient Healthcare	3	40,946	13,649	117	3,280	100%	3,280
16	Hospital	5	241,351	48,270	220	6,366	100%	6,366

Table 16: Furniture Factor by Orientation

Area ID	CEC Type	Forecasted Construction [Msf]	CEC Type within DOE Type	Number of Buildings Forecasted	Forecasted Perimeter Area [Msf]	East/West Perimeter Area [Msf]	South Perimeter Area [Msf]	East and West Factor	South Factor
	OFF-SMALL	10.9	100%	1975					
1					3.16	2.11	1.05	0.46	0.56
2					0.79	0.53	0.26	0.8	0.8
	OFF-LRG	42.4	50%	395					
3					3.59	2.39	1.20	0.46	0.56
4					0.90	0.60	0.30	0.8	0.8
	OFF-LRG	42.4	50%	42					
5					2.37	1.58	0.79	0.46	0.56
6					0.59	0.40	0.20	0.8	0.8
7	REST	5.7	40%	415	0.83	0.55	0.28	0.8	0.8
8	REST	5.7	60%	1369	1.75	1.16	0.58	0.8	0.8
9	RETAIL	35.9	50%	719	3.25	2.16	1.08	0.46	0.56
10	RETAIL	35.9	50%	797	3.41	2.27	1.14	0.46	0.56
11	FOOD	9.5	100%	212	1.30	0.87	0.43	0.8	0.8
12	SCHOOL	15.3	34%	70	0.56	0.37	0.19	0.8	0.8
13	SCHOOL	15.3	66%	48	0.91	0.61	0.30	0.8	0.8
14	COLLEGE	7.0	100%	5	0.30	0.20	0.10	0.8	0.8
15	HOSP	9.1	50%	111	1.09	0.73	0.36	0.46	0.56
16	HOSP	9.1	50%	19	0.60	0.40	0.20	0.46	0.56
					Weighted Furniture Factors			**0.57**	**0.63**

Appendix C: BOUNDED STATISTICAL APPROACH TO MANUAL SHADE BEHAVIOR

A method is discussed below whereby the effect of shading behaviors of a large population on overall statewide daylighting energy savings can be estimated. Although the method has a large number assumptions and approximations, it is presented to provide some level of justification for an approach to estimate statewide energy savings for the proposed measures.

To find the limits of the energy impact of manual shade behaviors, a plot of behaviors versus energy use may be assumed. In this plot, energy use is ordered from highest to lowest. This assumed plot is illustrated in Figure 62.

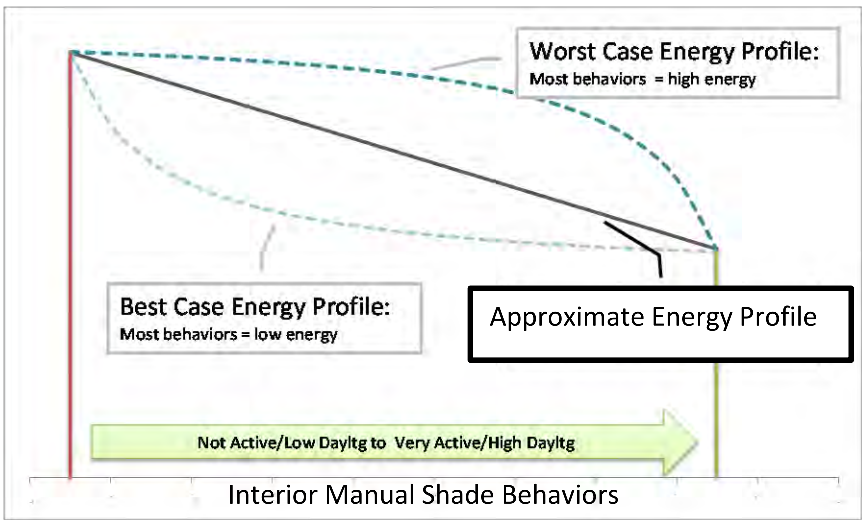

Figure 62: Assumed manual shade operation ordered by energy impact

The red vertical line on the left represents the extreme case of high energy use. The green vertical line on the right represents the extreme of low energy use. In between these two vertical lines, three curves represent the possible sets of all behaviors, ordered from highest to lowest energy use. These behaviors have energy impacts lower than the high extreme and higher than the low extreme.

The Worst Case Energy Profile represents the hypothetical situation where most behaviors result in high energy use. The Best Case Energy Profile represents the inverse that most behaviors result in low energy use.

The curve of the actual real-life set of behaviors is currently unknown, but must lie somewhere within the region bounded on the top by the hypothetical Worst Case Energy Profile and bounded on the bottom by the hypothetical Best Case Energy Profile. Given that the actual real-life curve is unknown, the Approximate Energy Profile may be assumed to be a reasonable approximation for the energy use no matter where the actual curve may lie. With the Approximate Energy Profile, the energy use of all potential behaviors may be estimated even without knowing what those specific behaviors are.

In conjunction with the ordering of energy use from highest to lowest, another assumption was added that high energy behaviors corresponded to low occupant effort (inactive operation of manual shades) at the sacrifice of view through windows and that low energy behaviors corresponded to high effort (active operation of manual shades) with the benefit of more view hours.

This assumption lends itself to the consequence that the highest energy use was improbable because it sacrificed view and that the lowest energy case was also improbable because it required high effort. It was further assumed that moving along the curve towards the center from either extreme resulted in more likely behaviors.

A Gaussian distribution was assumed for this center-weighted characteristic. Given the statistically significant estimated population of occupants affected by changes to Title 24, Part 6, a Gaussian distribution was assumed to be appropriate. The curve is illustrated in Figure 63.

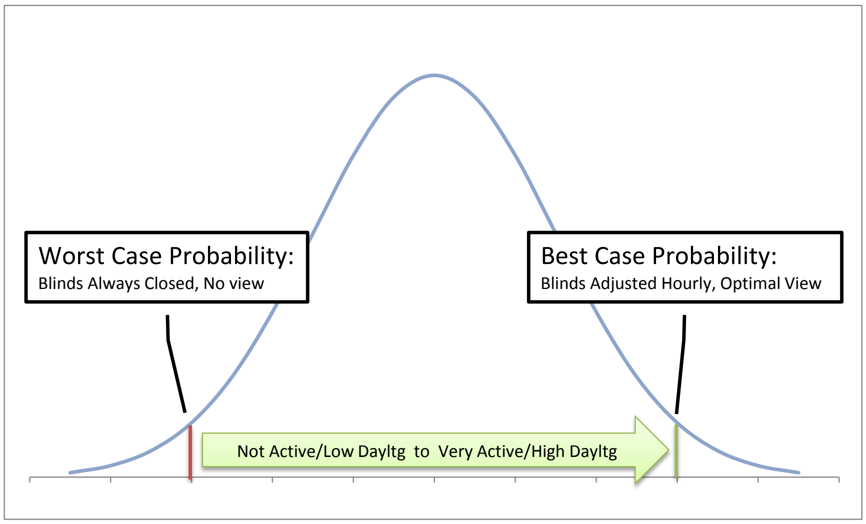

Figure 63: Assumed manual shade operation probability

If it is assumed that enough of the behaviors have been captured between the extremes (i.e., the Worst and Best Case are near the tails of the distribution), then a probability-weighted energy use could be calculated from these two curves.

Furthermore, due to the symmetry of the assumptions the probability-weighted average can be simplified. In this case, if the Approximate Energy Profile is linear and no skew is assumed for the probability distribution, the probability-weighted average energy use simplifies to the simple average of the Worst and Best Case endpoints of the Approximate Energy Profile.

Appendix D: Determination of Good Case and Bad Case Manual Shade Behavior

Shade Properties

To set shade properties for the Bad Case, venetian blinds that were tilted to full shut and completely covered the window were selected. For the Good Case, a diffusing shade which still permitted daylight into the space was selected. This diffusing shade is a perfectly Lambertian diffusing material available in the WINDOW 7 program. For the Good Case, since daylight still entered the space even when shades were closed, glare could occur even with closed shades. After various test runs in Climate Zone 12 at 40, 20, 10, 5, and 1 percent transmittance, it was found that at transmittances higher than one percent glare occurred frequently even through closed shades. At one percent transmittance, glare only occurred around 20 percent of the time when shades were closed. Therefore, a one percent transmittance was selected.

Even though a transmittance of one percent may be interpreted as low, the diffusing property of the shade resulted in a shading system that still permitted daylighting with shades closed. To analyze the extent of this phenomenon annual lighting energy with shades never closed was compared to annual lighting energy with the one percent diffusing shades always closed. This scenario was examined in Climate Zone 12 for the base view-window-only case and all fixed slat configurations with all WWRs, all control types, all setpoints, and all zones. Figure 64 is a graphic of the increase in lighting energy when shades were always closed versus shades never closed.

For more than a majority of the cases even with shades closed all year, the increase in lighting energy was only 15 percent. For more than 90 percent of the cases the energy only increased 40 percent. These thresholds were considered adequate to consider a 1 percent transmittance diffusing shade as a “Good Case” shade material.

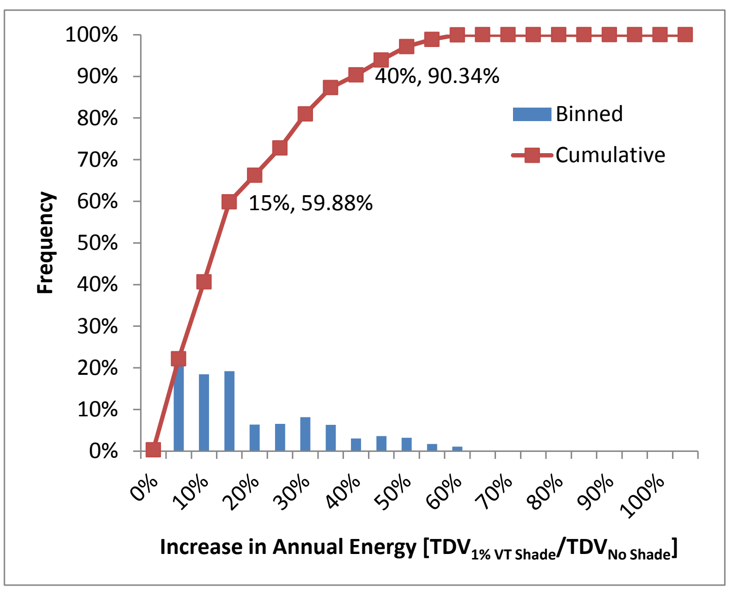

Figure 64: Shades never closed versus 1% VT diffusing shades always closed

Adjustment

In the University of Idaho review (Van Den Wymelenberg 2012) it was documented that studies found that around seven percent of manual shades were adjusted daily or multiple times per day (Rubin, Collins and Tibbott 1978, Nicol, Wilson and Chiancarella 2006). In addition, precedence has been set for modeling manual shade adjustment once in the morning and again in the afternoon (Jakubiec and Reinhardt 2012). This guided in selection of the adjustment frequency for the Good Case for daylighting.

On the other end of the spectrum, the review documented a study that showed that from February through May, 30 percent of occupants never adjusted their shades (Pigg, Eilers and Reed 1996). Shades that remained opened accounted for most of these, implying that the remaining small portion were shades that remained closed. Another study of six office buildings found that some shades were almost never adjusted over the four to seven-month period of the study. In addition, precedence has been set for modeling manual shade adjustment that is closed for many months (Newsham 1994). This guided in selection of the adjustment frequency for the Bad Case for daylighting.

There was conflicting evidence as to whether orientation affected the time of day for shade adjustment. One study found that orientation had no effect (M. S. Rea 1984) while two studies documented that orientation did have an effect (Littlefair 2002, Inoue, et al. 1988). Where an affect was documented, east-facing orientation orientations tended to adjust in the afternoon, versus south and west-facing orientations which tended to adjust in the mornings (Inoue, et al. 1988).

Discomfort Glare

To capture the effects of glare and any technologies which mitigate it, it was assumed that whenever an occupant encounters discomfort glare they close their shades.

Historically there have been many glare metrics developed. But the science of discomfort glare has not yet found a metric that is widely accepted among experts. A discussion of the available metrics and the rationale for the selection of the metric chosen for this study follows.

The Daylight Glare Index (DGI) was created in 1972 (Hopkinson 1972) and updated in 2001 (Nazzal 2001). DGI was derived for diffuse sky conditions. The proposed measures are intended to mitigate direct beam sunlight so this metric is not considered adequate.

Visual Comfort Probability (VCP) was defined by the Illuminating Engineering Society of North America (IESNA) and it takes a probabilistic approach to predicting glare. This feature works nicely with the proposed bounded statistical method. However, this metric was developed for artificial light sources which are not comparable to sky and sunlight conditions.

The Commission Internationale de l'Eclairage Glare Index (CGI) (Einhorn 1979) was developed using a body of studies existing at the time. However, no actual subjects were tested during its development. The Uniform Glare Rating (CIE Technical Committee 3-13 1995) was developed to simplify the calculation of glare required for CGI. The testing used in its development is unknown.

IES-LM-83 developed a daylight metric which used two percent of the floor area over 1000 lux as the threshold for glare. This makes this approach sensitive to the specific floor area being analyzed. This metric is also less sensitive to glare at low solar elevations, exactly when direct beam sunlight may reach occupants eyes on the east and west. Since the specific floor area is unknown when creating a standard and the sensitivity of occupants on the east and west was important for the analysis, this metric was not selected.

An exhaustive study was performed using data from 48 participants (Wymelenberg and Inanici 2015). More than 2000 existing and proposed luminance based metrics were compared to this data. The

Standard Deviation of Window Luminance showed a correlation higher than any other metric. However, at this time this metric only has preliminary thresholds for criteria development and has not been fully developed.

Daylight Glare Probability (DGP) measures by the probability that a person is disturbed instead of the glare magnitude (Wienold and Christoffersen, Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras and RADIANCE 2006). This coincides well with the proposed measure's probabilistic approach. The scale is based on data from 76 subjects from two different countries. Additional testing of another 28 subjects confirmed the correlation (Wienold, Daylight Glare analysis and metrics n.d.). It also has subject matter expert support (Lee 2017).

Comparing the above metrics DGP was assumed to have the most all around merit and pertinence to the proposed methodology. It has a large sample size, is a probabilistic metric (which aligns with the proposed methodology), is not sensitive to floor area, can account for low angle solar elevations, and has been verified in a separate study.

However, it is worth noting that the approach used in this study is less sensitive to the glare metric and is more sensitive to the duration of shade closure. Shade closure is the parameter which directly affects energy use; glare is simply the trigger for that closure. One glare metric may sense glare for a particular hour where another does not, but the overall annual energy impact would be similar. In short, what is important is that the Bad Case senses glare often and closes shades for an extended period and that the Good Case senses glare less often and closes shades for short periods.

Tuning

As mentioned above, shade closure affects the daylighting energy savings. The more time shades are closed, the less available daylight there is. Using the above as guidelines, shade closure frequency was calculated with variations on sensitivity to glare and how often occupants checked if they could reopen their shades. This was analyzed in a simulated office[9] (30 percent WWR) in Climate Zone 12. Results are presented in Table 17.

[9] The majority of studies referenced in this analysis studied offices.

Table 17: Annual Shade Closure Frequency by DGP and Reopen Check Interval

	DGP	Minimum Reopen Check Interval	East	South	West	Average
Good Case	0.40	Daily: 8 am and 1 pm	78%	59%	68%	68%
	0.45	Daily: 8 am and 1 pm	18%	51%	50%	40%
	0.50	Daily: 8 am and 1 pm	15%	45%	36%	32%
	0.55	Daily: 8 am and 1 pm	15%	41%	28%	28%
	0.60	Daily: 8 am and 1 pm	15%	39%	25%	26%
	0.65	Daily: 8 am and 1 pm	14%	37%	23%	25%
Bad Case	0.30	After a week: E: 1 pm, S/W: 8 am	100%	99%	100%	99%
		After two weeks: E: 1 pm, S/W: 8 am	100%	99%	100%	100%
		After three weeks: E: 1 pm, S/W: 8 am	100%	99%	100%	100%
		After four weeks: E: 1 pm, S/W: 8 am	100%	99%	100%	100%
	0.35	After a week: E: 1 pm, S/W: 8 am	99%	82%	98%	93%
		After two weeks: E: 1 pm, S/W: 8 am	99%	84%	100%	94%
		After three weeks: E: 1 pm, S/W: 8 am	100%	86%	100%	95%
		After four weeks: E: 1 pm, S/W: 8 am	100%	83%	99%	94%
	0.40	After a week: E: 1 pm, S/W: 8 am	95%	67%	74%	79%
		After two weeks: E: 1 pm, S/W: 8 am	97%	70%	75%	81%
		After three weeks: E: 1 pm, S/W: 8 am	98%	72%	79%	83%
		After four weeks: E: 1 pm, S/W: 8 am	99%	68%	79%	82%

For all cases, if a glare threshold was passed during occupied hours, the shades were closed. Once the shades were closed, they were only reopened during occupied hours and only at the times specified.

Note that east-facing exposures always had a 1 pm check time versus an 8 am check time. Without this, east-facing exposures always had closed shades for all cases. This afternoon checking for east-facing facades was backed up by data from the studies mentioned above.

For the Good Case, checking more than once a day if shades could be reopened was documented in the studies so this was modeled. Specifically, 8 am and 1 pm were selected to model an occupant arriving in the morning and checking and checking again when returning from lunch.

Shade closure frequency began to level off for DGP higher than 0.60 for the Good Case; no further increase in glare tolerance would meaningfully decrease the shade closure frequency. Given this leveling off, 0.60 seemed the minimum DGP that could be representative of the maximum daylighting potential.

For the Bad Case the guidance about the duration of shade closure was that some shades go virtually unadjusted for months. At 0.30 and 0.35, on average, the shades were virtually closed year-round. Year-round closure was never documented in the studies and would not provide meaningful differences when comparing technologies. It is not until a DGP of 0.40 that months-long closure results on average.

DGPs higher than 0.40 were not considered for the Bad Case because 0.40 is the boundary between "perceptible" and "disturbing", i.e., any higher is usually considered disturbing glare. For this reason, any level higher than 0.40 was not considered defensible for the Bad Case.

Considering the above discussion, a DGP of 0.40 was selected for the Bad Case. The shade closure frequency was relatively insensitive to the number of weeks of closure. A minimum reopen check interval of three weeks was selected because it had the highest average shade closure for the cases for 0.40 DGP.

A graph of DGP and shade closure intervals for the Good and Bad Case on the southern façade for the first half of the year is given in Figure 65. The grey line represents the DGP with no shading. The red line represents the Good Case response to DGP. The black line represents the Bad Case response. A value of one for the red and green line represents a closed shade.

The red line oscillates much more frequently between open and closed. This demonstrates that the Good Case occupant opens and closes blinds more actively. The Bad Case oscillates infrequently between open and closed.

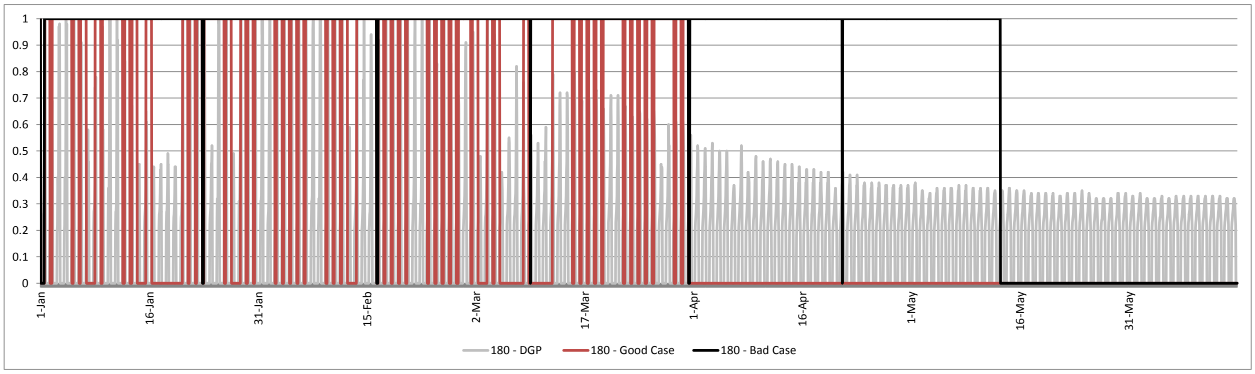

Figure 65: Good and bad case manual shade closure: Climate Zone 12 office, southern façade

Appendix E: CODE IMPLEMENTATION CONSIDERATIONS

PAFs

To simplify the code, the large set of results of all savings for all analyzed parameters was reduced to the set of parametric values that provided a minimum level of savings. If this had not been done, the PAFs would comprise several pages of a complex table in the code.

The proposed PAFs were calculated using a conservative approach. In this way, some energy savings are likely to be seen with their inclusion in Title 24, Part 6. As evidenced in the figures in Section 4.3, TDV energy savings were generally higher than the 5 to 7 percent used in the PAFs.

A one-foot clerestory was used in the analysis. In the Statewide CASE Team's experience, this represented a short clerestory rarely seen in buildings. Taller clerestories are generally expected and will usually result in higher energy savings.

To simplify the PAFs, PAFs were given on a statewide basis as is consistent with all previous PAFs.

Slat projection is similar to overhang projection so similar requirements were included to ensure that the slats extended beyond the sides of the window jambs so as not to permit glare from entering through the side. For the prescriptive path, slats are also required to extend the entire height of the fenestration. This ensures that the cutoff angle is consistent. Shorter extensions will be allowed in the performance method.

Only opaque slats were modeled in the analysis and these will be currently permitted. Daylighting experts on the Statewide CASE Team also deemed that perforated slats and low visible transmittance slats should be allowed to be inclusive products on the market.

The relative slat thickness to slat spacing affects how much daylight enters the space. Thick slats with tight spacing effectively block daylight from entering. Therefore, a maximum slat thickness requirement was considered, but the Statewide CASE Team determined that it was not necessary. It is assumed that the demand for occupant view will motivate designs that are not thick enough to obscure view. This design preference to maximize view was in turn assumed to be adequate to provide adequate daylight.

The slat projection factor captures all slat angles that meet a particular cutoff angle. The modeling results and their corresponding cutoff angle and slat angle were investigated to determine appropriate ranges for the slat projection factor that would yield a minimum lighting energy savings. To allow for possible future technologies, the code language allows adjustment of slats, but only if the adjustments are limited to within the range of the fixed slat requirement.

For simplicity, slat projections were rounded to the nearest whole number. This generally only affected the cutoff angle by a small amount: a 3.0 projection factor is a cutoff angle of 18 degrees instead of the targeted 20 degrees, a 2.0 projection factor is a cutoff angle of 26.5 degrees instead of the targeted 25 degrees, and a 1.0 projection factor is a cutoff angle of 45 degrees instead of the targeted 40 degrees.

If there is no direct sun to block, then slats and DRDs do not add any value to a design. They show no savings. For slats, if an object is reaches higher than the cutoff angle, then it is blocking the direct sunlight that the slat would have blocked had the object not been there.

If an object's distance factor is defined as its distance divided by its elevation, then an examination of the solar positions from the SOLPAS data showed that if a window has slats with a projection factor of PR, if an object is has a distance factor of 0.3 times PR, the object is blocking as many sunlight exposure hours below the slat's cutoff angle as the slat would block above the cutoff angle. Per this analysis, a requirement that objects have a distance factor of at least 0.3 times a slat's projection factor was added.

For example, if an east-facing window on the lowest floor of a building has slats with a 2.0 projection factor then any objects blocking the window must be at least 0.3 x 2.0 = 0.6 times as far away compared to their height above the window sill. If a 3-story, 40-foot tall building is across the street, then the street plus sidewalk, etc., must be at least 24-feet.

The above analysis assumes that an object spans the width of the view from the window. This is not a bad approximation for many cases, such as a typical street that is zoned for maximum building heights or landscapes with regular terrain. In the case where designs may have a more irregular view from the window an exception was added, the 50 percent minimum frequency of blocked direct beam sunlight seen in Figure 6 was used to determine this exception.

Per the SOLPAS data the average exposure to the sun during occupied hours (8 a.m. to 5 p.m.) is about 1,000 hours on the east and west and about 1,500 hours on the south. Applying the minimum 50 percent from above this translated to 500 hours on the east and west and 750 hours on the south.

Per the BSDFs for LightLouver and the 3M DRF, above a 30-degree solar elevation corresponded to the range of their maximum transmission in the upward direction. Therefore, DRDs had a similar requirement added except that the distance factor was determined by a 30-degree solar elevation, i.e., a distance factor of 0.6.

In Figure 42 a general trend of increase in savings with increase in reflectance can be seen for slats. However, requiring a high reflectance would limit the aesthetic choices of designers and discourage use of the slats. Aluminum is the material of choice for a large portion of manufactured fixed slats and uncoated aluminum has a reflectance of 0.55, so this also fits well with market availability and designer choice. Therefore, a minimum reflectance of 0.5 was deemed reasonable. Using the aging formulas for reflectance in Section 4.2.1.1 a new reflectance of 0.5 corresponded to an aged reflectance range of 0.35. This implied that requiring a minimum reflectance of 0.5 in the code would result in long-term savings corresponding to 0.35 reflectance.

Light shelves must be mounted below a finished ceiling so that the ceiling surface can redirect the daylight downwards, therefore a requirement was added that light shelves be mounted one foot below a finished ceiling.

The Statewide CASE Team decided that using the proposed slat projection ratios for the overhang required with light shelves resulted in overhang lengths that were not practical. In fact, some ratios went beyond the proposed overhang exception for secondary controls. As such, the results from the large overhang analysis were used to determine the overhang depth. The overhang analysis showed savings loss for east and west-facing overhangs, so no PAF was given for light shelves at these orientations.

Clerestory savings were determined using a one-foot clerestory on a 10-foot façade. The absolute height of the clerestory is not relevant to daylighting, but rather the clerestory's height relative to the sidelit daylit zone depth, which, in turn, is related to the clerestory's head height. Therefore, the height of the clerestory relative to the clerestory head height was set as the requirement. Consideration was given to ceilings with exposed ducts, but the Statewide CASE Team decided that these cases need not be handled by the PAF.

Historically, Title 24, Part 6 has not specified the location of blinds. However, the Statewide CASE Team's experience held that having separate blinds between clerestory and view window was a critical feature to maintain energy savings. So, a requirement was included that, in the case that blinds are installed, they must be controlled and separate between clerestory and view window. The Statewide CASE Team expects that this will mostly apply to tenant improvement projects.

Currently, there is no industry standard metric for daylight redirecting devices. An Energy Commission approval requirement was discussed but the level of effort to implement this was considered too onerous. In addition, the Attachments Energy Rating Council has already been formed to develop methodologies and metrics to rate the performance of devices like these. However, neither their methodology nor metric will be ready for the 2019 update. It is expected that they will be ready for the 2022 update. To maintain that daylight redirecting devices be ready for gradual implementation before the 2030 code cycle a simple metric was developed in the interim.

The proposed metric first ensures that adequate light is directed at the ceiling by setting a minimum transmittance upwards. Then, to ensure that daylight is actually being redirected, a minimum ratio of transmittance upwards versus transmittance downwards was set.

ASTM E2387 was used as the base for the methodology of the requirement, but a couple of new definitions in Title 24, Part 6 were added to facilitate communication of the requirements. Some stakeholders expressed concerns that the ASTM E2387 procedure for goniophotometers could not be used to test devices with "large" features such as LightLouver. Research showed that goniophotometers exist that are large enough to accommodate the LightLouver, and ASTM E2387's section 6.3.2.1 addresses the need for averaging for larger features. ASTM E2387 was therefore considered adequate.

The specific threshold level for the minimum transmittance and transmittance ratio was determined using the BSDFs of LightLouver and the 3M DRF.

PAFs must be simple and flexible so that their use is encouraged and compliance is workable. Therefore, the number of PAFs available was reduced considering the expected common cases for implementation combined with a consideration of pushing for higher-efficiency options. Under these guidelines, the PAFs controls were limited to requiring continuous dimming controls in both the primary and secondary sidelit daylit zones, and a range of fixed slat geometry. A setpoint of 300 lux was assumed for the savings values. Figure 66 illustrates an example of a slat geometry that would comply under the proposed requirements set in Section 7.1.

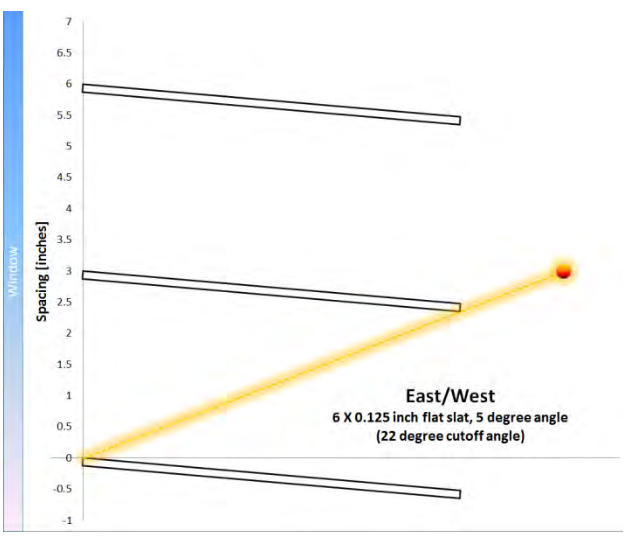

Figure 66: PAF slat geometry example

Certain PAFs were allowed to be added to other PAFs because they complement each other. Daylight dimming plus OFF will further extend the energy savings of any of the proposed measures. Clerestories or daylight redirecting devices can be installed along with fixed slats on the view window. The energy savings from both technologies can then be realized.

Exterior-mounted devices are effectively fins that can expose the interior of the building to a large surface area of heat exchange with the outdoor environment, but the Statewide CASE Team decided that requiring a thermal break would be complex and onerous on manufacturers and designers and was not necessary considering the mild climate of California.

Performance Compliance Option

A software program performs all the savings lookups and calculations for compliance. Therefore, contrary to PAFs, a compliance option in the performance approach can have many options without being as onerous on the designer. For this reason, the remaining savings results for WWR, control type, setpoint, cutoff angle, and slat angle that were analyzed in this study can be included in the performance approach. The user will simply select the parameters of their proposed design and the software will perform the lookups, adjustments, and calculations. In addition, adjustments for slat visible reflectance and window VT will be included.

Some installations of fixed slats have an interstitial space between the slats and the window for access, aesthetics, or to mitigate a thermal bridge. This gap is not used on all installations and is not necessary but it is common. Figure 67 illustrates an example. The proposed measure would allow this configuration in the performance approach but adjustments must be made to the PAFs to account for any loss in savings.

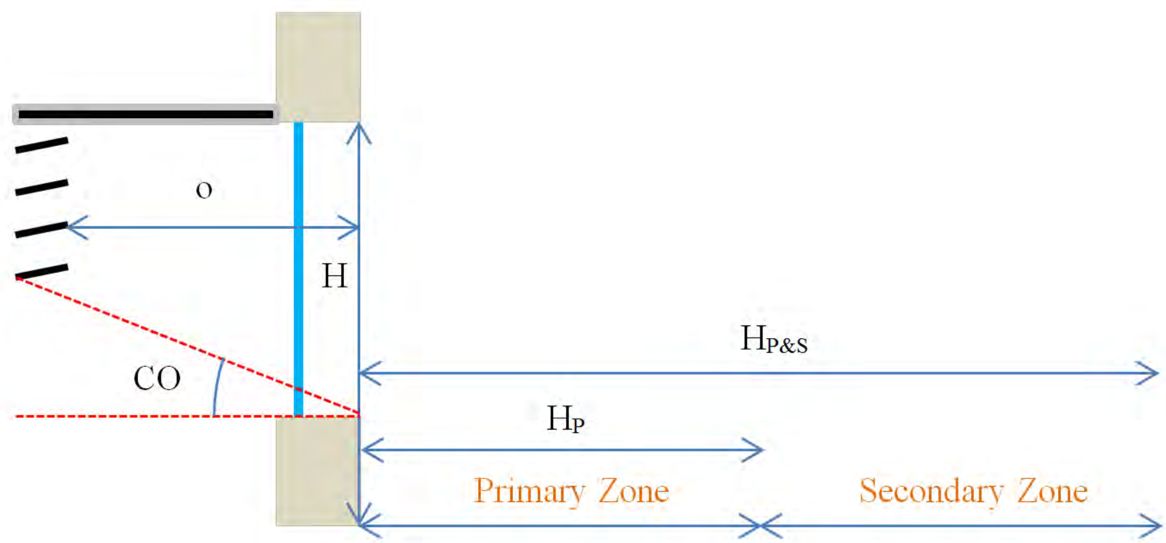

Figure 67: Fixed slats suspended from an overhang

As the projection of the slats increases, the slats are offset from the window. This means that the daylit surface of the slat moves farther from the space. As this light moves farther away from the space, it's intensity in the space drops off inversely with the square of distance. This effect decreases the daylight level and associated savings. An adjustment to account for this loss in savings will be included in the performance approach.

When slats do not cover the entire height of the window, the cutoff angle of the front edge of the lowermost slat needs to be considered. Figure 67 illustrates the case. To ensure that direct beam sunlight remains blocked for the number of hours used in the savings calculations, the cutoff angle, CO, of the front edge must be less than or equal to the slat geometry's cutoff angle. The performance approach will not allow proposed designs which do not meet this requirement.