CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

2008 CEC Title 24 Building Energy Efficiency Standards Rulemaking Proceeding
July 5, 2006

Draft Report
Updates to Skylighting Requirements

DOCKET
07-BSTD-1
DATE JUL 05 2006
RECD. APR 29 2008

This report was prepared by Pacific Gas and Electric Company and funded by the California utility customers under the auspices of the California Public Utilities Commission.

Copyright 2006 Pacific Gas and Electric Company.

All rights reserved, except that this document may be used, copied, and distributed without modification.

Neither PG&E nor any of its employees makes any warranty, express of implied; or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any data, information, method, product, policy or process disclosed in this document; or represents that its use will not infringe any privately-owned rights including, but not limited to, patents, trademarks or copyrights

Created on 7/5/2006 11:28 AM

Table of Contents

Overview ***3***

Description *3*
Energy Benefits *5*
Non-energy Benefits *5*
Statewide Energy Impacts *5*
Environmental Impact *5*
Type of Change *5*
Technology Measures *6*
Performance Verification *8*
Cost Effectiveness *8*
Analysis Tools *8*
Relationship to Other Measures *8*

Methodology ***8***

Revised Power Adjustment Factors *8*
Minimum Space Size Requirements for Skylighting *9*

Results ***14***

Revised Power Adjustment Factors *14*
Minimum Space Size Requirements for Skylighting *15*
Well efficiency of specular light pipes *23*
Statewide Energy Savings *27*

Recommendations ***27***

Proposed Standards Language *27*
Alternative Calculation Manual *43*
Nonresidential Compliance Manual *53*

Bibliography and Other Research ***53***

Acknowledgments ***54***

Appendix 1: B/C Ratios for Skylighting Minimum Area Criteria ***55***

Appendix 2: Market Response to Skylights and Photocontrol Adoption ***65***

Summary of Results *65*
Methodology *65*
Results *67*
Summary *71*

Document information

Category: Codes and Standards

Keywords: PG&E CASE, Codes and Standards Enhancements, Title 24, nonresidential, 2008, efficiency

Overview

Skylighting as an energy savings measure was introduced for the first time in the 2005 revision to Title 24. As a first time measure, the breadth of the scope was conservative and some of the language was found to be convoluted. After further review, we found that the skylight U-factor and SHGC requirements give credit to skylights that use the default fenestration product U-factors and SHGC's in tables 116A and B or the defaults in Table NI-1 of the Appendix NI of the ACM Manual. The default table U-factors are lower than the prescriptive U-factors required in table 143(a). This is a problem because plans that are submitted using the performance approach receive compliance credit using minimally compliant skylights from the default tables and can use this credit to reduce the efficiency of other building features.

From interviews with 60 building departments and review of a couple of daylighting controls plans, we found no projects in our sample that are using the astronomical time switch option for indoor daylighting controls. Thus in large daylit spaces where daylight responsive controls are required, photocontrols should be required and not given compliance credit. This proposal intends to increase the scope of the skylighting requirements, clarify the language and close loopholes. This will ultimately yield significant cost-effective savings for the state of California

Description

The upgrades to the skylighting requirements are:

- **Minimum space size that triggers requirements for skylighting**. Currently the criteria for requiring skylights is in low-rise spaces greater than 25,000 sf directly under a roof, the ceiling height is taller than 15 feet, and have general lighting power density greater than 0.5 W/sf. This proposal finds that it is cost-effective to drop the size requirement to spaces that are greater than 8,000 sf. The research for this proposal also considered lowering the ceiling height but found that the cost of the light well and the reduced allowable spacing for sufficient uniformity resulted in substantially higher systems costs.

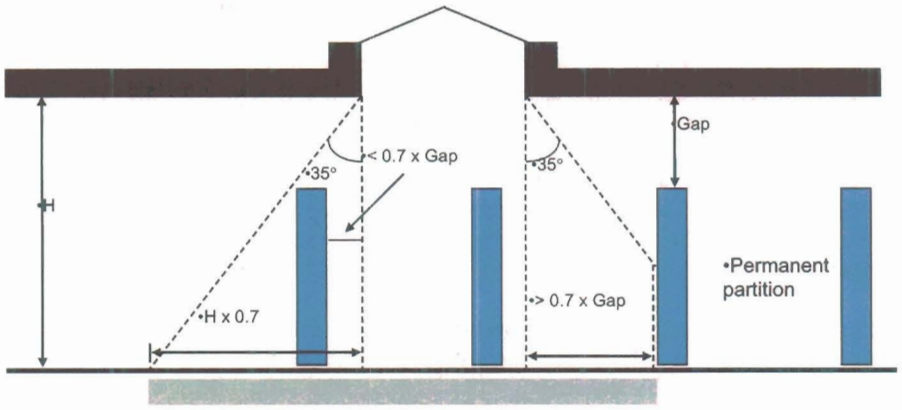


Figure 1: Proposed skylit area under skylights

- **Daylit area under skylights**. The current definition of the daylit area under skylights, limits the boundary of this area to "the rough opening of the skylight plus, in each of the lateral and longitudinal dimensions of the skylight, the lesser of 70% of the floor-to-ceiling height, the *distance to the nearest 60-inch or higher permanent partition…*" Often the actual availability of daylight is not limited by 5 foot tall partitions. The new definition would revise this definition so that the daylit areas is limited only partitions that are further

away than 70% of the height of the space between the top of the partition and the ceiling. This change is illustrated in Figure 1. In the 2005 definition, the daylit area would end at the partition to the left of the skylight if the partition where greater than 5 feet tall. To differentiate from the sidelit area by windows, we are also changing the terminology from daylit area to "skylit area" under skylights.

- **Photocontrols required in the skylit area under skylights**. Currently, when the skylit area under skylights in a space is greater than 2,500 sf, automatic multi-level daylighting controls are required. Currently, this would allow either astronomical time switches or photocontrols. The astronomical time switch is thought to save less energy but designers are more familiar with this technology than photocontrols. Currently one receives a lighting control credit for using photocontrols. This proposal would require the use of photocontrols in large skylit zones and remove the control credit in these cases. Astronomical time switches would be an allowed alternative only when there is a substantial amount of daylight in the space. In this case, the effect of overcast skies does not impact the design significantly.

- **Lighting control credits allowed only when total daylit area in an enclosed space is less than 2,500 sf.** This recognizes that photocontrols now required in most cases. This increases the stringency of the standard.

- **Lighting control credits updated.** The power adjustment factors (PAF) in the 2005 standards were based upon a regression equation. The form of the equation, though useful for most commonly found configurations gave relatively accurate results, this equation could provide inaccurate results when the effective aperture was either very high or very low. In addition, there was no guidance to the plans checker what the range of the values would be merely by looking at the equation. Thus for ease of enforcement, a look up table is proposed for the PAFs.

- **Exempt multi-level requirement for daylighting controls when LPD is lower than 0.5 W/sf**. This recognizes that metal halide lighting systems designed to low lighting power densities below 0.5 W/sf may not have even 1-1/2 lamps per skylight. This would still require a single level photocontrol.

- **Single level controls for skylight retrofits**. For existing buildings that are under consideration for adding skylights, the multi-level daylighting controls can be fairly expensive if re-circuiting to provide multi-level daylighting control is required. In this proposal, we are recommending that one could use single level photocontrols in skylighting retrofits as long as all the luminaires controlled are in the daylit area under skylights. This can be easily achieved if the skylighting retrofit is daylighting the entire space.

- **Requirement for a deadband adjustment.** The current standards require that photocontrols have a deadband between on and off light levels for each control step. However, if this deadband is not adjustable, the steps can be too wide resulting in less than optimal energy savings and if the deadband is too narrow this will lead to cycling on and off of the lights and ultimately disabling of the controls.

- **Clarify area controls and multi-level switching requirements**. This is for clarification and ease of enforcement only. Features of the control are separated from how the control is installed. Thus the feature of the photocontrol (adjustable deadband) is placed in Section 119 while how the controls are installed to control lighting (such as multi-level requirements) are placed in Section 131(c).

- **Update the skylight U-factor and SHGC requirements to match default skylight properties.** Many of the plastic skylights sold in California do not have NFRC ratings. As a result, they are evaluated by the standards using the properties for skylights in the default fenestration tables (Tables 116A&B). The U-factor and SHGC requirements in Table 143a essentially require double glazed tinted skylights with thermally broken metal frames to comply. However, these requirements in table 143a are slightly less stringent that the default skylight properties. As a result, when one uses the performance approach to model the skylights, compliance credit is given which can be used to reduce the efficiency of another part of the building. We propose to eliminate this loophole by matching the values in Table 143a to the values in the default table.

Energy Benefits

On average, the addition of skylights and photocontrols save approximately 1.8 kWh/sf of building stock. More energy is saved in big box retail and less energy is saved in warehouses.

Non-energy Benefits

Thoughtful design of buildings using daylight can improve lighting quality and increase productivity (HMG 1999, Heschong et al 2001).

Statewide Energy Impacts

This estimate will be conducted for the final CASE report on skylighting.

Environmental Impact

The environmental impacts of this measure are overwhelmingly positive. Commercial skylights are primarily a plastic glazing held in place with an extruded aluminum frame. They displace a similar area's worth of roofing product and are often mounted on a wood site assembled curb. Photocontrols consist of a silicon photodetector and a control module, which is a printed circuit board and electronic components. A very small amount of these materials are used to save large amounts of electricity. Lighting is switched with relays – many of which already are required for automatic shut-off controls requirement in Title 24 §131(d). Peak demand savings from daylighting lead to reduced emissions from peaking power plants.

The emissions impacts of this measure are calculated by multiplying the change in statewide electricity and natural gas consumption by the respective emissions factor values generated by the California Energy Commission for evaluating the environmental impacts of the 2005 standards as shown in Table 1 below.[1]

Table 1:Emissions Factors used to calculate the air emissions reductions resulting from end-use reductions in electricity and natural gas consumption

Emissions factors	NOx	CO	CO2	PM10
Natural Gas, California (lbs/MMBtu)	0.094	0.03	115	0.01
Electricity, Western States (lbs/MWh)	0.383	0.23	1200	0.06

Statewide environmental impacts will be generated at the same time as the statewide energy savings estimate.

Type of Change

This proposal updates the skylight requirements in several sections and thus results in changes to the mandatory, prescriptive and performance section of the standards.

[1] Table 1, Appendix B page 2, Initial Study/Proposed Negative Declaration for the 2005 Building Energy Efficiency Standards for Residential and Nonresidential Buildings September 2003 P400-03-018 http://www.energy.ca.gov/reports/2003-09-12_400-03-018.PDF Values provided by the CEC System Assessment and Facilities Siting Division.

Mandatory Measure	Changes to requirements for photocontrols (§119) and the daylighting control requirements (§131(c)) are mandatory and cannot be traded off against equivalent measures. The photocontrol requirements in section 131(c) are triggered by the presence of skylights.
Prescriptive Requirement	The change would add or modify the prescriptive requirement for when skylighting is required in Section 143(c) and the required material properties of skylights over conditioned spaces in Section 143(a). Prescriptive requirements must be met for prescriptive compliance and define the Standards baseline building in performance calculations, but are not mandatory when the performance approach is used.
Compliance Option	The change would add a new means to comply with the standards by adding a new compliance option. This could be a simple energy credit, or it could entail a relatively complex analysis procedure.
Modeling	The change would modify the calculation procedures or assumptions used in making performance calculations. This change would not add a compliance option or a new requirement, but would affect the way that tradeoffs are made. We are proposing that the savings from photocontrols be directly calculated within the compliance software calculation kernel instead of using a fixed reduced lighting power density.

Technology Measures

This proposal encourages the use of natural light through the installation of skylights, and at the same time reduces electric lighting in daylit zones through the use of automatic controls. Skylights are essentially "roof windows" designed to keep water out but let light in. Since most nonresidential floor space is directly under a roof, opening up a small fraction (typically 3% - 5%) of the roof area to take advantage of available natural light can provide most of the lighting requirements for most of the daytime hours. Skylight technology is relatively well developed, with many manufacturers mass producing skylights.

Adding skylights by themselves does not save energy – the energy savings are realized when electric lighting is reduced in response to available daylight. This concept of automatically turning off or reducing electric lighting during times when sufficient daylight is available is commonly used for street lighting and other outdoor lighting applications and is a mandatory requirement for nonresidential exterior lighting in the building efficiency standards (see 2005 Title 24 §131f). This code change proposal would expand requirements for automatic daylighting controls to buildings that have enough skylights and enough installed lighting power to render daylighting controls cost effective. Photocontrols measure the amount of daylight entering a space and automatically switch off lights or send a signal to dim lights. When lights are switched off, this uses the well-established relay technology that operates almost any automatically controlled electrical device from elevators to traffic lights. The technology to dim ballasted lamps is not as established but has been available in the lighting market for over a decade.

Measure Availability and Cost

Skylight manufacturers with whom we spoke are confident that they can ramp up quickly to accommodate increased demand for skylights in California. This is because much of their current capacity is exported outside of the state and can be diverted to California in the short term while additional production lines are installed. Capital costs for installing new production lines are relatively inexpensive. Installed costs for a 32 square foot skylight are

Overview

Skylighting as an energy savings measure was introduced for the first time in the 2005 revision to Title 24. As a first time measure, the breadth of the scope was conservative and some of the language was found to be convoluted. After further review, we found that the skylight U-factor and SHGC requirements give credit to skylights that use the default fenestration product U-factors and SHGC's in tables 116A and B or the defaults in Table NI-1 of the Appendix NI of the ACM Manual. The default table U-factors are lower than the prescriptive U-factors required in table 143(a). This is a problem because plans that are submitted using the performance approach receive compliance credit using minimally compliant skylights from the default tables and can use this credit to reduce the efficiency of other building features.

From interviews with 60 building departments and review of a couple of daylighting controls plans, we found no projects in our sample that are using the astronomical time switch option for indoor daylighting controls. Thus in large daylit spaces where daylight responsive controls are required, photocontrols should be required and not given compliance credit. This proposal intends to increase the scope of the skylighting requirements, clarify the language and close loopholes. This will ultimately yield significant cost-effective savings for the state of California

Description

The upgrades to the skylighting requirements are:

- **Minimum space size that triggers requirements for skylighting**. Currently the criteria for requiring skylights is in low-rise spaces greater than 25,000 sf directly under a roof, the ceiling height is taller than 15 feet, and have general lighting power density greater than 0.5 W/sf. This proposal finds that it is cost-effective to drop the size requirement to spaces that are greater than 8,000 sf. The research for this proposal also considered lowering the ceiling height but found that the cost of the light well and the reduced allowable spacing for sufficient uniformity resulted in substantially higher systems costs.

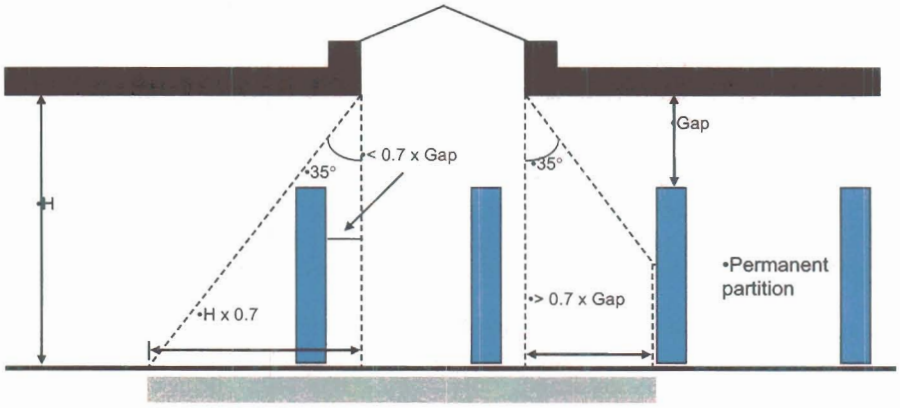


Figure 1: Proposed skylit area under skylights

- **Daylit area under skylights**. The current definition of the daylit area under skylights, limits the boundary of this area to "the rough opening of the skylight plus, in each of the lateral and longitudinal dimensions of the skylight, the lesser of 70% of the floor-to-ceiling height, the *distance to the nearest 60-inch or higher permanent partition…*" Often the actual availability of daylight is not limited by 5 foot tall partitions. The new definition would revise this definition so that the daylit areas is limited only partitions that are further

away than 70% of the height of the space between the top of the partition and the ceiling. This change is illustrated in Figure 1. In the 2005 definition, the daylit area would end at the partition to the left of the skylight if the partition where greater than 5 feet tall. To differentiate from the sidelit area by windows, we are also changing the terminology from daylit area to "skylit area" under skylights.

- **Photocontrols required in the skylit area under skylights**. Currently, when the skylit area under skylights in a space is greater than 2,500 sf, automatic multi-level daylighting controls are required. Currently, this would allow either astronomical time switches or photocontrols. The astronomical time switch is thought to save less energy but designers are more familiar with this technology than photocontrols. Currently one receives a lighting control credit for using photocontrols. This proposal would require the use of photocontrols in large skylit zones and remove the control credit in these cases. Astronomical time switches would be an allowed alternative only when there is a substantial amount of daylight in the space. In this case, the effect of overcast skies does not impact the design significantly.

- **Lighting control credits allowed only when total daylit area in an enclosed space is less than 2,500 sf.** This recognizes that photocontrols now required in most cases. This increases the stringency of the standard.

- **Lighting control credits updated.** The power adjustment factors (PAF) in the 2005 standards were based upon a regression equation. The form of the equation, though useful for most commonly found configurations gave relatively accurate results, this equation could provide inaccurate results when the effective aperture was either very high or very low. In addition, there was no guidance to the plans checker what the range of the values would be merely by looking at the equation. Thus for ease of enforcement, a look up table is proposed for the PAFs.

- **Exempt multi-level requirement for daylighting controls when LPD is lower than 0.5 W/sf**. This recognizes that metal halide lighting systems designed to low lighting power densities below 0.5 W/sf may not have even 1-1/2 lamps per skylight. This would still require a single level photocontrol.

- **Single level controls for skylight retrofits**. For existing buildings that are under consideration for adding skylights, the multi-level daylighting controls can be fairly expensive if re-circuiting to provide multi-level daylighting control is required. In this proposal, we are recommending that one could use single level photocontrols in skylighting retrofits as long as all the luminaires controlled are in the daylit area under skylights. This can be easily achieved if the skylighting retrofit is daylighting the entire space.

- **Requirement for a deadband adjustment.** The current standards require that photocontrols have a deadband between on and off light levels for each control step. However, if this deadband is not adjustable, the steps can be too wide resulting in less than optimal energy savings and if the deadband is too narrow this will lead to cycling on and off of the lights and ultimately disabling of the controls.

- **Clarify area controls and multi-level switching requirements**. This is for clarification and ease of enforcement only. Features of the control are separated from how the control is installed. Thus the feature of the photocontrol (adjustable deadband) is placed in Section 119 while how the controls are installed to control lighting (such as multi-level requirements) are placed in Section 131(c).

- **Update the skylight U-factor and SHGC requirements to match default skylight properties.** Many of the plastic skylights sold in California do not have NFRC ratings. As a result, they are evaluated by the standards using the properties for skylights in the default fenestration tables (Tables 116A&B). The U-factor and SHGC requirements in Table 143a essentially require double glazed tinted skylights with thermally broken metal frames to comply. However, these requirements in table 143a are slightly less stringent that the default skylight properties. As a result, when one uses the performance approach to model the skylights, compliance credit is given which can be used to reduce the efficiency of another part of the building. We propose to eliminate this loophole by matching the values in Table 143a to the values in the default table.

Energy Benefits

On average, the addition of skylights and photocontrols save approximately 1.8 kWh/sf of building stock. More energy is saved in big box retail and less energy is saved in warehouses.

Non-energy Benefits

Thoughtful design of buildings using daylight can improve lighting quality and increase productivity (HMG 1999, Heschong et al 2001).

Statewide Energy Impacts

This estimate will be conducted for the final CASE report on skylighting.

Environmental Impact

The environmental impacts of this measure are overwhelmingly positive. Commercial skylights are primarily a plastic glazing held in place with an extruded aluminum frame. They displace a similar area's worth of roofing product and are often mounted on a wood site assembled curb. Photocontrols consist of a silicon photodetector and a control module, which is a printed circuit board and electronic components. A very small amount of these materials are used to save large amounts of electricity. Lighting is switched with relays – many of which already are required for automatic shut-off controls requirement in Title 24 §131(d). Peak demand savings from daylighting lead to reduced emissions from peaking power plants.

The emissions impacts of this measure are calculated by multiplying the change in statewide electricity and natural gas consumption by the respective emissions factor values generated by the California Energy Commission for evaluating the environmental impacts of the 2005 standards as shown in Table 1 below.[1]

Table 1:Emissions Factors used to calculate the air emissions reductions resulting from end-use reductions in electricity and natural gas consumption

Emissions factors	NOx	CO	CO2	PM10
Natural Gas, California (lbs/MMBtu)	0.094	0.03	115	0.01
Electricity, Western States (lbs/MWh)	0.383	0.23	1200	0.06

Statewide environmental impacts will be generated at the same time as the statewide energy savings estimate.

Type of Change

This proposal updates the skylight requirements in several sections and thus results in changes to the mandatory, prescriptive and performance section of the standards.

[1] Table 1, Appendix B page 2, Initial Study/Proposed Negative Declaration for the 2005 Building Energy Efficiency Standards for Residential and Nonresidential Buildings September 2003 P400-03-018 http://www.energy.ca.gov/reports/2003-09-12_400-03-018.PDF Values provided by the CEC System Assessment and Facilities Siting Division.

Mandatory Measure	Changes to requirements for photocontrols (§119) and the daylighting control requirements (§131(c)) are mandatory and cannot be traded off against equivalent measures. The photocontrol requirements in section 131(c) are triggered by the presence of skylights.
Prescriptive Requirement	The change would add or modify the prescriptive requirement for when skylighting is required in Section 143(c) and the required material properties of skylights over conditioned spaces in Section 143(a). Prescriptive requirements must be met for prescriptive compliance and define the Standards baseline building in performance calculations, but are not mandatory when the performance approach is used.
Compliance Option	The change would add a new means to comply with the standards by adding a new compliance option. This could be a simple energy credit, or it could entail a relatively complex analysis procedure.
Modeling	The change would modify the calculation procedures or assumptions used in making performance calculations. This change would not add a compliance option or a new requirement, but would affect the way that tradeoffs are made. We are proposing that the savings from photocontrols be directly calculated within the compliance software calculation kernel instead of using a fixed reduced lighting power density.

Technology Measures

This proposal encourages the use of natural light through the installation of skylights, and at the same time reduces electric lighting in daylit zones through the use of automatic controls. Skylights are essentially "roof windows" designed to keep water out but let light in. Since most nonresidential floor space is directly under a roof, opening up a small fraction (typically 3% - 5%) of the roof area to take advantage of available natural light can provide most of the lighting requirements for most of the daytime hours. Skylight technology is relatively well developed, with many manufacturers mass producing skylights.

Adding skylights by themselves does not save energy – the energy savings are realized when electric lighting is reduced in response to available daylight. This concept of automatically turning off or reducing electric lighting during times when sufficient daylight is available is commonly used for street lighting and other outdoor lighting applications and is a mandatory requirement for nonresidential exterior lighting in the building efficiency standards (see 2005 Title 24 §131f). This code change proposal would expand requirements for automatic daylighting controls to buildings that have enough skylights and enough installed lighting power to render daylighting controls cost effective. Photocontrols measure the amount of daylight entering a space and automatically switch off lights or send a signal to dim lights. When lights are switched off, this uses the well-established relay technology that operates almost any automatically controlled electrical device from elevators to traffic lights. The technology to dim ballasted lamps is not as established but has been available in the lighting market for over a decade.

Measure Availability and Cost

Skylight manufacturers with whom we spoke are confident that they can ramp up quickly to accommodate increased demand for skylights in California. This is because much of their current capacity is exported outside of the state and can be diverted to California in the short term while additional production lines are installed. Capital costs for installing new production lines are relatively inexpensive. Installed costs for a 32 square foot skylight are

approximately $610/ea for single-glazed and $725/ea for a double-glazed skylight[2]. Each of these skylights can illuminate approximately 1,000 square feet of floor space, so installed unit costs are less than $1 per square foot.

We also have performed an investigation into additional costs associated with skylights. There have been anecdotal reports of skylights leaking or being broken and this resulting in damage to the building or its contents. From a discussion with specialists from the loss analysis and engineering departments at Factory Mutual Global, their experience has been that losses from skylights have been rare. The losses they cover are from a sudden event such as skylight breakage, and don't consider events that are chronic such as leaks. Given the low incidence of payments from skylight damage, there is usually not an insurance premium associated with skylights as a single building feature. The few sudden losses they have experienced are either weather related (severe hailstorms, hurricanes or the debris sent flying by these storms) or from fire. The severity of storms associated with skylight damage does not commonly occur in California. Where skylights have been implicated in fire damage the issues have been on skylight size and spacing – something then addressed by Section 2603.7 of the Uniform Building Code. In addition for some warehouses, skylights in the form of roof vents are already required by code with little resulting losses. Thus we have not found an insurance penalty associated with skylights.

Construction quality and weather-tightness of the roofing system, including curbs, is something already covered by the Uniform Building Code. Leakage from curbs whether they are for roof top HVAC units or skylights requires the vigilance of the construction industry and building officials. The essential building component is unchanged in this proposal (the curb) but this proposal would require more of them.

From discussions with established photocontrol manufacturers, we received quotes on the costs of three-circuit photocontrollers. These were controllers with adjustable setpoints, time delays and deadbands, and remote photodiode based sensors. In short, they are control systems that comply with the additional requirements for automatic daylighting control devices in this proposal. The remote sensor is an important feature so that the controller can be easily calibrated without self-shading by the commissioning agent. The lowest quote was $700 while the highest was $2,800 (this top of the line system contained dial-in access, a timeclock and other features not required by the proposed Standards) and the median value was $1,300. Incremental installation cost, beyond what is already required for automatic night sweep controls, is about $400. Thus a conservative (high) estimate of the installed cost of a high quality, three-circuit photocontrol system is $2,500. In addition the installed cost of a photocontrol system was $2,500 figure was quoted by a representative of the statewide Savings by Design nonresidential new construction energy efficiency program. Thus we are erring on the side of conservativism.

Useful Life, Persistence and Maintenance

The power savings and benefits of photocontrols are well established and are recognized in the Advanced Lighting Guidelines.[3] In the past, there was doubt as to whether photocontrols would yield reliable savings, as there were plenty of anecdotes of photocontrols being overridden in spaces sidelit with windows. Southern California Edison had sponsored a study of 33 skylit spaces to evaluate the realized savings from photocontrols. (HMG 2003, McHugh et al. 2004a) This study found that 32 out of 33 photocontrol systems were working with an average realized savings that was 98% of the predicted amounts. Thus savings from photocontrols in skylight spaces are indeed reliable. In our analysis we are conservative and use a 70% life cycle reliability factor for the calculation of the Power Adjustment Factor of the 15 year period of analysis. This accounts for the possibility that the installed lighting might last longer than the photocontrol.

---

[2] Values from 2005 Means Building Construction Cost data. This includes a weighted average cost for 4 California cities and a 20% mark-up for overhead and profit. These estimates are somewhat (as much as 50%) higher than those quoted by installers – thus the estimates of benefit cost ratio are conservative.

[3] New Buildings Institute, 2001. Advanced Lighting Guidelines, available at http://www.newbuildings.org/

Performance Verification

In the 2005 Title standards, acceptance testing was required for photocontrol systems. If these tests are conducted and the installed system passes them, there is a high likelihood that the photocontrol systems will work as designed.

Cost Effectiveness

As shown in the Results section of this report, installing skylighting in spaces greater than 15 feet tall and having a floor area greater than 8,000 sf is cost effective for a the climate zones evaluated (CTZs 3, 7 , 10, 12, 14) that are representative of the Bay Area, South Coast, Central Valley, Los Angeles Basin and the desert. In the previous study for the 2005 standards we found that skylighting was not cost-effective in warehouses in climate zones 1 and 16. The requirement for skylighting is therefore exempted in climate zones 1 (Oregon border) and 16 (Mountains) and is not evaluated in this report.

Analysis Tools

Currently the savings from daylighting in the nonresidential ACM (alternative compliance method) program are calculated as reductions in the LPD (lighting power density) by the PAF's (Power Adjustment Factors) contained in the existing standard. However, the calculation engine of the ACM program is DOE-2 and DOE-2 has well-developed daylighting calculation routines. Given that the savings from skylighting used in conjunction with photocontrols does not occur evenly during the day, it would be more accurate to predict the timing of savings using a daylighting model in the simulation software. This way the energy savings can be calculated on an hourly basis over the course of a typical year and the cost savings evaluated by multiplying these hourly savings by the time dependent valuation (TDV) multipliers. .

Relationship to Other Measures

There is a small amount of interaction between this measure and sidelighting (daylighting with windows or clerestories). Both measures make use of the same definitions for photocontrols and the daylit areas are similar as well. To differentiate between the daylit area by windows and that under skylights, we have updated the nomenclature to use the terms *skylit area* under skylights and the *sidelit area* by windows.

Methodology

The methodology used to calculate the Power Adjustment Factors and the cost-effectiveness of minimum skylight area requirements are described below.

Revised Power Adjustment Factors

The Power Adjustment Factor (PAF) is a lighting control credit that derates the installed lighting power by a fraction to account for reduced energy consumption due to controls. Since the adoption of TDV (time dependent valuation) in the 2005 standards, the PAF is supposed to account for the reduction in TDV energy resulting from controls. Time Dependent Valuation weights energy savings in a given hour by the value of energy during that hour. Times that are coincident with utility system peak are valued higher than those that are off-peak.

Revisions to the power adjustment factors were calculated using several tools funded by the utility energy efficiency programs. Hourly energy savings calculations made use of the daylight availability and control fraction values found in the SkyCalc skylight sizing spreadsheet. These hourly values were then multiplied by the Time Dependent Valuation (TDV) factors proposed for the 2008 Title 24 standards. The resulting output units from this calculation procedure are present valued dollar savings that include energy and capacity costs.

These TDV savings were calculated as a fraction of TDV costs of electric lighting without daylighting controls. For calculating Power Adjustment Factors, the TDV savings were derated by a 70% factor to account for the combined effects that some photocontrols might not be working correctly and that these control may not last as long as the lights they are controlling.

Building on work developed for the 2005 standards, it was recognized that the Power Adjustment Factors are a function of the control type, the luminous efficacy of the lighting source, the optical efficiency of the luminaire, climate and the effective aperture of the skylights. The combination of the luminous efficacy of the source and the optical efficiency of the luminaire and the geometry of the space defines the design illuminance. The effective aperture (EA), which is the product of the maintained light transmittance and the skylight area to floor area ratio (SFR), describes the fraction of daylight is transmitted through the roof. Some climates have more sunny days than others and thus they will have greater savings from photocontrols.

The model used was a spreadsheet model that made use of hourly illuminance values for a given reference building in Climate Temperature Zone (CTZ) 3, which is represented by weather data from San Francisco. This climate zone was selected due to this zone representing a fairly large population center in the state with relatively lower illuminances as compared to Southern California. Thus the resulting Power Adjustment Factors (PAFs) generated would be conservative.

The design footcandle levels were calculated from the coefficients of utilization for the fixture type used and the maintained luminous efficacy of the light source. Fluorescent fixtures were assumed to have T-8 lamps and electronic ballasts for a maintained luminous efficacy of 85 lumens per Watt.

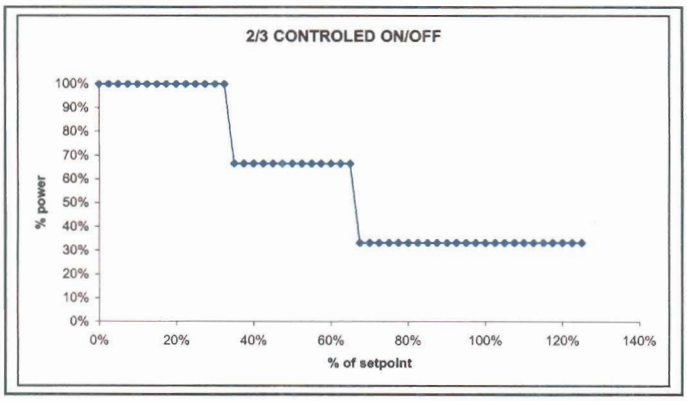


Figure 2: Daylighting control strategy for PAF analysis: 2/3's on/off

Since the PAF describes the energy savings fraction with controls relative to the annual lighting energy consumption of a system without the control in question, this analysis uses the nonresidential lighting schedule as described in the nonresidential ACM (Alternative Compliance Method) manual. This analysis uses the same mapping of day of week to date as does the TDV factors – this uses the calendar from 1991 so it is in concordance with the schedules in the nonresidential ACM.

This evaluation was conducted using the minimally compliant control strategy, "2/3s Controlled On/Off." This switching control turns off one third of the lights when interior daylight illuminance exceeds one third of the target illuminance for the space and turns off two thirds of the lights when interior daylight illuminance exceeds two thirds of the target illuminance for the space. The last third of the lights always remain on. Power consumption is proportional to electric light output. This strategy minimally meets the multi-level daylighting control requirement of having a control step between 50% and 70% of full power and a minimum automatic control step that is less than 35% of full power. This control strategy is illustrated in Figure 2.

Minimum Space Size Requirements for Skylighting

Since the savings estimates are based upon the trade-offs between daylighting savings and thermal gains and losses through skylights, the methodology has to model the interactions of skylights with the HVAC system. The three major building types under consideration are warehouses, big box retails and offices. The analysis here was performed with the SkyCalc analysis tool with many built-in defaults that account for skylight properties, geometries of the building and skylight well and building schedules. One of SkyCalc's primary features is that it parametrically varies the skylight area – a feature that is well suited for this analysis.

Warehouse Analysis

The analysis of warehouses used the SkyCalc skylighting design tool which parametrically varies the skylight to floor ratio (SFR) of a prototypical warehouse for climate zones 3, 7, 10, 12, 14. This prototype has lighting setpoint, internal loads, occupant density as well as HVAC, lighting and occupancy schedules that come from calibrated DOE-2 models used to create the Unit Energy Savings (UES) tables. We analyzed four sizes for the prototypical warehouse with conditioned area of 1) 10,000 square feet; 2) 8,000 square feet 3) 6,000 square feet and 3) 4,000 square feet. All three models had a 15-foot ceiling height. The warehouse is modeled with 15 foot tall and 8 feet wide shelves that are evenly spaced by 12-foot wide aisles.

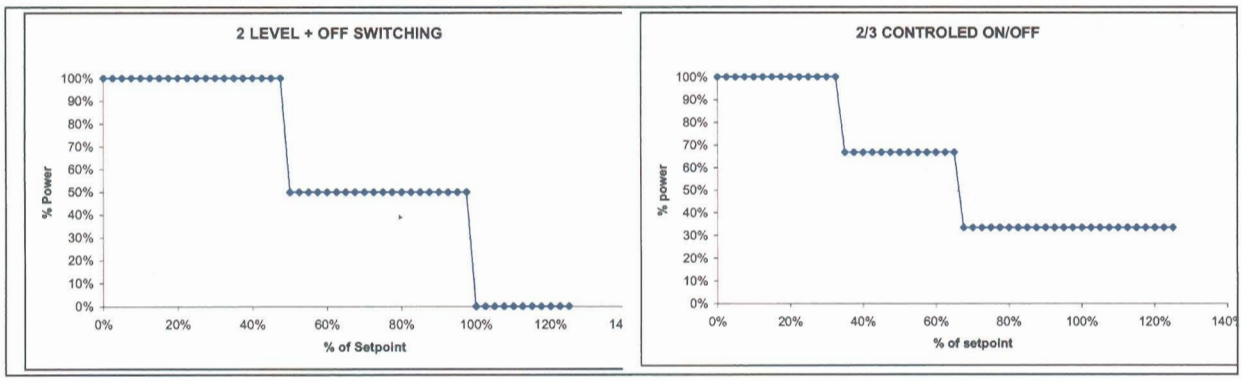


Figure 3: Warehouse Photocontrol Models: Lighting Power in Response to Daylight

The skylights are described as typical double glazed, clear over medium white, acrylic skylights. The height of the skylight wells is 1ft – this is essentially the depth of the skylight curb and framing. The double glazed skylight has a visible transmittance of 39%, a SHGC of 0.30, and a U-factor 0.97 Btu/h·°F·sq. ft. It should be noted that the definition of U-factor is in terms of the total heat transfer per degree F of temperature difference divided by the area of the rough opening (not the total surface area of the skylight). Thus the U-factors for the skylights seem high when compared to windows – this is because though U-factor is defined in terms of heat transfer per area of rough opening the skylight does lose heat through its greater surface area.

This analysis assumes that skylights are spaced appropriately to provide acceptable uniformity (i.e. the entire space is within the daylit zone under skylights). We estimated the number of skylights required for each size of building using a spacing criterion of 1.3, which resulted in 25, 21 and 16 skylights for the 10,000, 8,000, and 6,000 square foot buildings respectively. For each of the four model sizes, the number of skylights remains the same, but as the skylight to floor ratio (SFR) increases the skylight area increases as well.

The unit installed costs for a 12 square foot skylight (the skylight size used for the 3% SFR scenario for 10,000 square foot building) including contractor overhead and profit are estimated to be $308 for double-glazed skylights. In addition to this, the incremental cost for adding photocontrols to the automatic shut-off controls was estimated as $2,500. The costs of the skylights used for the warehouse analysis are shown in Table 2.

Table 2: Installed Costs of Skylights in the Warehouse models

	10,000 sq.ft Model 25 skylights			8,000 sq.ft Model 21 skylights			6,000 sq.ft Model 16 skylights		
SFR	Area/ skylight	Cost/ skylight	Total Cost*	Area/ skylight	Cost/ skylight	Total Cost*	Area /skylight	Cost/ skylight	Total Cost*
0.0%	0	$0	$0	0	$0	$0	0	$0	$0
1.0%	4	$131	$5,784	4	$127	$5,170	4	$126	$4,513
2.0%	8	$220	$7,991	8	$211	$6,936	8	$209	$5,838
3.0%	12	$308	$10,199	11	$295	$8,702	11	$291	$7,162
4.0%	16	$396	$12,407	15	$379	$10,468	15	$374	$8,487
5.0%	20	$485	$14,615	19	$464	$12,235	19	$457	$9,812
6.0%	24	$573	$16,822	23	$548	$14,001	23	$540	$11,136
8.0%	32	$750	$21,238	30	$716	$17,533	30	$705	$13,786
10.0%	40	$926	$25,653	38	$884	$21,066	38	$871	$16,435
12.0%	48	$1,103	$30,069	46	$1,052	$24,598	45	$1,037	$19,084

* Total Costs is cost of all skylights in the model and includes $2,500 for costs of photocontrols

In the warehouse model, two lighting control strategies were used with each type of skylight: 1) Two level plus off switching and 2) 2/3 controlled on/off. Each of these control strategies is graphed in **Figure 2** in the previous section on the PAF analysis.

In this analysis, we assumed that the lighting technology used was pulse start metal halide with a maintained luminous efficacy of 72 lm/W. The space by space method allows only 0.7 W/SF for a lighting power density and the whole building method for warehouses allows 1.0 W/SF. We ran the analysis for both cases but assumed that only 90% of the lights were controlled by the photocontrol system. Given this maintained efficacy, the lighting setpoint for a lighting power density of 0.7 W/SF is 22 footcandles and for a LPD of 1.0 W/SF, a setpoint of 32 fc. We also ran each LPD level with three cases of space conditioning, namely 1) Heating Only; 2) Unconditioned space and 3) A/C and Heating.

By applying the approved 15 year present valued electricity and gas rates to the energy savings we were able to calculate the 15 year discounted energy cost savings from different combinations of skylight area and control strategies. Finally, benefit-to-cost ratios were calculated for every case by dividing the present valued energy cost savings by the incremental first cost to make it easier to see which cases are cost effective. In all we studied six cases for warehouse.

Table 3: Cases studied for Warehouse

Case No.	Building Type	Ceiling Ht	Light Well Ht	LPD W/sf	Space Conditioning
Case 1	Warehouse	15'	1'	0.7	only heating
Case 2	Warehouse	15'	1'	1	only heating
Case 3	Warehouse	15'	1'	0.7	unconditioned
Case 4	Warehouse	15'	1'	1	unconditioned
Case 5	Warehouse	15'	1'	0.7	with A/C and heating
Case 6	Warehouse	15'	1'	1	with A/C and heating

Retail Analysis

The big box retail store is analyzed the same way as the warehouse except:

- General lighting had a lighting power density of 1.6 W/SF and used a retail lighting schedule.
- Lighting controls considered were fluorescent dimming and 2/3 on/off switching control (see Figure 4)

- Lighting used was open cell fluorescent for the cases with 4 foot light wells, and industrial fluorescent for the case with 1 foot light well

- Shelving had a back to back width of 6 feet, a height of 7 feet and was separated by 10 feet wide aisles

- We created three cases for big-box retail by changing the ceiling height from 15 feet to 12 feet to 10 feet. The models with the 12 feet and 10 feet ceiling heights had a light well of 4 feet with splays. To model the effect of splays in SkyCalc we modified the skylight's well efficiency. Using splays increases the well factor from 59% to 69%. Note that retail spaces with open ceilings have typically ceiling heights higher than 15 feet,; we used 15 feet for the open ceiling since that is the current height criteria and results in a conservative estimate of cost-effectiveness. As ceiling heights get taller, larger skylights spaced further apart are possible, this is cheaper than smaller skylights spaced closer together.

- The design illuminance was 59 fc

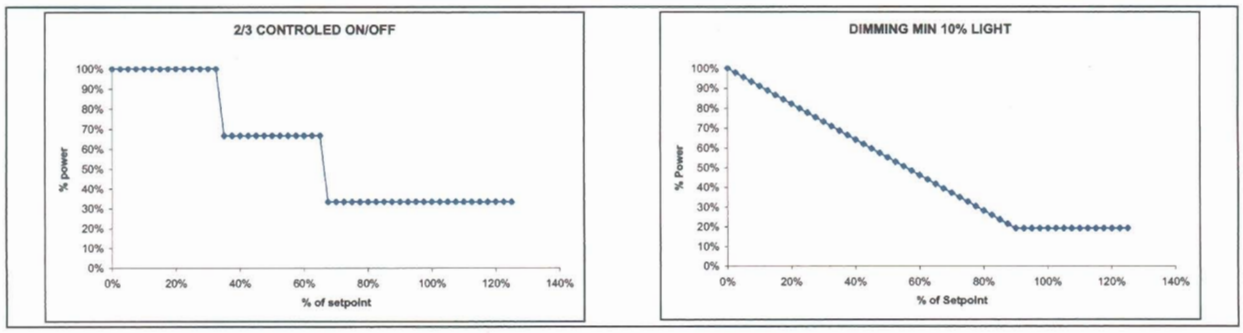


Figure 4: Retail Photocontrol Models: Lighting Power in Response to Daylight

In all we studied three cases for big-box retail.

Table 4: Cases Studied for Retail Big-Box

Case No.	Building Type	Ceiling Ht	Light Well Ht	LPD	Space Conditioning
Case 7	Big-Box Retail	15'	1'	1.6	with A/C
Case 8	Big-Box Retail	12'	4' with splays	1.6	with A/C
Case 9	Big-Box Retail	10'	4' with splays	1.6	with A/C

The cost for skylights with the 1ft well was the same as that for the warehouse in Table 2. However for the cases with 10 foot and 12 foot ceilings with 4 foot wells, the costs for light wells and splays were added to get the total costs. Also the skylights have to be closer together than in the warehouse model because the ceiling is lower hence increasing the total number of skylights required. The costs for these cases are given in Table 5 and Table 6.

Table 5: Installed Costs of Skylights in the Retail models with 12 foot ceiling and 4 foot light wells

	10,000 sq.ft Model 30 skylights				8,000 sq.ft Model 24 skylights				6,000 sq.ft Model 16 skylights			
SFR	Area/ skylight	Cost/ skylight	Cost/ lightwell	Total Cost*	Area/ skylight	Cost/ skylight	Cost/ lightwell	Total Cost*	Area/ skylight	Cost/ skylight	Cost/ lightwell	Total Cost*
0.0%	0	$0	$0	$0	0	$0	$0	$0	0	$0	$0	$0
1.0%	3	$117	$996	$35,865	3	$117	$996	$29,192	3	$117	$996	$22,519
2.0%	7	$190	$1,058	$39,938	7	$190	$1,058	$32,451	7	$190	$1,058	$24,963
3.0%	10	$264	$1,120	$44,012	10	$264	$1,120	$35,710	10	$264	$1,120	$27,407
4.0%	13	$337	$1,182	$48,086	13	$337	$1,182	$38,969	13	$337	$1,182	$29,852
5.0%	17	$411	$1,244	$52,160	17	$411	$1,244	$42,228	17	$411	$1,244	$32,296
6.0%	20	$485	$1,307	$56,233	20	$485	$1,307	$45,487	20	$485	$1,307	$34,740
8.0%	27	$632	$1,431	$64,381	27	$632	$1,431	$52,005	27	$632	$1,431	$39,628
10.0%	33	$779	$1,555	$72,528	33	$779	$1,555	$58,523	33	$779	$1,555	$44,517
12.0%	40	$926	$1,680	$80,676	40	$926	$1,680	$65,041	40	$926	$1,680	$49,405

* Total Costs is cost of all skylights in the model and includes $2,500 for costs of photocontrols

Table 6: Installed Costs of Skylights in the Retail models with 10 foot ceiling and 4 foot light wells

	10,000 sq.ft Model 41 skylights				8,000 sq.ft Model 33 skylights				6,000 sq.ft Model 25 skylights			
SFR	Area/ skylight	Cost/ skylight	Cost/ lightwell	Total Cost*	Area/ skylight	Cost/ skylight	Cost/ lightwell	Total Cost*	Area/ skylight	Cost/ skylight	Cost/ lightwell	Total Cost*
0.0%	0	$0	$0	$0	0	$0	$0	$0	0	$0	$0	$0
1.0%	2	$97	$979	$46,605	2	$97	$979	$37,979	2	$96	$978	$29,353
2.0%	5	$151	$1,024	$50,678	5	$150	$1,024	$41,238	5	$149	$1,023	$31,798
3.0%	7	$205	$1,070	$54,752	7	$204	$1,069	$44,497	7	$202	$1,068	$34,242
4.0%	10	$258	$1,115	$58,826	10	$257	$1,114	$47,756	10	$255	$1,112	$36,686
5.0%	12	$312	$1,161	$62,900	12	$311	$1,160	$51,015	12	$308	$1,157	$39,130
6.0%	15	$366	$1,206	$66,973	15	$364	$1,205	$54,274	14	$361	$1,202	$41,575
8.0%	20	$474	$1,297	$75,121	19	$471	$1,295	$60,792	19	$467	$1,292	$46,463
10.0%	24	$582	$1,388	$83,268	24	$578	$1,386	$67,310	24	$573	$1,381	$51,352
12.0%	29	$689	$1,479	$91,416	29	$685	$1,476	$73,828	29	$679	$1,471	$56,240

* Total Costs is cost of all skylights in the model and includes $2,500 for costs of photocontrols

Office Analysis

The office case was analyzed the same way as the retail big-box case except:

- General lighting had a lighting power density of 1.10 W/SF and used the office lighting schedule with a design illuminance was 40 fc
- Lighting used was open cell fluorescent
- Lighting controls considered were fluorescent dimming and 2/3 on/off switching control, , the same controls used for the retail analysis (see Figure 4)
- 4 feet high partitions were modeled for 8 feet by 8 feet cubicles
- Ceiling height was 10 feet with a light well of 4 feet with splays. To model the effect of splays in SkyCalc we modified the skylight's well efficiency. Using splays essentially increases the well factor from 59% to 69%.

We studied one case for office.

Table 7: Case Studied for Office

Case No.	Building Type	Ceiling Ht	Light Well Ht	LPD	Space Conditioning
Case 10	Office	10'	4' with splays	1.1	with A/C

The cost for skylights for the office case was the same as that for the retail big-box with 4 foot wells shown in Table 5.

Results

Describe the results of the research. What was learned? How is it relevant to the standards? Results are not all computational. Some results are based on market share of equipment and applicability of measure limited to certain applications.

Revised Power Adjustment Factors

We calculated the Power Adjustment Factors (PAF) with Fluorescent lighting having a luminous efficacy of 85 lumens/Watt... For each case, we calculated PAFs for four effective aperture sizes of 0.6%, 1%, 1.2% and 1.8%. The results are shown in Table 8.

Table 8:Fraction of Annual TDV Lighting Energy Saved by 2/3 On/Off Daylighting Control

	Effective Aperture (EA)			
LPD (W/sf)	0.6%	1.0%	1.4%	1.8%
0.7	34%	43%	47%	49%
1	27%	37%	42%	46%
1.4	17%	31%	37%	41%
1.6	12%	28%	34%	39%

The fraction of annual TDV lighting energy saved, LES_{TDV}, is given by the following equation:

$$LES_{TDV} = 1 - \frac{\sum_{h=1}^{8,760} LS_h \times DCF_h \times TDV_h}{\sum_{h=1}^{8,760} LS_h \times TDV_h}$$

Where,

LS_h = lighting schedule for hour h

DCF_h = daylighting control fraction, fraction of rated power used by lights for hour h, based on daylight illuminance in hour h

TDV_h = time dependent valuation multiplier for hour h

The Power Adjustment factor is calculated by derating the lighting energy savings by a constant factor of 70% to account for miscalibration or the daylighting controls system not lasting as long as the luminaires it controls. These values are also rounded to the nearest 2% value.

Table 9: Power Adjustment Factors as Function of (LPD) and (EA) with 70% Derating

	Effective Aperture (EA)			
LPD (W/sf)	**0.6% ≤ EA < 1%**	**1% ≤ EA < 1.4%**	**1.4% ≤ EA < 1.8%**	**1.8% ≤ EA**
LPD < 0.7	24%	30%	32%	34%
0.7 ≤ LPD < 1.0	18%	26%	30%	32%
1.0 ≤ LPD < 1.4	12%	22%	26%	28%
1.4 ≤ LPD	8%	20%	24%	28%

As can be seen from this table, one would need to have at least an effective aperture of 1.4% at and LPD > 1.4 W/sf, the yield the same PAF for an effective aperture less than 1% for a space with an LPD < 0.7 W/sf.

Minimum Space Size Requirements for Skylighting

Energy and Cost Savings

Table 10 illustrates for the retail open ceiling case, a SkyCalc calculation of lighting, cooling and heating energy savings (or in the case of negative savings, increased energy consumption) and their conversion into 15 year present dollar savings. This conversion is based on a 15 year present value of $1.63 for each kWh and $12.72/therm. Savings are compared relative to an opaque roof with no skylights and no controls. As described earlier, we are using the conservative ceiling height of 15 feet to compare savings and costs.

Table 10: Energy and cost savings fors big box retail 15 foot ceiling, 1 ft light well, dimming controls

		Lighting kWh/yr-sf	Cooling kWh/yr-sf	Total Elec kWh/yr-sf	Elec 15 yr PV$/sf	Heating Therms/yr-sf	Heating 15 yr PV$/sf	Total Energy 15 yr PV $/sf
CZ3	**SFR**							
	0%	0.00	0.00	0.00	$0.00	0	$0.00	$0.00
	1%	0.36	0.03	0.39	$0.63	0.00	-$0.05	$0.58
	2%	1.30	0.12	1.42	$2.32	-0.01	-$0.10	$2.22
	3%	1.89	0.11	2.00	$3.26	-0.01	-$0.16	$3.10
	4%	2.26	0.07	2.33	$3.81	-0.02	-$0.22	$3.58
	5%	2.48	0.03	2.51	$4.09	-0.02	-$0.30	$3.79
	6%	2.63	-0.03	2.60	$4.24	-0.03	-$0.38	$3.87
	8%	2.86	-0.13	2.73	$4.45	-0.04	-$0.55	$3.89
	10%	3.00	-0.24	2.75	$4.49	-0.06	-$0.73	$3.76
	12%	3.09	-0.35	2.73	$4.46	-0.07	-$0.92	$3.54
CZ7	**SFR**							
	0%	0.00	0.00	0.00	$0.00	0.00	$0.00	$0.00
	1%	0.43	-0.01	0.41	$0.67	0.00	$0.01	$0.68
	2%	1.46	0.14	1.60	$2.61	0.00	$0.02	$2.63
	3%	2.12	0.13	2.25	$3.67	0.00	$0.02	$3.69
	4%	2.41	0.05	2.46	$4.00	0.00	$0.02	$4.02
	5%	2.62	-0.07	2.56	$4.17	0.00	$0.02	$4.18
	6%	2.76	-0.20	2.56	$4.17	0.00	$0.01	$4.18
	8%	2.93	-0.46	2.46	$4.02	0.00	-$0.01	$4.01
	10%	3.01	-0.74	2.27	$3.70	0.00	-$0.04	$3.66
	12%	3.08	-1.02	2.05	$3.35	-0.01	-$0.08	$3.27
CZ10	**SFR**							
	0%	0.00	0.00	0.00	$0.00	0.00	$0.00	$0.00
	1%	0.43	-0.06	0.38	$0.61	0.00	-$0.03	$0.58
	2%	1.47	0.02	1.49	$2.43	0.00	-$0.06	$2.36
	3%	2.07	-0.06	2.02	$3.29	-0.01	-$0.10	$3.18
	4%	2.34	-0.23	2.11	$3.44	-0.01	-$0.16	$3.28
	5%	2.53	-0.41	2.13	$3.47	-0.02	-$0.22	$3.25
	6%	2.66	-0.60	2.07	$3.37	-0.02	-$0.28	$3.09
	8%	2.82	-1.00	1.81	$2.96	-0.03	-$0.40	$2.56
	10%	2.93	-1.41	1.52	$2.47	-0.04	-$0.53	$1.95
	12%	3.01	-1.83	1.18	$1.93	-0.05	-$0.65	$1.28
CZ12	**SFR**							
	0%	0.00	0.00	0.00	$0.00	0.00	$0.00	$0.00
	1%	0.40	-0.04	0.36	$0.58	0.00	-$0.05	$0.53
	2%	1.35	0.04	1.39	$2.27	-0.01	-$0.11	$2.16
	3%	1.89	-0.04	1.85	$3.02	-0.01	-$0.18	$2.85
	4%	2.27	-0.17	2.10	$3.42	-0.02	-$0.26	$3.16
	5%	2.48	-0.34	2.14	$3.49	-0.03	-$0.36	$3.12
	6%	2.62	-0.52	2.10	$3.42	-0.04	-$0.48	$2.94
	8%	2.85	-0.87	1.97	$3.21	-0.06	-$0.72	$2.49
	10%	2.99	-1.24	1.75	$2.85	-0.08	-$0.99	$1.86
	12%	3.08	-1.61	1.47	$2.39	-0.10	-$1.25	$1.14
CZ14	**SFR**							
	0%	0.00	0.00	0.00	$0.00	0.00	$0.00	$0.00
	1%	0.54	-0.13	0.42	$0.68	0.00	-$0.04	$0.63
	2%	1.70	-0.11	1.60	$2.61	-0.01	-$0.09	$2.51
	3%	2.30	-0.29	2.01	$3.27	-0.01	-$0.14	$3.13
	4%	2.56	-0.58	1.99	$3.24	-0.02	-$0.20	$3.04
	5%	2.72	-0.88	1.84	$3.00	-0.02	-$0.26	$2.73
	6%	2.83	-1.19	1.64	$2.67	-0.03	-$0.33	$2.34
	8%	2.95	-1.83	1.12	$1.82	-0.04	-$0.46	$1.36
	10%	3.04	-2.49	0.55	$0.90	-0.05	-$0.60	$0.29
	12%	3.10	-3.14	-0.04	-$0.07	-0.06	-$0.75	-$0.82

The energy savings are shown for two control types over the range of skylight areas are shown in Table 11 for the following models: a retail space with an open 15 foot ceiling, a retail space with a four foot deep light well and a 12 foot ceiling, a heated but not air-conditioned warehouse with an open ceiling with a 0.7 W/sf LPD and a similar warehouse with a 1 W/sf LPD (representative of an industrial building). The highest energy cost savings for each climate zone is in bold.

*Table 11: Fifteen year present valued savings per square foot, retail conditioned and warehouse heated only and conditioned models(**highest savings in bold**)*

		Retail, 1.6 W/sf, 15' ceiling, 1' well		Retail, 1.6 W/sf, 12' ceiling, 4' well		Warehouse, 0.7 W/sf, 15' ceiling, 1' well, Heating Only		Warehouse, 0.7 W/sf, 15' ceiling, 1' well, HVAC		Warehouse, 1.0W/sf, 15' ceiling, 1' well, Heating Only	
		2/3 on/off	Dimming 20%	2/3 on/off	Dimming 20%	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off
CZ 03	SFR										
	0%	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
	1%	$0.58	$1.38	$0.55	$1.36	$0.50	$0.71	$0.37	$0.55	$0.38	$0.49
	2%	$2.22	$2.83	$2.18	$2.79	$1.47	$1.20	$1.34	$1.07	$1.58	$1.50
	3%	$3.10	$3.53	$3.07	$3.50	$1.81	$1.32	$1.64	**$1.15**	$2.31	$1.86
	4%	$3.58	$3.84	$3.57	$3.83	$1.94	**$1.37**	**$1.73**	$1.10	$2.69	$1.98
	5%	$3.79	$3.97	$3.78	$3.96	$2.01	$1.35	$1.70	$1.01	$2.87	$2.04
	6%	$3.87	**$4.01**	$3.86	**$4.00**	**$2.03**	$1.31	$1.64	$0.88	$2.95	**$2.05**
	8%	**$3.89**	$3.93	**$3.90**	$3.93	$1.98	$1.20	$1.43	$0.59	**$3.04**	$1.99
	10%	$3.76	$3.75	$3.76	$3.75	$1.88	$1.05	$1.15	$0.26	$3.00	$1.87
	12%	$3.54	$3.51	$3.54	$3.51	$1.74	$0.87	$0.84	($0.09)	$2.90	$1.72
CZ 07	SFR							$0.00	$0.00		
	0%	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
	1%	$0.68	$1.63	$0.69	$1.60	$0.69	$0.95	$0.50	$0.81	$0.55	$0.67
	2%	$2.63	$3.26	$2.59	$3.22	$2.00	$1.63	$1.85	$1.52	$2.07	$1.95
	3%	$3.69	$3.99	$3.66	$3.97	$2.47	$1.86	$2.33	**$1.62**	$3.05	$2.43
	4%	$4.02	$4.23	$4.01	$4.21	$2.71	$1.97	**$2.44**	$1.56	$3.54	$2.67
	5%	**$4.18**	**$4.29**	**$4.18**	**$4.28**	$2.85	$2.04	$2.42	$1.45	$3.84	$2.81
	6%	$4.18	$4.24	$4.18	$4.23	$2.94	$2.06	$2.33	$1.29	$4.02	$2.90
	8%	$4.01	$3.98	$4.00	$3.98	$3.03	$2.10	$2.06	$0.93	$4.25	$2.98
	10%	$3.66	$3.62	$3.67	$3.62	$3.07	**$2.10**	$1.72	$0.54	$4.37	$3.02
	12%	$3.27	$3.21	$3.28	$3.21	**$3.09**	$2.09	$1.34	$0.13	**$4.41**	**$3.03**
CZ 10	SFR							$0.00	$0.00		
	0%	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
	1%	$0.58	$1.48	$0.56	$1.45	$0.63	$0.88	$0.37	$0.64	$0.51	$0.61
	2%	$2.36	$2.96	$2.33	$2.93	$1.80	$1.42	$1.51	**$1.13**	$1.94	$1.78
	3%	$3.18	$3.48	$3.17	$3.46	$2.15	$1.57	**$1.76**	$1.04	$2.76	$2.13
	4%	**$3.28**	**$3.52**	**$3.28**	**$3.50**	$2.31	$1.62	$1.66	$0.82	$3.13	$2.29
	5%	$3.25	$3.37	$3.25	$3.37	$2.39	**$1.63**	$1.47	$0.55	$3.33	$2.36
	6%	$3.09	$3.15	$3.10	$3.15	$2.43	$1.62	$1.23	$0.25	$3.45	$2.39
	8%	$2.56	$2.58	$2.56	$2.58	**$2.44**	$1.58	$0.66	($0.40)	$3.56	**$2.39**
	10%	$1.95	$1.93	$1.95	$1.93	$2.40	$1.50	$0.04	($1.07)	**$3.58**	$2.35
	12%	$1.28	$1.24	$1.28	$1.24	$2.34	$1.40	($0.62)	($1.77)	$3.56	$2.27
CZ 12	SFR							$0.00	$0.00		
	0%	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
	1%	$0.53	$1.39	$0.50	$1.35	$0.51	$0.72	$0.28	$0.50	$0.42	$0.50
	2%	$2.16	$2.78	$2.10	$2.75	$1.49	$1.16	$1.23	**$0.89**	$1.60	$1.49
	3%	$2.85	$3.29	$2.82	$3.27	$1.78	**$1.27**	**$1.36**	$0.78	$2.29	$1.79
	4%	**$3.16**	**$3.38**	**$3.12**	**$3.37**	$1.89	$1.26	$1.26	$0.50	$2.61	$1.90
	5%	$3.12	$3.28	$3.12	$3.27	**$1.91**	$1.21	$1.04	$0.20	$2.78	**$1.91**
	6%	$2.94	$3.08	$2.94	$3.07	$1.89	$1.14	$0.76	($0.14)	**$2.85**	$1.89
	8%	$2.49	$2.53	$2.48	$2.53	$1.77	$0.92	$0.12	($0.88)	$2.83	$1.76
	10%	$1.86	$1.85	$1.86	$1.86	$1.56	$0.69	($0.60)	($1.66)	$2.74	$1.55
	12%	$1.14	$1.10	$1.14	$1.10	$1.34	$0.44	($1.37)	($2.44)	$2.58	$1.32
CZ 14	SFR							$0.00	$0.00		
	0%	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
	1%	$0.63	$1.59	$0.60	$1.56	$0.78	$1.05	$0.39	$0.72	$0.66	$0.77
	2%	$2.51	$3.07	$2.48	$3.04	$2.06	$1.61	$1.59	**$1.07**	$2.31	$2.03
	3%	**$3.13**	**$3.37**	**$3.11**	**$3.35**	$2.43	$1.70	**$1.65**	$0.78	$3.13	$2.41
	4%	$3.04	$3.17	$3.04	$3.16	$2.53	**$1.74**	$1.37	$0.36	$3.54	$2.50
	5%	$2.73	$2.80	$2.73	$2.80	$2.59	$1.71	$0.96	($0.11)	$3.68	$2.55
	6%	$2.34	$2.35	$2.34	$2.35	**$2.59**	$1.68	$0.54	($0.61)	$3.75	**$2.56**
	8%	$1.36	$1.34	$1.36	$1.34	$2.54	$1.58	($0.44)	($1.65)	**$3.82**	$2.50
	10%	$0.29	$0.25	$0.30	$0.25	$2.44	$1.46	($1.46)	($2.72)	$3.78	$2.40
	12%	($0.82)	($0.88)	($0.80)	($0.87)	$2.33	$1.32	($2.51)	($3.80)	$3.70	$2.28

What is interesting about these comparisons is that the retail space with the light wells has virtually the same energy cost savings. However, when we compare the cost-effectiveness of these two spaces, the retail spaces without light wells is very cost-effective, but the high cost of the light well renders the retail space with light well not cost-effective. Note that in most cases, the cost savings are positive over the legally allowable range (0% to 5% of gross roof area) of skylight areas.

When comparing the heated but uncooled warehouse models, one can see that greater savings are available with greater lighting power density. When looking at the heated only models one might think that one should optimize

energy savings by installing up to 8% SFR. However, by looking at the warehouse with heating and air conditioning, one can see that the optimally 4% or less. One can use this conditioned space model as a proxy for the discomfort that one might experience by adding too many skylights even if no one is paying for cooling.

Cost-effectiveness

Cost-effectiveness = Life cycle O&M cost savings / Incremental cost

Often life cycle savings is merely the energy savings multiplied by the present value of the energy cost over 15 years at a 3% discount rate (HMG or the CEC will provide this value for electricity and natural gas). In other cases where the maintenance or replacement costs or periods change then these costs are also considered as part of the life cycle savings. SkyCalc is an annual simulation that multiplies an average electricity and heating energy cost by the annual energy savings.

The following tables show the results from our parametric analysis for four sizes of buildings: 10,000 square feet, 8,000 square feet, 6,000 square feet and 4,000 square feet.

The parametric SkyCalc runs, described in the methodology section, yielded energy cost savings, which were compared to the incremental costs of adding skylights and adding automatic daylighting controls.

This analysis was designed to identify the minimum space size under which adding skylights and automatic daylighting controls provide cost-effective energy savings. The variables in this analysis are:

- Building size parametrically varied: 10,000 sf, 8,000 sf, 6,000 sf and 4,000 square feet
- Climate zones 3, 7, 10, 12, and 14 (this accounts for all major climatic regions excluding the North Coast, CTZ1 and the Mountains CTZ16 which were found to have marginal savings for spaces with lower lighting power densities)
- Skylight modeled was clear over medium white plastic skylight
- The skylight to floor ratio (SFR) was varied between 0 to 12%
- The lighting power density (LPD) from 0.7 to 1.6 W/sf depends upon occupancy
- The lighting control algorithms

We found that when the ceiling is dropped below 15 feet, to either 10 feet or 12 feet in both retail and office cases, the benefit to cast ratio drops below 1.0 for all climate zones, as seen in Table 14. This is due to the additional costs of light wells and need for extra skylights to provide uniform daylighting in a dropped ceiling condition. The results for the Case1-Warehouse with heating only, 15 foot ceiling and 0.7 W/sf LPD and Case7-Retail Big-Box with air conditioning and heating, 15 foot ceiling and 1.6 W/sf are discussed in this section. The remainders of the results are contained in the Appendix of this report.

Benefit/Cost Tables

Table 12 has the benefit/cost (B/C) ratios relative to no skylights or controls, for Case1-Warehouse. The climate zones considered are 3, 7, 10, 12, and 14 and different skylight areas are described in terms of a skylight to floor area ratio (SFR). Table 13 shows the benefit/cost ratios for Case7-Retail, while Table 14 for Case10-Office. The tables are split into four major columns for the four building sizes: 10,000 square feet, 8,000 square feet, 6,000 square feet and 4,000 square feet. Within each of these major headings two different control strategies are compared. For the retail store we compare fluorescent dimming with 2/3 on/off control. In both strategies, some of the ambient lighting is always on. It is felt that this is necessary in a retail occupancy to show that the store is open for business. In contrast, for the warehouse analysis, 2 level + off control is compared to 2/3's on/off control – using

lighting as a marketing tool is not necessary in a warehouse environment. The savings for each control strategy for each building and climate zone have been calculated in terms of a 15 year period of analysis.

As the space size is reduced the benefit/cost ratio drops. This is expected as the cost of the skylighting system has two parts: a variable cost component and a fixed cost component . The variable cost component is the costs associated with the number of skylights needed – in a smaller space needs less skylights. The photocontrol system is primarily a fixed cost. The same controller is required even though the size of the space increased within the limits we are looking at.

All of the spaces with light wells turned out to have benefit/cost ratios less than 1.0, they were not cost effective. This is due to the high cost required to fabricate skylight wells. The cost of the light well has been the primary barrier to requiring skylights in spaces with lower ceiling heights.

Table 12: Case1-Warehouse B/C Ratios

Case 1: Warehouse, 15' ceiling ht, 1' light well, 0.7 LPD, Heat Only

		10,000 sq.ft		***8,000 sq.ft***		***6,000 sq.ft***		***4,000 sq.ft***	
		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio	
	SFR	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off
CZ 03	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.86	1.21	0.77	1.09	0.66	0.94	0.52	0.73
	2.0%	1.83	1.49	1.70	1.38	1.51	1.23	1.24	1.01
	3.0%	1.77	1.29	1.67	1.21	1.52	1.10	1.29	0.94
	4.0%	1.56	1.10	1.49	1.04	1.37	0.97	1.20	0.84
	5.0%	1.37	0.92	1.32	0.88	1.23	0.83	1.09	0.73
	6.0%	1.21	0.78	1.16	0.75	1.10	0.71	0.98	0.64
	8.0%	0.93	0.56	0.91	0.55	0.86	0.52	0.79	0.48
	10.0%	0.73	0.41	0.71	0.40	0.69	0.38	0.64	0.35
	12.0%	0.58	0.29	0.57	0.28	0.55	0.27	0.51	0.26
	SFR								
CZ 07	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	1.18	1.64	1.07	1.47	0.92	1.27	0.72	0.99
	2.0%	2.49	2.03	2.30	1.88	2.05	1.67	1.69	1.37
	3.0%	2.41	1.81	2.27	1.71	2.07	1.56	1.76	1.32
	4.0%	2.17	1.58	2.07	1.51	1.91	1.39	1.66	1.21
	5.0%	1.94	1.39	1.86	1.33	1.74	1.24	1.54	1.10
	6.0%	1.74	1.22	1.68	1.18	1.58	1.11	1.42	1.00
	8.0%	1.42	0.99	1.38	0.96	1.32	0.91	1.21	0.84
	10.0%	1.19	0.82	1.17	0.80	1.12	0.77	1.04	0.71
	12.0%	1.03	0.69	1.00	0.68	0.97	0.66	0.91	0.62
CZ 10	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	1.08	1.51	0.97	1.36	0.83	1.17	0.65	0.91
	2.0%	2.24	1.76	2.08	1.63	1.85	1.46	1.52	1.20
	3.0%	2.10	1.53	1.98	1.44	1.80	1.31	1.53	1.11
	4.0%	1.86	1.30	1.77	1.24	1.63	1.14	1.42	1.00
	5.0%	1.63	1.11	1.56	1.07	1.46	1.00	1.29	0.88
	6.0%	1.44	0.96	1.39	0.93	1.31	0.88	1.17	0.79
	8.0%	1.15	0.74	1.11	0.72	1.06	0.69	0.97	0.63
	10.0%	0.93	0.58	0.91	0.57	0.88	0.55	0.81	0.51
	12.0%	0.78	0.46	0.76	0.46	0.73	0.44	0.69	0.41
CZ 12	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.87	1.23	0.79	1.11	0.68	0.95	0.53	0.74
	2.0%	1.85	1.45	1.72	1.34	1.53	1.20	1.26	0.98
	3.0%	1.74	1.24	1.64	1.17	1.49	1.06	1.27	0.90
	4.0%	1.52	1.01	1.44	0.96	1.33	0.89	1.16	0.77
	5.0%	1.30	0.83	1.25	0.79	1.17	0.74	1.03	0.66
	6.0%	1.12	0.67	1.08	0.65	1.02	0.61	0.91	0.55
	8.0%	0.83	0.43	0.81	0.42	0.77	0.40	0.70	0.37
	10.0%	0.61	0.27	0.59	0.26	0.57	0.25	0.53	0.23
	12.0%	0.45	0.15	0.44	0.14	0.42	0.14	0.40	0.13
CZ 14	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	1.34	1.80	1.21	1.62	1.04	1.39	0.81	1.09
	2.0%	2.57	2.00	2.38	1.85	2.12	1.65	1.74	1.35
	3.0%	2.38	1.66	2.24	1.57	2.04	1.43	1.73	1.21
	4.0%	2.03	1.39	1.94	1.33	1.79	1.23	1.56	1.07
	5.0%	1.76	1.17	1.69	1.12	1.58	1.05	1.40	0.93
	6.0%	1.54	0.99	1.48	0.96	1.40	0.90	1.25	0.81
	8.0%	1.19	0.74	1.16	0.72	1.10	0.69	1.01	0.63
	10.0%	0.95	0.57	0.93	0.55	0.89	0.53	0.83	0.49
	12.0%	0.77	0.44	0.76	0.43	0.73	0.42	0.69	0.39

Table 13: Case7-Retail B/C Ratios

Case 7: Retail, 15' ceiling ht, 1' light well, 1.6 LPD, AC and Heat

		10,000 sq.ft		8,000 sq.ft		6,000 sq.ft		4,000 sq.ft	
		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio	
		2/3 on/off	Dim 20%	2/3 on/off	Dim 20%	2/3 on/off	Dim 20%	2/3 on/off	Dim 20%
CZ 03	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	1.00	2.38	0.90	2.14	0.77	1.84	0.60	1.44
	2.0%	2.76	3.52	2.56	3.26	2.28	2.90	1.87	2.38
	3.0%	3.03	3.44	2.85	3.24	2.60	2.95	2.21	2.51
	4.0%	2.88	3.09	2.74	2.94	2.53	2.72	2.20	2.36
	5.0%	2.58	2.71	2.48	2.60	2.32	2.43	2.05	2.15
	6.0%	2.29	2.38	2.21	2.29	2.08	2.16	1.87	1.94
	8.0%	1.83	1.85	1.78	1.79	1.69	1.71	1.55	1.57
	10.0%	1.46	1.46	1.43	1.42	1.37	1.37	1.27	1.27
	12.0%	1.18	1.16	1.15	1.14	1.11	1.10	1.04	1.03
	SFR								
CZ 07	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	1.17	2.79	1.06	2.52	0.91	2.16	0.71	1.69
	2.0%	3.27	4.06	3.03	3.76	2.70	3.35	2.22	2.75
	3.0%	3.60	3.89	3.39	3.67	3.09	3.34	2.62	2.84
	4.0%	3.23	3.40	3.07	3.23	2.84	2.99	2.47	2.60
	5.0%	2.86	2.92	2.74	2.80	2.56	2.62	2.27	2.32
	6.0%	2.48	2.51	2.39	2.42	2.25	2.28	2.02	2.05
	8.0%	1.88	1.87	1.83	1.81	1.74	1.73	1.60	1.59
	10.0%	1.42	1.41	1.39	1.37	1.34	1.32	1.24	1.23
	12.0%	1.09	1.07	1.06	1.04	1.03	1.01	0.96	0.95
CZ 10	SFR								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	1.00	2.54	0.90	2.29	0.78	1.97	0.61	1.54
	2.0%	2.94	3.68	2.72	3.41	2.43	3.04	1.99	2.50
	3.0%	3.11	3.40	2.92	3.20	2.67	2.92	2.26	2.48
	4.0%	2.64	2.82	2.51	2.69	2.32	2.49	2.02	2.16
	5.0%	2.22	2.30	2.12	2.21	1.99	2.06	1.76	1.83
	6.0%	1.83	1.87	1.77	1.80	1.67	1.70	1.50	1.52
	8.0%	1.20	1.21	1.17	1.18	1.12	1.12	1.02	1.03
	10.0%	0.76	0.75	0.74	0.73	0.71	0.70	0.66	0.65
	12.0%	0.42	0.41	0.42	0.40	0.40	0.39	0.38	0.36
CZ 12	SFR								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.91	2.38	0.82	2.15	0.71	1.85	0.55	1.44
	2.0%	2.69	3.46	2.49	3.21	2.22	2.86	1.82	2.35
	3.0%	2.78	3.22	2.62	3.03	2.38	2.76	2.02	2.34
	4.0%	2.54	2.72	2.41	2.58	2.23	2.39	1.94	2.08
	5.0%	2.13	2.24	2.04	2.14	1.91	2.01	1.69	1.78
	6.0%	1.74	1.83	1.68	1.76	1.59	1.66	1.42	1.49
	8.0%	1.17	1.19	1.14	1.16	1.08	1.10	0.99	1.01
	10.0%	0.72	0.72	0.71	0.70	0.68	0.68	0.63	0.63
	12.0%	0.38	0.36	0.37	0.36	0.36	0.35	0.34	0.32
CZ 14	SFR								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	1.09	2.73	0.98	2.46	0.84	2.12	0.66	1.65
	2.0%	3.13	3.83	2.90	3.55	2.58	3.16	2.12	2.59
	3.0%	3.05	3.29	2.87	3.10	2.62	2.82	2.22	2.40
	4.0%	2.44	2.54	2.32	2.42	2.15	2.24	1.87	1.95
	5.0%	1.87	1.91	1.79	1.83	1.67	1.71	1.48	1.51
	6.0%	1.39	1.39	1.34	1.34	1.26	1.27	1.13	1.14
	8.0%	0.64	0.63	0.62	0.61	0.59	0.58	0.54	0.53
	10.0%	0.11	0.10	0.11	0.09	0.11	0.09	0.10	0.08
	12.0%	(0.27)	(0.29)	(0.27)	(0.29)	(0.26)	(0.28)	(0.24)	(0.26)

Table 14: Case10-Office B/C Ratios

Case 10: Office, 10' ceiling ht, 4'+Splays light well, 1.1 LPD, AC and Heat

		10,000 sq.ft		***8,000 sq.ft***		***6,000 sq.ft***		***4,000 sq.ft***	
		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio	
	SFR	2/3 on/off	Dim 20%	2/3 on/off	Dim 20%	2/3 on/off	Dim 20%	2/3 on/off	Dim 20%
CZ 03	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.11	0.20	0.10	0.20	0.10	0.19	0.10	0.19
	2.0%	0.28	0.33	0.27	0.31	0.26	0.31	0.26	0.30
	3.0%	0.32	0.34	0.31	0.33	0.30	0.32	0.30	0.32
	4.0%	0.31	0.33	0.30	0.32	0.29	0.31	0.29	0.31
	5.0%	0.29	0.30	0.28	0.29	0.28	0.28	0.27	0.28
	6.0%	0.27	0.27	0.26	0.26	0.25	0.26	0.25	0.26
	8.0%	0.21	0.21	0.20	0.20	0.20	0.20	0.20	0.20
	10.0%	0.16	0.15	0.15	0.15	0.15	0.15	0.15	0.15
	12.0%	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	SFR								
CZ 07	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.13	0.24	0.13	0.23	0.12	0.23	0.12	0.23
	2.0%	0.33	0.37	0.32	0.36	0.31	0.35	0.31	0.35
	3.0%	0.35	0.37	0.34	0.36	0.33	0.35	0.33	0.35
	4.0%	0.33	0.34	0.32	0.33	0.31	0.32	0.31	0.32
	5.0%	0.29	0.30	0.28	0.29	0.28	0.28	0.28	0.28
	6.0%	0.25	0.25	0.25	0.24	0.24	0.24	0.24	0.24
	8.0%	0.17	0.17	0.17	0.17	0.17	0.16	0.16	0.16
	10.0%	0.10	0.10	0.10	0.10	0.10	0.09	0.10	0.09
	12.0%	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
CZ 10	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.10	0.21	0.10	0.20	0.09	0.19	0.09	0.19
	2.0%	0.27	0.31	0.26	0.30	0.25	0.29	0.25	0.29
	3.0%	0.26	0.28	0.25	0.27	0.24	0.26	0.24	0.26
	4.0%	0.21	0.22	0.21	0.22	0.20	0.21	0.20	0.21
	5.0%	0.16	0.16	0.15	0.16	0.15	0.16	0.15	0.15
	6.0%	0.10	0.11	0.10	0.10	0.10	0.10	0.10	0.10
	8.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10.0%	(0.08)	(0.09)	(0.08)	(0.09)	(0.08)	(0.08)	(0.08)	(0.08)
	12.0%	(0.16)	(0.16)	(0.16)	(0.16)	(0.15)	(0.16)	(0.15)	(0.16)
CZ 12	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.08	0.18	0.07	0.18	0.07	0.17	0.07	0.17
	2.0%	0.23	0.27	0.22	0.26	0.21	0.26	0.21	0.26
	3.0%	0.23	0.25	0.22	0.24	0.21	0.24	0.21	0.23
	4.0%	0.19	0.20	0.18	0.19	0.18	0.19	0.17	0.19
	5.0%	0.13	0.14	0.13	0.14	0.12	0.13	0.12	0.13
	6.0%	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	8.0%	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
	10.0%	(0.11)	(0.12)	(0.11)	(0.11)	(0.11)	(0.11)	(0.11)	(0.11)
	12.0%	(0.19)	(0.20)	(0.19)	(0.19)	(0.19)	(0.19)	(0.18)	(0.19)
CZ 14	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.10	0.21	0.09	0.21	0.09	0.20	0.09	0.20
	2.0%	0.25	0.28	0.24	0.27	0.23	0.26	0.23	0.26
	3.0%	0.20	0.21	0.19	0.21	0.19	0.20	0.19	0.20
	4.0%	0.12	0.12	0.12	0.12	0.11	0.12	0.11	0.12
	5.0%	0.04	0.04	0.04	0.03	0.04	0.03	0.03	0.03
	6.0%	(0.05)	(0.05)	(0.04)	(0.05)	(0.04)	(0.05)	(0.04)	(0.04)
	8.0%	(0.19)	(0.19)	(0.18)	(0.19)	(0.18)	(0.18)	(0.18)	(0.18)
	10.0%	(0.31)	(0.31)	(0.30)	(0.31)	(0.30)	(0.30)	(0.29)	(0.30)
	12.0%	(0.41)	(0.41)	(0.40)	(0.41)	(0.40)	(0.40)	(0.39)	(0.40)

To mandate skylights in these areas we are looking for benefit cost ratios that are greater than 1.0 (the minimum needed to show cost-effectiveness). When the benefit cost ratio is greater than 1.0 the cells in the table are highlighted in light gray, B/C ratios greater than 1.5 are in medium gray and greater than 2.0 black.

For this analysis we will look at the B/C ratios for the 3% SFR as that is the current prescriptive requirement for the skylights in spaces above 25,000 square feet for the Retail with 15 foot ceiling and Warehouse cases. From Table 12 and Table 13, it can be seen that for the retail case, skylight at 3% SFR have a B/C ratio greater than 2 across all climate zones and across the four building sizes. But for the warehouse case, we see that for CZ12 and CZ3, we begin to get B/C ratios at 3% SFR, less than 1 for the 4,000 square feet building case. The ratios are slightly above 1 for the 6,000 square feet building, and comfortably above 1 for the 8,000 and 10,000 square feet buildings.

Keeping this a conservative estimate, we can safely recommend that 8,000 square feet be the minimum space before skylighting can be prescriptively required in climate zones 3, 7, 10, 12 and 14 for buildings with a minimum ceiling height of 15 feet.

The main conclusions that can be drawn from this data are:

- Skylights are cost-effective at 3% SFR in climate zones 3, 7, 10, 12 and 14. for buildings above 6,000 square feet.

- Buildings with dropped ceilings fail to achieve B/C ratios of 1 or greater across the climate zones considered and building sizes considered. This is due to the additional costs of light wells and need for extra skylights to provide uniform daylighting in a dropped ceiling condition

Other conclusions that can be drawn from the work that went into this analysis are:

- The initial costs of skylighting systems are reduced with taller ceilings – skylights can be spaced further apart while maintaining lighting uniformity

- The optimal skylight area increases as lighting power density increases

The B/C ratios for the remaining cases can be found in the Appendix of this report.

Well efficiency of specular light pipes

The current Title 24 standards address the light losses due to light wells via the calculation of well efficiency. This calculation is relatively accurate for rectangular light wells with diffusing surfaces. But this calculation underestimates the well efficiency of specularly reflective tubular light wells. As tubular skylights with specular light wells are becoming increasingly more popular in nonresidential spaces, we thought the standards and the ACM Manual should have more representative models of these types of skylights.

Seminal work on tubular light well efficiency was developed by Swift and Smith (1995). However, they developed their algorithms in a format that still required numerical integration across the opening of the tube. This integration has been conducted and several regression models have been developed. Laoudi published these regressions in his paper validating his skylighting program SkyVision.

The transmittance of a light pipe (a.k.a. tubular light well), VTpipe is a function of the reflectance of the light pipe, the incident angle of light and the length over diameter ratio, L/D.

The simplest and fairly accurate formulation was developed by Zastrow and Wittwer as follows:

$$VT_{pipe} = \rho^{\left(\frac{4}{\pi} * \frac{L}{D} * \tan\theta\right)}$$

where,

ρ = specular reflectance of interior pipe wall

L/D = ratio of pipe length to pipe inner diameter

Θ = angle of incidence with respect to pipe axis

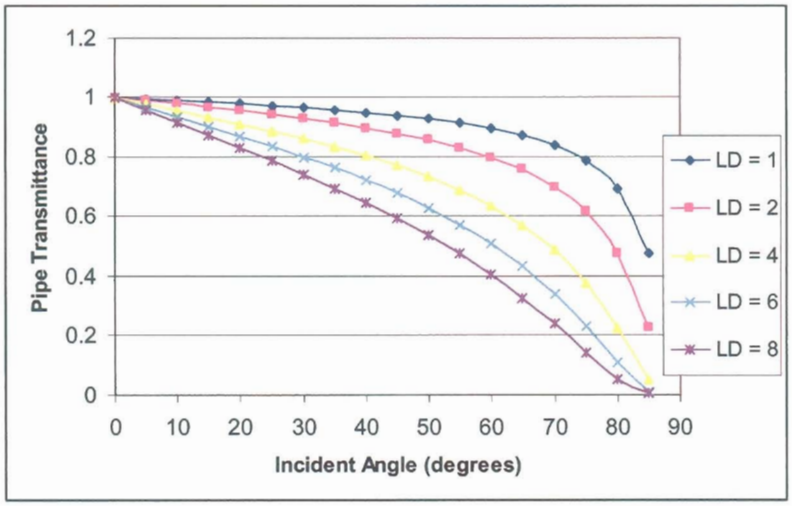


Figure 5: Zastrow and Wittwer corrleation for calculating Light Pipe Transmittance

For a hand calculation of well efficiency as is used for calculating effective aperture we need to pick a representative sun angle to characterize the performance of the skylight over the course of the year. The following section describes why we have chosen 30 degree solar elevation (or 60° angle of incidence with the axis of the tubular light well) as the appropriate value in calculating the tubular light well efficiency.

The daylight availability model in IESNA Handbook calculates horizontal illuminance as a combination of horizontal direct beam illuminance and horizontal illuminance as produced by the sky. Both the beam and sky illuminance terms increase with solar altitude. Thus there is less sunlight available when sun is lowest in the sky. When the sun is high in the sky, there is an excess of sunlight available. Thus the highest consideration for skylight transmittance is at low solar altitudes.

San Diego Average Global Horizontal Illuminance (fc) from TMY2 data file												
Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	195	402	519	346	225	75	0	0	0
7	0	97	476	1,229	1,393	1,548	1,360	1,116	840	506	207	0
8	601	1,053	1,990	3,019	3,148	3,509	3,002	2,685	2,329	1,866	1,262	749
9	2,009	2,706	3,718	4,917	4,968	5,394	5,083	4,738	4,116	3,422	2,877	2,036
10	3,360	4,195	5,121	6,418	6,413	6,946	6,872	6,993	5,502	5,117	4,280	3,220
11	4,602	5,337	6,508	7,790	7,635	8,195	8,474	8,538	7,057	6,433	5,206	4,318
12	5,056	5,954	7,154	8,345	8,493	8,904	8,931	8,895	7,977	6,953	5,549	4,823
13	5,199	6,003	7,260	8,584	8,793	8,393	8,982	9,134	8,030	6,834	5,337	4,756
14	4,516	5,490	6,680	7,827	7,908	7,805	8,230	8,314	7,080	6,047	4,516	4,100
15	3,386	4,307	5,421	6,643	6,585	6,470	7,088	6,790	5,536	4,432	3,191	2,932
16	1,980	2,829	3,832	4,802	4,728	4,882	5,543	5,253	3,755	2,649	1,585	1,396
17	531	1,198	2,070	2,703	2,931	3,226	3,593	3,239	1,794	844	329	285
18	0	173	458	842	1,167	1,510	1,661	1,252	404	35	0	0
19	0	0	0	31	194	333	348	149	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0

Figure 6. Average exterior illuminance in San Diego by month and hour

Figure 6 illustrates the average outdoor illuminance by hour for each month of the year in San Diego. The plot is progressively shaded depending upon the amount of light available. If we have a skylighting system that could deliver 1% of exterior light to the floor of the interior space and one was turning off 1/3 of lights when the interior daylight light levels were above 25 fc (exterior illuminance greater than 2,500 fc) and turning off a total of 2/3 of the lights when the internal daylight light levels were above 50 fc (exterior illuminance greater than 5,000 fc), this would be represented by the hour and month matrix in Figure 6. Cells with greater than 5,000 exterior fc are shaded white – 2/3 s of the lights could be tuned off. Cells with less than 5,000 fc and greater than 2,500 fc are shaded light grey (blue in color images) – enough light to turn off 1/3 of the lights. What one can also see is that there is usually more than enough light to turn off electric lighting in the middle of the day for most months. The key determinate of how much the system saves is how many hours the building interior is daylit enough in the mornings and during the winter months.

San Diego Average Solar Altitude (degrees)												
Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°
2	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°
3	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°
4	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°
5	0°	0°	0°	0°	1°	1°	1°	0°	0°	0°	0°	0°
6	0°	0°	1°	4°	7°	9°	7°	4°	2°	1°	0°	0°
7	1°	2°	6°	14°	19°	21°	19°	15°	11°	6°	3°	1°
8	7°	10°	18°	26°	32°	33°	31°	27°	23°	18°	12°	8°
9	17°	22°	30°	39°	44°	46°	44°	40°	35°	29°	22°	18°
10	26°	31°	40°	50°	57°	58°	56°	52°	46°	38°	30°	26°
11	33°	39°	49°	60°	68°	70°	68°	63°	55°	45°	36°	31°
12	36°	43°	54°	66°	76°	80°	77°	70°	59°	47°	38°	34°
13	36°	44°	54°	65°	73°	77°	76°	69°	57°	45°	37°	33°
14	32°	39°	49°	57°	63°	66°	66°	60°	50°	39°	31°	29°
15	25°	32°	40°	46°	51°	53°	54°	49°	40°	30°	23°	21°
16	16°	22°	29°	34°	38°	41°	41°	37°	29°	20°	13°	12°
17	6°	11°	17°	22°	25°	28°	28°	24°	16°	8°	4°	4°
18	1°	3°	5°	9°	13°	16°	16°	12°	5°	1°	0°	0°
19	0°	0°	0°	1°	3°	5°	5°	3°	0°	0°	0°	0°
20	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°
21	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°
22	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°
23	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°
24	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°

Figure 7. Average solar altitude in San Diego by month and hour

Figure 7 shows the average solar elevations by month and hour in San Diego having the same hours shaded for 2/3's of the lights and 1/3 of the lights on as in Figure 6. The solar altitudes of interest are those which might affect the number of hours that lights are controlled. These solar altitudes of interest are those where there is a transition of one control state to another in Figure 7, this is the transition from the white center cells to the light gray (blue in color images) and the transition from light gray to medium gray. These transitions for this skylighting system occur at solar altitudes of around 25° for turning the first third of lights off and around 40° for turning the second bank of lights off. Not only are the hours of relatively low light levels and low solar elevations the times when visible transmittance of the system needed the most to gain savings, it turns out that most of the daytime hours of the year have solar altitudes less than 30°. The histograms in Figure 8 show that from Southern California (San Diego) to the Oregon border (Eureka), the mode and the median of daylit hours are around 30° to 35°.

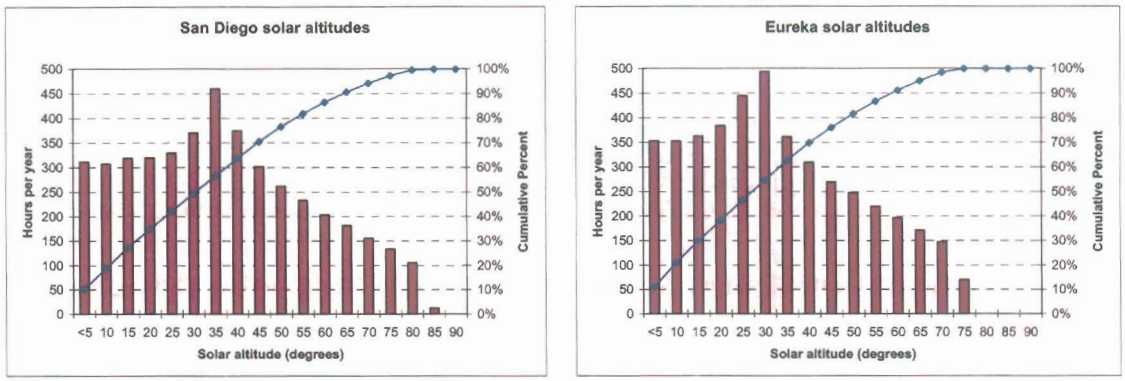


Figure 8. Frequency of solar altitudes in San Diego, CA and Eureka, CA.

Thus the measurement and rating of skylight visible transmittance should predict well the visible transmittance of skylights around 30° solar altitude or 60° angle of incidence from directly above the skylight.

Thus the well efficiency for tubular light wells should be based upon a 60 degree angle of incidence and the equation for various length/diameter ratios and well reflectances can be simplified as follows:

$$WE_{Tube} = \rho^{\left(2.2 * \frac{L}{D}\right)}$$

where,

ρ	=	specular reflectance of interior pipe wall
L/D	=	ratio of pipe length to pipe inner diameter
2.2	=	4 / pi x tan(60°)

Statewide Energy Savings

Statewide energy savings estimates will be based on the energy savings for retail and warehouse spaces that would fall under the new criteria for section 143(c). Namely that the minimum enclosed space area that the requirement will apply will drop from 25,000 sf to 8, 000. Thus the electricity savings of 1.51 kWh/sf for warehouse and the retail electricity savings 2.2/kWh/sf (and 0.16 therms/sf heating fuel increase) will be applied to the building stock of these occupancies that are between 8,000 and 25,00 sf. This estimate will be generated in the final version of this report.

Recommendations

Proposed Standards Language

Proposed language for the standards includes section number and original standards language in black font, deleted text is ~~in red text with hard strikeouts~~ and added language contained is in blue font and underlined.

SECTION 119 – MANDATORY REQUIREMENTS FOR LIGHTING CONTROL DEVICES

Any automatic time switch control device, occupant-sensor, motion sensor, photosensor, or automatic daylighting control device or systems having these functions shall be installed only if the manufacturer has certified to the commission that the device or system complies with all of the applicable requirements of Subsections (a) through (~~f~~g) ~~and Subsections (h) through (j),~~ and if the device or system is installed in compliance with Subsection (~~g~~h).

(e) **Automatic Daylighting Control Devices**. Automatic daylighting control devices used to control lights in daylit zones shall:

1. Be capable of reducing the light output of the general lighting of the controlled area by at least one half in response to the availability of daylight while maintaining relatively uniform illumination throughout the area; and
2. If the device is a dimmer, provide electrical outputs to lamps for reduced flicker operation through the dimming range and without causing premature lamp failure; and
3. If the devices reduce lighting in control steps, incorporate time-delay circuits to prevent cycling of light level changes of less than three minutes and have a deadband adjustment to provide sufficient separation ~~(deadband)~~ of on and off points for each control step to prevent cycling; and
4. If the devices have a time delay, have the capability for the time delay to be over-ridden or set to less than 5 seconds time delay for the purpose of set up and calibration, and automatically restore its time delay settings to normal operation programmed time delays after no more than 60 minutes; and
5. Have a setpoint control that easily distinguishes settings to within 10% of full scale adjustment; and
6. Have a light sensor that has a linear response with 5% accuracy over the range of illuminances measured by the light sensor; and
7. Have a light sensor that is physically separated from where calibration adjustments are made; and
8. If the device is a stepped switching control device, show the status of lights in the controlled zone by an indicator on the control device; and
9. If the device is a continuous dimming control device, display the light level measured by the light sensor, if the controlled electric lighting cannot be viewed from where setpoint adjustments are made.

   EXCEPTION to Section 119(e) ~~7 & 8~~ **8&9:** If the control device is part of a networked system with a central display of each control zone status, the status indicator or light level display on each individual control device shall not be required if control setpoint adjustments can be made at the central display.

(f) **Interior Photosensors**. Interior photosensor shall not have a mechanical slide cover or other device that permits easy unauthorized disabling of the control, and shall not be incorporated into a wall-mounted occupant-sensor.

(~~h~~g) **Multi-level Astronomical Time-switch Controls.** Multi-level astronomical time-switch controls used to control lighting in daylit zones shall:

1. Contain at least 2 separately programmable steps (relays) per zone that reduces illuminance in a relatively uniform manner as specified in Section 131(b); and
2. Have a separate offset control for each step of 1 to 240 minutes; and
3. Have sunrise and sunset prediction accuracy within +/- 15 minutes and timekeeping accuracy within 5 minutes per year; and
4. Store time zone, longitude and latitude in non-volatile memory; and
5. Display date/time, sunrise and sunset, and switching times for each step; and

6. Have an automatic daylight savings time adjustment; and
7. Have automatic time switch capabilities specified in Section 119 (c).

(~~g~~ h) **Installation in Accordance with Manufacturer's Instructions**. If an automatic time switch control device, occupant-sensor, automatic daylighting control device, or interior photosensor is installed, it shall comply with both Items 1 and 2 below.

1. The device shall be installed in accordance with the manufacturer's instructions; and
2. Automatic daylighting control devices shall:
   A. Be installed so that automatic daylighting control devices control only luminaires within the daylit area; and
   B. Have photosensor that are either ceiling mounted or located so that they are accessible only to authorized personnel, and that are located so that they maintain adequate illumination in the area in accordance with the designer's or manufacturer's instructions.

~~(i) Automatic Multi-Level Daylighting Controls. An automatic multi-level daylighting control used to control lighting in daylit zones shall:~~

~~1. Meet all the requirements of section 119 (e) for automatic daylighting control devices; and~~

~~2. Meet all the multi-level and uniformity requirements of section 131 (b); and~~

~~3. Have a light sensor that is physically separated from where setpoint adjustments are made; and~~

~~4. Have controls for calibration adjustments to the lighting control device that are readily accessible to authorized personnel.~~

SECTION 131 – INDOOR LIGHTING CONTROLS THAT SHALL BE INSTALLED

(a) **Area Controls.**

1. Each area enclosed by ceiling-height partitions shall have an independent switching or control device. This switching or control device shall be:
   A. Readily accessible; and
   B. Located so that a person using the device can see the lights or area controlled by that switch, or so that the area being lit is annunciated; and
   C. Manually operated, or automatically controlled by an occupant-sensor that meets the requirements of Section 119 (d).
2. Automatic time switch controls may be installed in conjunction with the switching or control device, provided the area control is an override switching device as described in §131(d)2.
3. Other lighting control devices may be installed in conjunction with the area switching or control device provided that they:
   A. Permit the area switching or control device to ~~override the action of all other devices~~ turn the lights off in each area enclosed by ceiling-height partitions; and
   B. When the area switching or control device is not turning off the lights, ~~Reset the mode of~~ any other automatic system ~~to~~ is in normal operation mode without further action.

EXCEPTIONS to Section 131 (a):

1. Up to ~~one-half~~ 0.3 watt per square foot of lighting in any area within a building that must be continuously illuminated for reasons of building security or emergency egress, if:

   A. The area is designated a security or emergency egress area on the plans and specifications submitted to the enforcement agency under Section 10-103 (a) (2) of Title 24, Part 1; and

   B. The area is controlled by switches accessible only to authorized personnel.

2. Public areas with switches that are accessible only to authorized personnel.

(b) **Multi-Level Lighting Controls**. The general lighting of any enclosed space 100 square feet or larger in which the connected lighting load exceeds 0.8watts per square foot, and that has more than one light source (luminaire), shall have multi-level lighting controls. A multi-level lighting control is a lighting control that reduces lighting power by either continuous dimming, stepped dimming, or stepped switching while maintaining a reasonably uniform level of illuminance throughout the area controlled. Multilevel controls shall have at least one control step that is between 50% and 70% of design lighting power in addition to turning lights completely off. ~~and at least one step of minimum light output operating at less than 35% of full rated lighting system power (this control step could be completely off, creating a bi-level control)~~. A reasonably uniform level of illuminance in an area shall be achieved by any of the following:

1. Dimming all lamps or luminaires; or

2. Switching alternate lamps in luminaires, alternate luminaires, and alternate rows of luminaires.

EXCEPTION to Section 131 (b): Lights in corridors.

(c) **Daylit Areas**. Luminaires providing general lighting that are in or are partially in the ~~daylit~~ skylit or the primary sidelit areas shall be controlled according to the applicable requirements in items 1 and 2 below.

The ~~daylit~~ skylit area under skylights shall be the rough opening of the skylight plus, in each of the lateral and longitudinal dimensions of the skylight, the lesser of : 70% of the floor-to-ceiling height, ~~the distance to the nearest 60-inch or higher permanent partition~~, the distance to any permanent partition which is farther away than 70% of the distance between the top of the partition and the ceiling, or one half the horizontal distance to the edge of the closest skylight or vertical glazing.

The primary sidelit ~~daylit~~ area illuminated by vertical glazing shall be the primary sidelit ~~daylit~~ depth multiplied by the sidelit ~~daylit~~ width.~~, where the~~ The primary sidelit ~~daylit~~ depth is one window head height horizontal distance ~~15 feet the height of the~~ , ~~or the distance on the floor,~~ perpendicular to the glazing , to the nearest 60-inch or higher permanent partition, whichever is less; and the ~~daylit~~ sidelit width is the width of the window plus, on each side, either 2 feet, the distance to a permanent partition, or one half the distance to the closest skylight or vertical glazing, whichever is least.

The secondary sidelit area illuminated by vertical glazing shall be the secondary sidelit depth multiplied by the sidelit width minus the primary sidelit area. The secondary sidelit depth is two window head heights horizontal distance perpendicular to the glazing, to the nearest 60-inch or higher permanent partition, whichever is less; and the sidelit width is the width of the window plus, on each side, either 2 feet, the distance to a permanent partition, or one half the distance to the closest skylight or vertical glazing, whichever is least.

1. ~~Daylit~~ Skylit areas or primary sidelit areas greater than 250 square feet in any enclosed space shall have at least one lighting control that:

   A. Controls at least 50% of the power in the skylit areas and primary sidelit ~~daylit~~ areas separately from other lighting in the enclosed space; and

   B. Controls luminaires in ~~vertically daylit~~ primary sidelit areas separately from ~~horizontally daylit~~ skylit areas.

   C. Maintains a reasonably uniform level of illuminance in the daylit area using one of the methods specified in Section 131 (b) items 1 or 2.

2. When the ~~daylit~~ skylit area or primary sidelit area in any enclosed space ~~is under skylights and~~ has a total area greater than 2,500 square feet, the general lighting ~~in the daylit area under skylights~~ skylit area or primary

sidelit area shall be controlled separately by ~~either~~ an ~~automatic multi-level~~ daylighting control device that meets the requirements of Section 119 (e ~~i~~) and,

A. Meet all the multi-level and uniformity requirements of section 131 (b); and

B. When daylight in the space is at the design illuminance levels of the controlled lighting, such control shall automatically reduce the power consumption of the controlled lighting so that the controlled lighting is consuming no more than 35% of rated power. ~~or a multi-level astronomical time switch that meets the requirements of section 119 (h) and has override switches that meet the requirements of section 131 (d) 2~~.

C. When the ceiling height is greater than 11 feet, the controls for calibration adjustments to the daylighting control device are readily accessible to authorized personnel.

EXCEPTIONS to Section 131 (c)2

1. When the lighting power density of the general lighting in the skylit area or primary sidelit area is less than 0.5 W/sf, the control need not meet the multi-level requirements of §131(c)2a.

2. When the skylight effective aperture exceeds 2.0%, a multi-level astronomical time switch that meets the requirements of Section 119(g) and has override switches that meet the requirements of section 131 (d) 2 shall be a deemed to comply. The skylight effective aperture is specified in Equation 146-A.

EXCEPTIONS to Section 131 (c)

1. ~~Daylit areas~~ Primary sidelit areas where the effective aperture is less than 0.1 ~~for vertical glazing~~ and skylit areas where the effective aperture is less than 0.006 ~~for skylights~~. ~~The effective aperture for vertical glazing is the visible light transmittance (VLT) times the window wall ratio.~~. The effective aperture for skylights is specified in Section 146 (a) 4 E.

2. Daylit areas where existing adjacent structures or natural objects obstruct daylight to the extent that effective use of daylighting is not feasible.

3. Skylit areas or primary sidelit areas where the lighting power density of general lighting is less than 0.3 W/sf

(d) **Shut-off Controls**.

1. For every floor, all indoor lighting systems shall be equipped with a separate automatic control to shut off the lighting. This automatic control shall meet the requirements of Section 119 and may be an occupant sensor, automatic time switch, or other device capable of automatically shutting off the lighting.

   EXCEPTIONS to Section 131 (d) 1:

   1. Where the system is serving an area that must be continuously lit, 24 hour per day/365 days per year.

   2. Lighting in corridors, guestrooms, and lodging quarters of high-rise residential buildings and hotel/motels.

   3. Up to ~~one-half~~ 0.3 watt per square foot of lighting in any area within a building that must be continuously illuminated for reasons of building security or emergency egress.

2. If an automatic time switch control device is installed to comply with Section 131 (d) 1, it shall incorporate for each area enclosed by ceiling-height partitions an override switching device that:

   A. Is readily accessible; and

   B. Is located so that a person using the device can see the lights or the area controlled by that switch, or so that the area being lit is annunciated; and

   C. Is manually operated; and

   D. Allows the lighting to remain on for no more than two hours when an override is initiated; and

   EXCEPTION to Section 131 (d) 2 D: In malls, auditoriums, single tenant retail spaces, industrial facilities, and arenas, where captive-key override is utilized, override time may exceed two hours.

E. Controls an area enclosed by ceiling height partitions not exceeding 5,000 square feet.

EXCEPTION to Section 131 (d) 2 E: In malls, auditoriums, single tenant retail spaces, parking garages, industrial facilities, convention centers and arenas, the area controlled may not exceed 20,000 square feet.

3. If an automatic time switch control device is installed to comply with Section 131 (d) 1, it shall incorporate an automatic holiday "shut-off" feature that turns off all loads for at least 24 hours, then resumes the normally scheduled operation.

EXCEPTION to Section 131 (d) 3: Retail stores and associated malls, restaurants, grocery stores, churches, and theaters.

(e) **Display Lighting**. Display lighting shall be separately switched on circuits that are 20 amps or less.

<Note additional language for this section in Indoor Lighting CASE proposal>

(f) **Lighting Control Acceptance.** Before an occupancy permit is granted for a new building or space, or a new lighting system serving a building or space is operated for normal use, all lighting controls serving the building or space shall be certified as meeting the Acceptance Requirements for Code Compliance. A Certificate of Acceptance shall be submitted to the building department that:

1. Certifies plans, specifications, installation certificates, and operating and maintenance information meet the requirements of Part 6.
2. Certifies that automatic daylighting controls meet the requirements of Section 119 (e) through Section 119 (g).
3. Certifies that lighting controls meet the requirements of Section 131 (a) through Section 131 (c), Sections 131 (e) and (f), and Section 146(a) 4 D.
4. Certifies that automatic lighting controls meet the requirements of Section 119 (c) and 131 (d).
5. Certifies that occupant-sensors meet the requirements of Section 119 (d) and 131 (d).

SECTION 10-112 – CRITERIA FOR DEFAULT TABLES

(a) The commission shall maintain tables of default U-factors and SHGCs for use as an alternative to U-factors and SHGCs derived using the NFRC rating procedure. The default values shall meet the following criteria:

1. The values shall be derived from simulations of products using the same computer simulation program(s) used in the NFRC Rating Procedure.
2. The default values shall be set so that they do not provide to any significant number of products a lower U-factor or SHGC than those products would obtain if they were rated using the full NFRC Rating Procedure, including testing and simulation.

(b) The commission shall periodically review and revise the default tables as necessary to ensure that the criteria are met.

NOTE: Authority cited: Section 25402.1, Public Resources Code. Reference: Section 25402.1, Public Resources Code.

TABLE 116-A DEFAULT FENESTRATION PRODUCT U-FACTORS

FRAME TYPE[1]	PRODUCT TYPE	SINGLE PANE U-FACTOR	DOUBLE PANE U-FACTOR[2]
Metal	Operable	1.28	0.79
Metal	Fixed	1.19	0.71
Metal	Greenhouse/garden window	2.26	1.40
Metal	Doors	1.25	0.77
Metal	Skylight	1.98	1.3
Metal, Thermal Break	Operable	N.a	0.66
Metal, Thermal Break	Fixed	N.a	0.55
Metal, Thermal Break	Greenhouse/garden window	N.a	1.12
Metal, Thermal Break	Doors	N.a	0.59
Metal, Thermal Break	Skylight	N.a	1.11
Nonmetal	Operable	0.99	0.58
Nonmetal	Fixed	1.04	0.55
Nonmetal	Doors	0.99	0.53
Nonmetal	Greenhouse/garden windows	1.94	1.06
Nonmetal	Skylight	1.47	0.84

[1] Metal includes any field-fabricated product with metal cladding. Nonmetal-framed manufactured fenestration products with metal cladding must add 0.04 to the listed U-factor. Nonmetal frame types can include metal fasteners, hardware, and door thresholds. Thermal break product design characteristics are:

a. The material used as the thermal break must have a thermal conductivity of not more than 3.6 Btu-inch/hr/ft^2/°F,

b. The thermal break must produce a gap of not less than 0.210 inch, and

c. All metal members of the fenestration product exposed to interior and exterior air must incorporate a thermal break meeting the criteria in Items a. and b. above.

In addition, the fenestration product must be clearly labeled by the manufacturer that it qualifies as a thermally broken product in accordance with this standard. Thermal break values shall not apply to field-fabricated fenestration products.

[2]For all dual-glazed fenestration products, adjust the listed U-factors as follows:

a. Subtract 0.05 for spacers of 7/16 inch or wider.

b. Subtract 0.05 for products certified by the manufacturer as low-E glazing.

c. Add 0.05 for products with dividers between panes if spacer is less than 7/16 inch wide.

d. Add 0.05 to any product with true divided lite (dividers through the panes).

TABLE 116-B DEFAULT SOLAR HEAT GAIN COEFFICIENT

FRAME TYPE	PRODUCT	GLAZING	TOTAL WINDOW SHGC[2]	
			Single Pane	Double Pane
Metal	Operable	Clear	0.80	0.70
Metal	Fixed	Clear	0.83	0.73
Metal	Operable	Tinted	0.67	0.59
Metal	Fixed	Tinted	0.68	0.60
Metal, Thermal Break	Operable	Clear	N.a	0.63
Metal, Thermal Break	Fixed	Clear	N.a	0.69
Metal, Thermal Break	Operable	Tinted	N.a.	0.53
Metal, Thermal Break	Fixed	Tinted	N.a.	0.57
Nonmetal	Operable	Clear	0.74	0.65
Nonmetal	Fixed	Clear	0.76	0.67
Nonmetal	Operable	Tinted	0.60	0.53
Nonmetal	Fixed	Tinted	0.63	0.55

[2] SHGC = Solar Heat Gain Coefficient.

SECTION 143 – PRESCRIPTIVE REQUIREMENTS FOR BUILDING ENVELOPES

A building complies with this section by being designed with and having constructed and installed either (1) envelope components that comply with each of the requirements in Subsection (a) for each individual component and the requirements of Subsection (c) where they apply, or (2) an envelope that complies with the overall requirements in Subsection (b) and the requirements of Subsection (c) where they apply. When making calculations under Subsection (a) or (b), all of the rules listed in Section 141 (c) 1, 4, and 5 shall apply.

(a) **Envelope Component Approach.**

6. **Skylights**. Skylights shall:

   A. Have an area no greater than five percent of the gross exterior roof area; and

      EXCEPTION to Section 143 (a) 6 A: Atria over 55 feet high shall have a skylight area no greater than 10 percent of the gross exterior roof area.

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

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

TABLE 143-A PRESCRIPTIVE ENVELOPE CRITERIA FOR NONRESIDENTIAL BUILDINGS (including relocatable public school buildings where manufacturer certifies use only in specific climate zone; not including high-rise residential building and guest rooms of hotel/motel buildings)

		CLIMATE ZONES									
		1, 16		**3-5**		**6-9**		**2, 10-13**		**14, 15**	
Roof/Ceiling											
U-factor		0.051		0.051		0.076		0.051		0.051	
R-value[1]		19		19		11		19		19	
Wall											
R-value or		13		11		11		13		13	
U-factor											
Wood frame		0.102		0.110		0.110		0.1024		0.102	
Metal frame		0.217		0.224		0.224		0.217		0.217	
Metal building		0.113		0.123		0.123		0.113		0.113	
Mass/7.0≤ HC<15.0		0.330		0.430		0.430		0.430		0.430	
Mass/15.0≤HC		0.360		0.650		0.690		0.650		0.410	
Other		0.102		0.110		0.110		0.102		0.102	
Floor/Soffit											
R-value or		19		11		11		11		11	
U-factor											
Mass/7.0≤HC		0.090		0.139		0.139		0.090		0.139	
Other		0.048		0.071		0.071		0.071		0.071	
Windows											
U-factor[2]		0.47		0.77		0.77		0.47		0.47	
Relative solar heat gain		Non-North	North	Non-North	North	Non-North	North	Non-North	North	Non-North	North
0-10% WWR		0.49	0.72	0.61	0.61	0.61	0.61	0.47	0.61	0.46	0.61
11-20% WWR		0.43	0.49	0.55	0.61	0.61	0.61	0.36	0.51	0.36	0.51
21-30% WWR		0.43	0.47	0.41	0.61	0.39	0.61	0.36	0.47	0.36	0.47
31-40% WWR		0.43	0.47	0.41	0.61	0.34	0.61	0.31	0.47	0.31	0.40
Skylights											
U-factor[2]	Glass w/Curb	~~1.18~~ 1.11		~~1.42~~1.11		~~1.42~~ 1.11		~~1.18~~ 1.11		~~1.18~~ 1.11	
	Glass w/o Curb	0.68		0.82		0.82		0.68		0.68	
	Plastic w/Curb	1.04		~~1.56~~ 1.11		~~1.56~~ 1.11		~~1.32~~ 1.11		~~1.32~~ 1.11	
SHGC Glass	0-2%	~~0.68~~ NR		~~0.79~~ 0.57		~~0.79~~ 0.57		0.46		0.46	
	2.1-5%	~~0.46~~ NR		0.40		0.40		0.36		0.36	
SHGC Plastic	0-2%	~~0.77~~ NR		~~0.79~~ 0.57		~~0.77~~ 0.57		~~0.77~~ 0.57		~~0.71~~ 0.57	
	2.1-5%	~~0.58~~ NR		~~0.65~~ 0.57		~~0.62~~ 0.57		~~0.62~~ 0.57		~~0.58~~ 0.57	

Note: Construction assembly U-factors shall be calculated in accordance with Appendix IV.

[1] R-value cannot be used for compliance when roof has metal framing members or a metal deck unless additional rigid insulation is installed. See Section 143 (a) 1 C.

[2] U-factor adjustments are made to make the criteria consistent with revised NFRC rating procedures.

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

		CLIMATE ZONES									
		1, 16		**3-5**		**6-9**		**2,10-13**		**14, 15**	
Roof/Ceiling											
U-factor		0.036		0.051		0.051		0.036		0.036	
R-value[1]		30		19		19		30		30	
Wall											
R-value or		19		11		11		13		13	
U-factor											
Wood frame		0.074		0.110		0.110		0.102		0.102	
Metal frame		0.183		0.224		0.224		0.217		0.217	
Metal building		0.061		0.123		0.123		0.113		0.113	
Mass/7.0≤ HC<15.0		0.330		0.430		0.430		0.430		0.430	
Mass/15.0≤HC		0.360		0.650		0.690		0.650		0.410	
Other		0.074		0.110		0.110		0.102		0.102	
Floor/Soffit											
R-value or		19		11		11		11		11	
U-factor											
Mass/7.0≤HC		0.090		0.139		0.139		0.090		0.090	
Other		0.048		0.071		0.071		0.071		0.071	
Raised concrete R-value		8		*		*		*		*	
Windows											
U-factor[2]		0.47		0.47		0.47		0.47		0.47	
Relative solar heat gain		Non-North	North	Non-North	North	Non-North	North	Non-North	North	Non-North	North
0-10% WWR		0.46	0.68	0.41	0.61	0.47	0.61	0.36	0.49	0.36	0.47
11-20% WWR		0.46	0.68	0.40	0.61	0.40	0.61	0.36	0.49	0.31	0.43
21-30% WWR		0.36	0.47	0.31	0.61	0.36	0.61	0.31	0.40	0.26	0.43
31-40% WWR		0.30	0.47	0.26	0.55	0.31	0.61	0.26	0.40	0.26	0.31
Skylights											
U-factor[2]	Glass w/Curb	~~1.18~~ 1.11		~~1.42~~ 1.11		~~1.42~~ 1.11		~~1.18~~ 1.11		~~1.~~18 1.11	
	Glass w/o Curb	0.68		0.82		0.82		0.68		0.68	
	Plastic w/Curb	1.04		~~1.56~~ 1.11		~~1.56~~ 1.11		~~1.32~~ 1.11		~~1.04~~ 1.11	
SHGC Glass	0-2%	0.46		~~0.58~~ 0.57		~~0.61~~ 0.57		0.46		0.46	
	2.1-5%	0.36		0.32		0.40		0.32		0.31	
SHGC Plastic	0-2%	0.71		~~0.~~65 0.57		~~0.65~~ 0.57		~~0.65~~ 0.57		~~0.65~~ 0.57	
	2.1-5%	0.55		0.39		~~0.65~~ 0.57		0.34		0.27	

Note: Construction assembly U-factors shall be calculated in accordance with Appendix IV.

[1] R-value cannot be used for compliance when roof has metal framing members or a metal deck unless additional rigid insulation is installed. See Section 143 (a) 1 C.

* Required insulation levels for concrete raised floors are R-8 in Climate Zones 2, 11, 13, and 14; R-4 in Climate Zones 12 and 15, and R-0 in Climate Zones 3 through 10.

[2]U-factor adjustments are made to make the criteria consistent with revised NFRC rating procedures.

TABLE 143-C PRESCRIPTIVE ENVELOPE CRITERIA FOR RELOCATABLE Public school buildings

		ALL CLIMATE ZONES
Roof/Ceiling		
U-factor		0.051
R-value[1]		19
Wall		
R-value or		13
U-factor		
Wood frame		0.102
Metal frame		0.261
Metal building		0.061
Mass/7.0≤ HC		0.330
Other		0.102
Floor/Soffit		
R-value or		19
U-factor		0.048
Windows		
U-factor		0.49
Relative solar heat gain		
0-10% WWR		0.46
11-20% WWR		0.36
21-30% WWR		0.36
31-40% WWR		0.31
Skylights		
U-factor	Glass w/Curb	0.99
	Glass w/o Curb	0.57
	Plastic w/Curb	0.87
SHGC Glass	0-2%	0.46
	2.1-5%	0.36
SHGC Plastic	0-2%	0.71
	2.1-5%	0.58

Note: Construction assembly U-factors shall be calculated in accordance with Appendix IV.

[1] R-value cannot be used for compliance when roof has metal framing members or a metal deck unless additional rigid insulation is installed. See Section 143 (a) 1 C.

(c) **Minimum Skylight Area for Large Enclosed Spaces in Low-Rise Buildings.** In climate zones 2 through 15, ~~Low~~ low rise conditioned or unconditioned enclosed spaces that are greater than ~~25,000~~ 8.000 ft^2 directly under a roof with ceiling heights greater than 15 ft and have a lighting power density for general lighting equal to or greater than 0.5 W/ft^2 shall meet sections 143 (c) 1-4 below:

1. **Daylit Area.** At least one half of the floor area shall be in the ~~daylit~~ skylit area under skylights.
2. **Minimum Skylight Area or Effective Aperture.** Areas that are daylit shall have a minimum skylight area to ~~daylit~~ skylit area ratio or minimum skylight effective aperture as shown in TABLE 143-F. Skylight effective aperture shall be determined as specified in Equation 146-A.
3. **Skylight Characteristics.** Skylights shall:

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

B. If the space is conditioned, meet the requirements in Section 143 (a) 6 or 143 (b).

4. **Controls.** Electric lighting in the daylit area shall be controlled as described in Section 131 (c) 2.

~~EXCEPTION 1 to Section 143 (c): Buildings in climate zones 1 or 16.~~

EXCEPTION ~~2~~ to Section 143 (c): Auditoriums, churches, ~~movie~~ theaters, museums, and refrigerated warehouses.

TABLE 143-F MINIMUM SKYLIGHT AREA TO ~~DAYLIT~~ SKYLIT FLOOR AREA OR MINIMUM SKYLIGHT EFFECTIVE APERTURE IN LOW-RISE ENCLOSED SPACES >25,000 FT^2 DIRECTLY UNDER A ROOF

General Lighting Power Density in Daylit Areas (W/ft^2)	**Minimum Skylight Area to ~~Daylit~~ Skylit Area Ratio**	Minimum Skylight Effective Aperture
1.4 W/ft^2 ≤ LPD	3.6%	1.2%
1.0 W/ft^2 ≤ LPD < 1.4 W/ft^2	3.3%	1.1%
0.5 W/ft^2 ≤ LPD < 1.0 W/ft^2	3.0%	1.0%

SECTION 146 – PRESCRIPTIVE REQUIREMENTS FOR INDOOR LIGHTING

A building complies with this section if the actual lighting power density calculated under Subsection (a) is no greater than the allowed indoor lighting power calculated under Subsection (b).

4. **Reduction of wattage through controls.** The controlled watts of any luminaire may be reduced by the number of controlled watts times the applicable factor from TABLE 146-A if:

   A. The control complies with Section 119; and

   B. At least 50 percent of the light output of the luminaire is within the applicable space listed in TABLE 146-A; and

   C. Except as noted in TABLE 146-A, only one power adjustment factor is used for the luminaire; and

   D. For occupant sensors used to qualify for the Power Adjustment Factor in small offices less than or equal to 250 square feet, the occupant sensor shall have an automatic OFF function that turns off all the lights, either an automatic or a manually controlled ON function, and have wiring capabilities so that each switch function activates a portion of the lights. The occupant sensor shall meet all the multi-level and uniformity requirements of Section 131 (b) for the controlled lighting. The first stage shall activate between 50-70% of the lights in a room either through an automatic or manual action. After that event occurs any of the following actions shall be assigned to occur when manually called to do so by the occupant.

      i. Activating the alternate set of lights.

      ii. Activating 100% of the lights.

      iii. Deactivating all lights.

   E. For daylighting control credits for conditions not covered by Section 131(c)2, the luminaire is controlled by the daylighting control, and the luminaire is located within the ~~daylit~~ skylit, primary sidelit area or secondary sidelit area. ~~The~~ For skylights the power adjustment factor is a function of the lighting power density of the general lighting in the space and the effective aperture of the skylights determined using Equation 146-A.

EQUATION 146-A – EFFECTIVE APERTURE OF SKYLIGHTS

$$\text{Effective Aperture} = \frac{0.85 \text{ x Total Skylight Area x Glazing Visible Light Transmittance x Well Efficiency}}{\text{Daylit Area Under Skylights}}$$

Total skylight area is the sum of skylight areas above the space. The skylight area is defined as the rough opening of the skylight.

Glazing visible light transmitance is the ratio of visible light that is transmitted through a glazing material to the light that is incident on the material. This shall include all skylighting system accessories including diffusers, louvers and other attachments that impact the diffusion of skylight into the space. The visible light transmittance of movable accessories shall be rated in the full open position. When the visible light transmittance of glazing and accessories are rated separately, the overall glazing transmittance is the product of the visible light transmittances of the glazings and accessories.

~~Daylight~~ Skylit area under skylights is as defined in Section 131(c).

Well Efficiency is the ratio of the amount of visible light leaving a skylight well to the amount of visible light entering the skylight well and shall be determined from the nomograph in FIGURE 146-A based on the weighted average reflectance of the walls of the well and the well cavity ratio (WCR), or other test method approved by the Commission.

The well cavity ratio (WCR) is determined by the geometry of the skylight well and shall be determined using either Equation 146-B or Equation 146-C.

EQUATION 146-B WELL CAVITY RATIO FOR RECTANGULAR WELLS

$$\text{WCR} = \left(\frac{5 \times \text{well height}\left(\text{well length} + \text{well width}\right)}{\text{well length} \times \text{well width}}\right)\text{; or}$$

EQUATION 146-C WELL CAVITY RATIO FOR NON-RECTANGULAR-SHAPED WELLS:

$$\text{WCR} = \left(\frac{2.5 \times \text{well height} \times \text{well perimeter}}{\text{well area}}\right)$$

Where the length, width, perimeter, and area are measured at the bottom of the well.

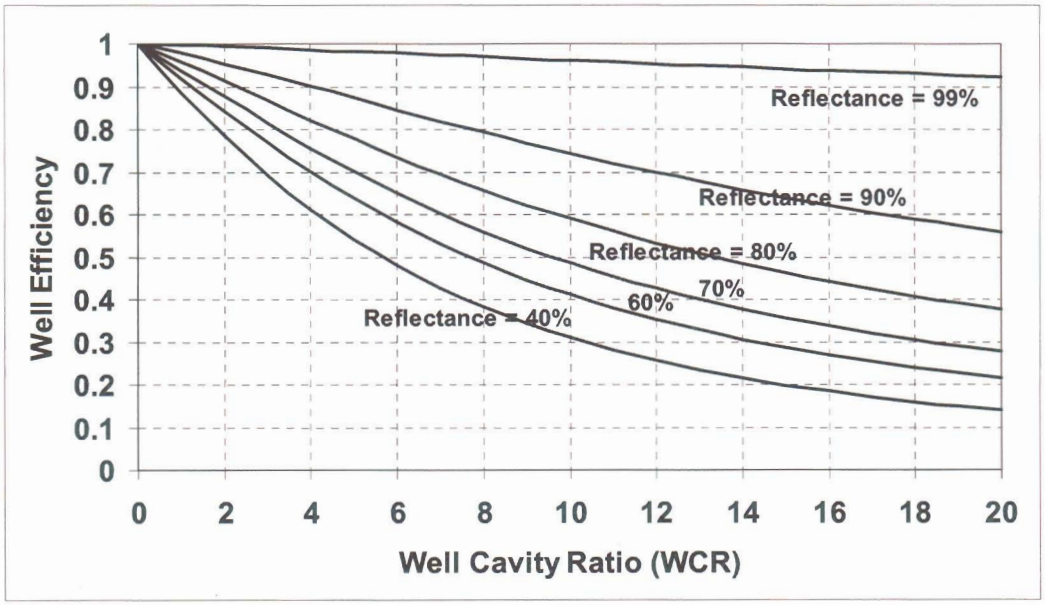


FIGURE 146-A WELL EFFICIENCY NOMOGRAPH

When light well is tubular and has a specular (mirror-like) reflecting surface, the well efficiency of the tubular light well shall be calculated according to the following equation.

EQUATION 146-D WELL EFFICIENCY FOR SPECULAR TUBULAR LIGHT WELLS:

$$WE_{Tube} = \rho^{\left(2.2 * \frac{L}{D}\right)}$$

where,

ρ = specular reflectance of interior pipe wall

L/D = ratio of pipe length to pipe inner diameter

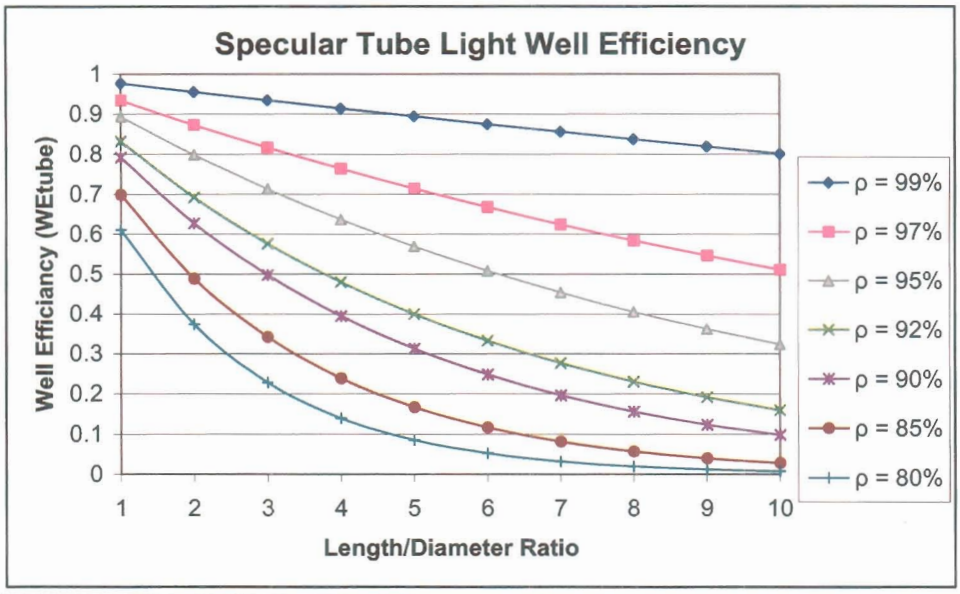


FIGURE 146-B SPECULAR TUBULAR WELL EFFICIENCY NOMOGRAPH

TABLE 146-A LIGHTING POWER ADJUSTMENT FACTORS

TYPE OF CONTROL	TYPE OF SPACE	FACTOR
Occupant sensor with "manual ON" or bi-level automatic ON combined with multi-level circuitry and switching	Any space ≤ 250 square feet enclosed by floor-to-ceiling partitions; any size classroom, corridor, conference or waiting room	0.20
Occupant sensor controlled multi-level switching or dimming system that reduces lighting power at least 50% when no persons are present	Hallways of hotels/motels	.25
	Commercial and Industrial Storage stack areas (max. 2 aisles per sensor)	.15
	Library Stacks (maximum 2 aisles per sensor)	.15
Dimming system		
Manual	Hotels/motels, restaurants, auditoriums, theaters	0.10
Multiscene programmable	Hotels/motels, restaurants, auditoriums, theaters	0.20
Manual dimming with automatic load control of dimmable electronic ballasts.	All building types	.25
Combined controls		
Occupant sensor With "manual ON" or bi-level automatic ON combined with multi-level circuitry and switching in conjunction with daylighting controls	Any space ≤ 250 square feet within a daylit area and enclosed by floor-to-ceiling partitions, any size classroom, corridor, conference or waiting room.	0.10 (may be added to daylighting control credit)
Manual Dimming with Dimmable Electronic Ballasts and Occupant sensor with "manual ON" or automatic ON to less than 50% power and switching	Any space ≤ 250 square feet enclosed by floor-to-ceiling partitions; any size classroom, corridor, conference or waiting room	0.25

Automatic Daylighting Controls with Windows (Stepped Switching or Stepped Dimming/Continuous Dimmed)

	Window Wall Ratio		
Glazing Type - Windows	< 20%	20% to 40%	> 40%
VLT ≥ 60%	0.20/0.30	0.30/0.40	0.40/0.40
VLT ≥ 35 and < 60%	0/0	0.20/0.30	0.30/0.40
VLT < 35%	0/0	0/0	0.20/0.40

Automatic Multi-Level Daylighting Controls with Skylights

Glazing Type - Skylights	Spaces where the daylit area under skylights is less than 2,500 sf
Glazing material or diffuser with ASTM D1003 haze measurement greater than 90%	$10 \times \text{Effective Aperture} - \frac{\text{Lighting Power Density}}{10} + 0.2$

~~WHERE~~

~~Effective Aperture is as calculated in the Equation 146-A.~~

~~Lighting Power Density is the lighting power density of general lighting~~

Effective Aperture (EA)

General lighting power density (W/sf)	0.6% ≤ EA < 1%	1% ≤ EA < 1.4%	1.4% ≤ EA < 1.8%	1.8% ≤ EA
LPD < 0.7	24%	30%	32%	34%
0.7 ≤ LPD< 1.0	18%	26%	30%	32%
1.0 ≤ LPD < 1.4	12%	22%	26%	28%
1.4 ≤ LPD	8%	20%	24%	28%

SECTION 149 – ADDITIONS, ALTERATIONS, AND REPAIRS TO EXISTING BUILDINGS THAT WILL BE NONRESIDENTIAL…

(b) **Alterations.** Alterations to existing nonresidential, high-rise residential, or hotel/motel buildings or alterations in conjunction with a change in building occupancy to a nonresidential, high-rise residential, or hotel/motel occupancy not subject to Subsection (a) shall meet either Item 1 or 2 below.

1. **Prescriptive approach.** The altered envelope, space conditioning, lighting and water heating components, and any newly installed equipment serving the alteration, shall meet the applicable requirements of Sections 110 through 139; and

<Add new section 149(b)1G and move G through K down one letter>

G. When the requirements of Section 131(c)2 are triggered by the addition of skylights to an existing building and the lighting system is not re-circuited, the daylighting control need not meet the multi-level requirements in Section 131(c)2A.

Alternative Calculation Manual

Daylit area

The base case for a skylighting system is the greater of the actual area skylit and one half of the enclosed space.

2.3.5.2 Area of Fenestration in Exterior Roofs

1. When the Skylight Roof Ratio (SRR) in the proposed design is < 0.05, for each roof fenestration, the standard design shall use the same skylight dimensions as the proposed design.

EXCEPTION: When skylights are required by Section 143(c) (low-rise conditioned or unconditioned enclosed spaces that are greater than 25,000 ft^2 directly under a roof with ceiling heights greater than 15 ft and have a lighting power density for general lighting equal to or greater than 0.5 W/ft^2) and the SRR in the proposed design is less than the minimum, the standard design shall have a SRR of 3.0% for 0.5 W/ft^2 = LPD < 1.0 W/ft^2, 3.3% for 1.0 W/ft^2 = LPD < 1.4 W/ft^2, and 3.6% for LPD = 1.4 W/ft^2 in the greater of the design daylit area or one half of the area of qualifying spaces.

Well efficiency of tubular skylights

The well efficiency of tubular light wells are calculated according to the formulation was developed by Zastrow and Wittwer:

$$WE_{Tube} = \rho^{\left(\frac{4}{\pi} * \frac{L}{D} * \tan\theta\right)}$$

where,

ρ = specular reflectance of interior pipe wall

L/D = ratio of pipe length to pipe inner diameter

Θ = angle of incidence with respect to pipe axis (zenith angle of the sun)

Skylighting requirements including minimum area

ACM Manual Language

2.3.5.2 Area of Fenestration in Exterior Roofs

Modeling Rules for Standard Design (New & Altered Existing):

ACMs shall calculate the maximum allowed area of fenestration in roofs. This Maximum Roof Fenestration Area is 5% of the gross exterior roof area of the entire permitted space or building.

1. When the Skylight Roof Ratio (SRR) in the proposed design is < 0.05, for each roof fenestration, the standard design shall use the same skylight dimensions as the proposed design.

EXCEPTION: When skylights are required by Section 143(c) (low-rise conditioned or unconditioned enclosed spaces that are greater than ~~25,000~~ 8,000 ft^2 directly under a roof with ceiling heights greater than 15 ft and have a lighting power density for general lighting equal to or greater than 0.5 W/ft^2) and the SRR in the proposed design is less than the minimum, the standard design shall have a SRR of 3.0% for 0.5 $W/ft^2 \leq LPD <$ 1.0 W/ft^2, 3.3% for 1.0 $W/ft^2 \leq LPD <$ 1.4 W/ft^2, and 3.6% for $LPD \geq$ 1.4 W/ft^2 in one half of the area of qualifying spaces.

2. When the Skylight Roof Ratio in the proposed design is > 0.05, the ACM shall adjust the dimensions of each roof fenestration of the standard design by multiplying them by a fraction equal to the square root of:

Equation N2-1 $SRR_{standard}/SRR_{proposed}$

4.3.4.12 Fenestration Areas of Glazing in Exterior Roofs (Skylights)

Describe how the user shall model the exposed surface area of each transparent or translucent surface, and shall describe how the user shall enter the proposed design fenestration areas as they are shown in the construction documents. Fenestration surfaces in roofs include openings in roofs and horizontal roof doors of the building.

Explain how the ACM determines the effects of these fenestration areas, including describing that:

1. When the Skylight Roof Ratio (SRR) in the proposed design is < 0.05, the standard design shall use the same fenestration area as on each proposed design exterior roof.

EXCEPTION: When skylights are required by Section 143(c) (low-rise conditioned or unconditioned enclosed spaces that are greater than ~~25,000~~ 8,000 ft2 directly under a roof with ceiling heights greater than 15 ft and have a lighting power density for general lighting equal to or greater than 0.5 W/ft2) and the SRR in the proposed design is less than the minimum, the standard design shall have a SRR of 3.0% for 0.5 W/ft2 ≤ LPD < 1.0 W/ft2, 3.3% for 1.0 W/ft2 ≤ LPD < 1.4 W/ft2, and 3.6% for LPD ≥ 1.4 W/ft2 in one half of the area of qualifying spaces.

2. When the Skylight Roof Ratio in the proposed design is > 0.05, the ACM shall determine the horizontal fenestration area of the standard design by multiplying the fenestration area in each exterior roof by a fraction equal to:

Equation N4-3 SRRstandard/SRRproposed.

The U-factor and solar heat gain coefficients of individual skylights may be combined by area-weighted averaging only if they are not being used for daylighting and if they are in the same zone.

Skylight Properties table updated in NACM Appendix NI

The skylight properties requirements in table 143(a) for plastic skylights should match the default skylight properties in Appendix NI of the ACM Manual. Consideration should be given to whether these requirements should be updated so that they are in terms of the nominal rating size used by the National Fenestration Rating Council (NFRC) 4 ft by 4 ft instead of the current assumed value of 2 ft by 4 ft that is the basis of the values in Table 116-A of the Title 24 standards, Table NI-1 – "Alternate U-Factors for Skylights and Eligible Site-Built Fenestration" in Appendix NI of the Nonresidential ACM Manual and in the Fenestration Tables in the ASHRAE Handbook of Fundamentals..

If one compares two skylights having identical construction characteristics: one with a 2' by 4' dimensions and another with 4' x 4' dimensions, the 4' by 4' skylight will have a substantially reduced U-factor due to the smaller fraction of total area that is dedicated to frame and edge of glass area. This essentially gives away compliance credit to designers who are using a minimally compliant NFRC rated skylight.

ACM Manual Language
2.3.5.6 Fenestration Thermal Properties

Description: ACMs shall model the overall U-factor and Solar Heat Gain Coefficient (SHGC) for each fenestration assembly, including inside and outside air films and effects of framing, spacers and other non-glass materials as applied to the full rough-out fenestration area. ACMs shall require the user to indicate the source of the U-factor and SHGC: Acceptable sources are NFRC label values, default values from Tables 116-A and 116-B, or alternate default values from the ACM Appendix.

....

Modeling Rules for Proposed Design

NFRC label values are allowed for all fenestration categories. If the user selects "NFRC labeled values" for a particular fenestration product, the ACM shall receive values for the U-factor and SHGC. Use the following rules:

• For site-built fenestration products in buildings with less than 10,000 square feet of site-built fenestration, the default values shall be the alternate default U-factor and SHGC using the defaults and calculations specified in ACM Appendix NI or the U-factor and SHGC listed in Table 116-A and Table 116-B of the Standard.

Photocontrols

Photocontrols are the prescriptive minimum requirement in any space where the daylit areas is greater than 2,500 sf. Otherwise photocontrols directly modeled and 70% of controlled power allocated to control and the other 30% uncontrolled to account for the shorter life of controls than the rest of the lighting system.

ACM Manual Language
2.4.2.2 Interior Lighting

.....

Modeling Rules for Proposed Design

The proposed design lighting level is restricted based on which of the above two conditions is selected by the user for the building. The proposed design lighting level is determined as follows:

1. *Lighting compliance not performed.* The proposed design lighting level shall be the lighting level listed in Table N2-2or N2-3. ACMs shall report the default lighting energy on PERF-1 and indicate that no lighting compliance was performed. ACMs shall not print any Lighting forms.

2. *Lighting compliance performed.* The proposed design lighting level for each space shall be as follows:

   a) *Nonresidential occupancies*: For each space the proposed design lighting level shall be the actual lighting level of the space as shown in the construction documents and lighting compliance documentation. For each space without specified lighting level, ACMs shall select the default lighting level from Table N2-3 according to the occupancy type of the space.

   b) *High-rise residential and hotel/motel occupancies*: User inputs for lighting (and lighting controls) for the residential units and hotel/motel guest rooms shall be ignored and the lighting levels determined from Table N2-3 shall be used.

ACMs shall print all applicable lighting forms and report the lighting energy use and the lighting level (Watts/ft^2) for the entire project. ACMs shall report "No Lighting Installed" for nonresidential spaces with no installed lighting. ACMs shall report "Default Residential Lighting" for residential units of high rise residential buildings and hotel/motel guest rooms.

If the modeled Lighting Power Density (LPD) is different than the actual LPD calculated from the fixture schedule for the building, ACMs shall model the larger of the two values for sizing the mechanical systems and for the compliance run. ACMs shall report the larger value on PERF-1. Lighting levels shall be adjusted by any lighting Control Credit Watts, if input by the user.

If daylighting controls are used for daylight zones under skylights ~~greater than 2,500 ft2 (see Section 131(c)2. of the Standards),~~ then 70% of the lighting power for the controlled lighting is modeled using the daylighting algorithms in the compliance software and 30% is treated as uncontrolled. ~~is reduced by Equation N2-2 for multi-level astronomical time switch controls and Equation N2-3 for automatic multi-level daylighting controls.~~

~~Equation N2-2 Error! Objects cannot be created from editing field codes.~~

~~Equation N2-3 PAFPHOTO = 2 x PAFASTRO~~

~~where~~

~~Equation N2-4 Error! Objects cannot be created from editing field codes.~~

~~VLTglazing = visible transmittance of the glazing system including diffusers, when the etire system is not rated as a whole VLTglazing is the product of the visible transmittance of the components~~

~~Well Efficiency = as defined in Standards Section 146(b)4.~~

~~Skylight area = the sum of the all of the skylight rough open areas in the zone~~

~~Daylit area under skylights = as described in Standards Section 131(c)~~

~~Note: In all cases where the photocontrol credit for skylighting is applied, the standard design shall include a multi-level astronomical time switch controls~~

Modeling Rules for Standard Design (New & Altered Existing):

ACMs shall determine standard design lighting level as follows:

1. *Lighting compliance not performed.* The standard design lighting level shall be the same as the proposed design lighting level.

2. *Lighting compliance performed.*

   a) If no Tailored Lighting Allotment is input and lighting plans will be submitted for the entire building (excluding the residential units of high-rise residential buildings and hotel/motel guest rooms), the standard design lighting level shall be determined from either the whole building or area category method.

   b) If lighting plans will be submitted only for portions of the building, the standard design lighting level in areas without lighting plans shall be the lighting level listed in Table N2-3.

   c) If a tailored lighting method is used, the use-it-or-lose-it power for the proposed design shall be entered separately from the general lighting. The standard design shall have the same use-it-or-lose-it lighting power as the proposed design.

   d) In spaces with skylights that meet the criteria of section 131(c)2, the lighting power density of general lighting shall be reduced by ~~PAFASTRO as given in Equation N2-6~~.using daylighting algorithms to model 70% of the general lighting in the daylit area with 2/3's On/Off controls. The remaining 30% of the general lighting in the daylit area under skylights will be modeled as not being controlled by photocontrols.

e) In spaces that meet the criteria of Standards Section 143(c), the space shall be modeled as having ~~astronomical time switch controls~~ 2/3's On/Off controls on 70% of the general lighting for the greater of the following areas: the actual daylit zone or one half of the area of the space. The remaining 30% of the general lighting in the defined area will be modeled as not being controlled by photocontrols. The skylights will be modeled as having an effective ~~The lighting power density of general lighting shall be reduced PAFASTRO as given in Equation N2-6. where Effective~~ aperture shall be taken as 0.01 for spaces with less than 1 W/SF general lighting power density and the effective aperture will be 0.012 for spaces with general lighting power densities greater or equal to 1W/SF.

Modeling of Skylights and Controls and Sample Algorithms

Not part of text of the ACM manual but is descriptive of text that would be inserted. The savings of the skylighting system could be impacted by the size of the modeled zone and the relative location of the sensor to the skylight. To prevent gaming o the performance method, we would ask that simple metrics of the daylighting system be input which are similar to the inputs of the compliance forms for calculating PAFs from skylighting. These inputs are: the LPD of general lighting, the power of general lighting on controls, the skylit area in the space, the skylight transmittances, the skylight dimensions, the light well depth and light well reflectance.

The lighting setpoint is calculated from the LPD of the general lighting in the skylit area, the maintained luminous efficacy of the light source and the Coefficient of Utilization (CU) for the default fixture type. This default fixture type is a function of the ceiling height.

To model skylighting compatible with time dependent valuation, we recommend that the sensor be located directly underneath an "average" skylight which has an area weighted average transmittance and average well efficiency. The transmittance of the skylight would be the product of:

- the area weighted average transmittance of skylights
- the area weighted well efficiency
- the ratio of the coefficient of utilization of the location that the sensor is placed versus that of the sensor on the floor at the edge of the daylit area.

Well efficiency is calculating using the lumen method. (See chapter 8 and 9 of the 2000 IESNA handbook (9th ed.)) from the skylight dimensions, well depth and well reflectance.

Skylight wells are modeled as a space having the same geometric relationships as the light well with a 99% reflective ceiling, a 0% reflective floor, and wall reflectance matching that of the reflectance of the light well walls. The skylight is treated as a Lambertian (perfectly diffusing) emitter.

The source code used to develop the well efficiency plots for the Title 24 code is given below. This Visual Basic for MS Excel code is giv3n as an example. The subroutines called within these user defined functions are also given below

********** CU calculation for light wells or other skylights**********

' User Defined Function to calculate

' Coefficients of Utilization (CU)

' IESNA Handbook 8th Ed. pp 412-413

```
'Function CU0(W, l, h, CeilRefl, WallRefl, FloorRefl) As Double

Dim kGN(1 To 9) As Double
Dim PhiN, PhiD, PhiU, FluxD, FluxU, FluxT, DG As Double
Dim C0, C1, C2, C3, CU1, CU2, CU3, G, F As Double
G = RCR(W, l, h)
'Lambertian Distribution - perfect diffuser
PhiD = 1#
PhiU = 0#
'These equations below could be simplified further by substituting in PhiD =
1 and PHIU = 0.  For instance CU2 goes away, it is equal to 0.
If G < 0.01 Then
    CU0 = (PhiD + CeilRefl * PhiU) / (1 - CeilRefl * FloorRefl)
 Else
      Call Fexch(F, W, l, h)

'Lambertian Distribution
DG = F

C1 = (1 - WallRefl) * (1 - F ^ 2) * G / (2.5 * WallRefl * (1 - F ^ 2) + G * F
* (1 - WallRefl))
C2 = (1 - CeilRefl) * (1 + F) / (1 + CeilRefl * F)
C3 = (1 - FloorRefl) * (1 + F) / (1 + FloorRefl * F)
C0 = C1 + C2 + C3
CU1 = 2.5 * WallRefl * C1 * C3 * (1 - DG) * PhiD / (G * (1 - WallRefl) * (1 -
FloorRefl) * C0)
CU2 = CeilRefl * C2 * C3 * PhiU / ((1 - CeilRefl) * (1 - FloorRefl) * C0)
CU3 = (1 - FloorRefl * C3 * (C1 + C2) / ((1 - FloorRefl) * C0)) * DG * PhiD /
(1 - FloorRefl)
CU0 = CU1 + CU2 + CU3
End If
End Function
```

**********Form Factor or Exchange Fraction **********

' F is the form factor for two equal sized parallel rectangles

" IESNA HAndbook 8th Ed. eq. 9-54

```
Sub Fexch(F, width, length, depth)
Dim x, y, F1, F2, F3, F4 As Double
'Pi = 3.14159265358979
x = length / depth
y = width / depth
F1 = 2 / (3.14159265358979 * x * y) * Application.Ln(((1 + x ^ 2) * (1 + y ^
2) / (1 + x ^ 2 + y ^ 2)) ^ 0.5)
F2 = 2 / (3.14159265358979 * x) * (1 + x ^ 2) ^ 0.5 * Application.Atan2((1 +
x ^ 2) ^ 0.5, y)
F3 = 2 / (3.14159265358979 * y) * (1 + y ^ 2) ^ 0.5 * Application.Atan2((1 +
y ^ 2) ^ 0.5, x)
F4 = -2 / (3.14159265358979 * x) * Application.Atan2(1, y) - 2 /
(3.14159265358979 * y) * Application.Atan2(1, x)
F = F1 + F2 + F3 + F4
End Sub
```

**********RCR calculation **********

'RCR is the room cavity ratio - identical to the well cavity ratio

```
Function RCR(W, l, d) As Double
RCR = 5 * d * (W + l) / (W * l)
End Function
```

********** Well efficiency for tubular skylights **********

Unlike all of the other algorithms this has not been tested in SkyCalc

The well efficiency of tubular light wells are calculated according to the formulation was developed by Zastrow and Wittwer:

$$WE_{Tube} = \rho^{\left(\frac{4}{\pi} * \frac{L}{D} * \tan\theta\right)}$$

where,

ρ = specular reflectance of interior pipe wall

L/D = ratio of pipe length to pipe inner diameter

Θ = angle of incidence with respect to pipe axis (zenith angle of the sun)

Example User Defined Function

```
Function WEtube(L, d, WallRefl, Zenith) As Double
' L = length of tubular light well, feet
'd = inside diameter of tubular light well, feet
'WallRefl = specular reflectance of light well, fraction
'Zenith = solar zenith angle, radians
```

```
Pi = 3.14159265358979
WEtube = WallRefl ^ (4 / Pi * L / d * Tan(Zenith))
End Function
```

Coefficients of utilization are also calculated for light fixtures, mounted at the ceiling height. The coefficient of utilization and the maintained luminous efficacy of the light source determines the design footcandles of the general lighting system. Ceiling, wall and floor reflectances have default values of 70%, 50% and 20% in keeping with IESNA defaults.

General lighting for ceiling heights over 20 feet are based on high by pulse start metal halide fixtures.

General lighting for ceiling heights between 14 feet and 20 feet are based on low bay pulse start metal halide fixtures

General lighting for less than 14 feet are based on instant start fluorescent troffers.

**********CU calculation for luminaires**********

' User Defined Function to calculate

' Coefficients of Utilization (CU)

' IESNA Handbook 8th Ed. pp 412-413

```
' Luminaire intensities are taken from "L_intens" named range
'
Function CU(L_ints_index, W, l, h, CeilRefl, WallRefl, FloorRefl) As Double
Dim kGN(1 To 9) As Double
Dim PhiN, PhiD, PhiU, FluxD, FluxU, FluxT, DG As Double
Dim intens_range As Range
Dim C0, C1, C2, C3, CU1, CU2, CU3, G, F As Double
Dim col, theta As Integer
Set intens_range = Range("L_intens")
col = Int(L_ints_index)
G = RCR(W, l, h)

' L_ints_index: 0 = Lambertian Distribution, 1 = Hi Bay, 2 = Lo Bay, 3 =
Troffer

If L_ints_index > 0 Then
'Zonal Multiplier Equation Constants Fig 9-27 IESNA handbook 8th Ed.
kGN(1) = 1
kGN(2) = Exp(-0.041 * G ^ 0.98)
kGN(3) = Exp(-0.07 * G ^ 1.05)
kGN(4) = Exp(-0.1 * G ^ 1.12)
kGN(5) = Exp(-0.136 * G ^ 1.16)
kGN(6) = Exp(-0.19 * G ^ 1.25)
kGN(7) = Exp(-0.315 * G ^ 1.25)
kGN(8) = Exp(-0.64 * G ^ 1.25)
kGN(9) = Exp(-2.1 * G ^ 0.8)
DG = 0#
```

```
FluxD = 0#
FluxU = 0#
'Pi = 3.14159265358979
For theta = 1 To 9
    PhiN = intens_range(theta, col) * (Cos((theta - 1) * 3.14159265358979 /
18) - Cos(theta * 3.14159265358979 / 18#))
    FluxD = FluxD + PhiN
    DG = DG + kGN(theta) * PhiN
Next theta
FluxD = FluxD * 2# * 3.14159265358979
DG = 2# * 3.14159265358979 * DG / FluxD
' This is equivalent to dividing the summation of kGN*PhiN by total lumens
' and fraction downward (eq 9-68)
For theta = 10 To 18
  FluxU = FluxU + intens_range(theta, col) * (Cos((theta - 1) *
3.14159265358979 / 18#) - Cos(theta * 3.14159265358979 / 18#))
Next theta
FluxU = FluxU * 2# * 3.14159265358979
FluxT = FluxD + FluxU
' Phi = Fraction of flux in Down and Up directions
' IES has normalized intensities to 1000 lamp lumens
' FluxT is total flux leaving the fixture
PhiD = FluxD / 1000#
PhiU = FluxU / 1000#
Else
'Lambertian Distribution - perfect diffuser
PhiD = 1#
PhiU = 0#
End If

If G < 0.01 Then
CU = (PhiD + CeilRefl * PhiU) / (1 - CeilRefl * FloorRefl)

Else
Call Fexch(F, W, l, h)

'Lambertian Distribution
If L_ints_index = 0 Then
DG = F
End If

C1 = (1 - WallRefl) * (1 - F ^ 2) * G / (2.5 * WallRefl * (1 - F ^ 2) + G * F
* (1 - WallRefl))
C2 = (1 - CeilRefl) * (1 + F) / (1 + CeilRefl * F)
C3 = (1 - FloorRefl) * (1 + F) / (1 + FloorRefl * F)
C0 = C1 + C2 + C3
CU1 = 2.5 * WallRefl * C1 * C3 * (1 - DG) * PhiD / (G * (1 - WallRefl) * (1 -
FloorRefl) * C0)
CU2 = CeilRefl * C2 * C3 * PhiU / ((1 - CeilRefl) * (1 - FloorRefl) * C0)
CU3 = (1 - FloorRefl * C3 * (C1 + C2) / ((1 - FloorRefl) * C0)) * DG * PhiD /
(1 - FloorRefl)
CU = CU1 + CU2 + CU3
End If
End Function
```

Table 15:Luminaire Intensities

Luminaire Intensity Table (normalized to Candelas per 1000 lumens)			
Luminaire Numbers*	17	22	42
Conic Angle	**Hi Bay**	**Lo Bay**	**Lensed Troffer**
5	470	136	253
15	384	151	249
25	344	171	236
35	290	175	214
45	210	182	172
55	86.5	158	95.5
65	18	90	45
75	5	41	19
85	1	17	7
95	0.5	8	0
105	0.5	7	0
115	0.5	7	0
125	0.5	5	0
135	1	0	0
145	3	0	0
155	8	0	0
165	0.5	0	0
175	0.5	0	0
*See pg 433 of IESNA Handbook 8th Ed.			

**********Effective Floor reflectance calculation **********

' User Defined Function to calculate the effective

' Reflectance of a rectangular cavity (ceiling or floor)

' IESNA HAndbook 8th Ed. eq. 9-53

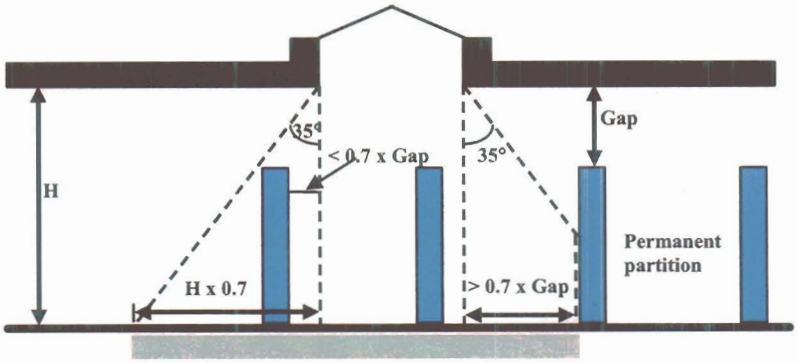
'

```
Function RHOeff(BaseRefl, WallRefl, width, length, depth) As Double
Dim F, Numerator, Denominator, Aw, Ab As Double
If depth = 0 Then
    RHOeff = BaseRefl
Else
    Aw = 2 * (width + length) * depth
    Ab = width * length
    Call Fexch(F, width, length, depth)
    Numerator = BaseRefl * WallRefl * F * (2 * Ab / Aw * (1 - F) - F) +
BaseRefl * F ^ 2 + WallRefl * Ab / Aw * (1 - F) ^ 2
    Denominator = 1 - BaseRefl * WallRefl * Ab / Aw * (1 - F) ^ 2 - WallRefl
* (1 - 2 * Ab / Aw * (1 - F))
```

```
    RHOeff = Numerator / Denominator
End If
End Function
```

Nonresidential Compliance Manual

Add the following figure to help explain the revision to the daylit area under skylights.



Skylit Area

Figure 9: Skyylit Area under Skylights

Bibliography and Other Research

Architectural Energy Corporation, *Life Cycle Cost Methodology 2008 California Building Energy Efficiency Standards* October 21, 2005 Prepared for California Energy Commission http://www.energy.ca.gov/title24/2008standards/documents/2005-10-24+25_workshop/2005-10-21_LCC_METHODOLOGY_2008_STANDARDS.PDF

[ASHRAE] 2005, *Handbook of Fundamentals*, American Society of Heating Refrigerating and Air-conditioning Engineers, Atlanta, GA.

ASTM D1003-00 *Standard Test Method for Haze and Luminous Transmittance of Transparent Plastics*. American Society for Testing and Materials, West Conshohocken, PA.

The *Skylighting Guidelines* and SkyCalc, available at http://www.energydesignresources.com

EIA 1995. US Department of Energy, Energy Information Administration, 1998. A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption and Energy Expenditures, DOE/EIA-0625(95), Washington, DC)

[HMG]Heschong Mahone Group, 1999b. *Daylighting and Schools: An Investigation in to the Relationship between Daylighting and Human Performance*, a report on behalf of the Pacific Gas and Electric Company available from http://www.h-m-g.com

[HMG] Heschong Mahone Group. 2003a. *Daylight and Retail Sales..* CEC PIER, Sacramento. October 2003 California Energy Commission Publication # P500-03-082-A-5

[HMG] Heschong Mahone Group, Inc. 2003b *Photocontrol Field Study: Final Report.* A report on behalf of Southern California Edison

Heschong, L., Wright, R., and Okura, S. 2001."Daylighting Impacts on Retail Sales Performance," *IESNA 2001 Conference Proceedings*, pp.233-240

IESNA 2000. *IESNA Lighting Handbook Ninth Edition*, Illuminating Engineering Society of North America, New York.

Laouadi, Abdelaziz (Aziz) and Arsenault, Chantal. June 2004 "Validation of SkyVision," Indoor Environment Research Program, Institute for Research in Construction, National Research Council Canada, Report No. IRC-RR-167 (includes specular light pipe correlations)

LBNL & LANL 1992. *DOE-2 Engineers Manual: Version 2.1A*, Prepared for the US Department of Energy under Contract DE-AC03-76SF00098. Lawrence Berkeley Laboratory & Los Alamos National Laboratory, November 1982.

McHugh, J., , Pande, A., Ander, G., & Melnyk, J. 2004a "Effectiveness of Photocontrols with Skylighting," 2004 *IESNA Annual Conference Proceedings* pp. 1-18 Illuminating Engineering Society of North America, New York

McHugh, J., Dee, R. & Saxena, M. 2004b, *Visible Light Transmittance of Skylights*, PIER Report, California Energy Commission, Contract Number 400-99-013. www.newbuildings.org/pier

RS Means, 2005. CostWorks Version 9.0. Kinston, MA

Swift, P.D., & Smith, G.B.,. "Cylindrical Light Pipes," *Solar Energy Materials and Solar Cells*, 1995, pp.159-168

Zastrow A. and Wittwer V.," Daylight with mirror light pipes and with fluorescent planar concentrators," *SPIE* vol. 692 Materials and optics for solar energy conversion and advanced lighting technology, pp. 227-234, 1986.

Acknowledgments

The Pacific Gas and Electric Company sponsored this report as part of its CASE (Codes and Standards Enhancement) project. Steve Blanc of PG&E is the project manager for this nonresidential CASE project. Pat Eilert is the program manager for the CASE program. The HESCHONG MAHONE GROUP is the prime contractor and provided coordination of the nonresidential CASE reports.

Jon McHugh, Mudit Saxena and Abhijeet Pande performed most of the analysis and reporting presented here. The Heschong Mahone Group provided technical and editorial review.

Appendix 1: B/C Ratios for Skylighting Minimum Area Criteria

Table 16: Case1-Warehouse B/C Ratios

Case 1: Warehouse, 15' ceiling ht, 1' light well, 0.7 LPD, Heat Only

		10,000 sq.ft		***8,000 sq.ft***		***6,000 sq.ft***		***4,000 sq.ft***	
		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio	
	SFR	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off
CZ 03	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.86	1.21	0.77	1.09	0.66	0.94	0.52	0.73
	2.0%	1.83	1.49	1.70	1.38	1.51	1.23	1.24	1.01
	3.0%	1.77	1.29	1.67	1.21	1.52	1.10	1.29	0.94
	4.0%	1.56	1.10	1.49	1.04	1.37	0.97	1.20	0.84
	5.0%	1.37	0.92	1.32	0.88	1.23	0.83	1.09	0.73
	6.0%	1.21	0.78	1.16	0.75	1.10	0.71	0.98	0.64
	8.0%	0.93	0.56	0.91	0.55	0.86	0.52	0.79	0.48
	10.0%	0.73	0.41	0.71	0.40	0.69	0.38	0.64	0.35
	12.0%	0.58	0.29	0.57	0.28	0.55	0.27	0.51	0.26
	SFR								
CZ 07	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	1.18	1.64	1.07	1.47	0.92	1.27	0.72	0.99
	2.0%	2.49	2.03	2.30	1.88	2.05	1.67	1.69	1.37
	3.0%	2.41	1.81	2.27	1.71	2.07	1.56	1.76	1.32
	4.0%	2.17	1.58	2.07	1.51	1.91	1.39	1.66	1.21
	5.0%	1.94	1.39	1.86	1.33	1.74	1.24	1.54	1.10
	6.0%	1.74	1.22	1.68	1.18	1.58	1.11	1.42	1.00
	8.0%	1.42	0.99	1.38	0.96	1.32	0.91	1.21	0.84
	10.0%	1.19	0.82	1.17	0.80	1.12	0.77	1.04	0.71
	12.0%	1.03	0.69	1.00	0.68	0.97	0.66	0.91	0.62
CZ 10	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	1.08	1.51	0.97	1.36	0.83	1.17	0.65	0.91
	2.0%	2.24	1.76	2.08	1.63	1.85	1.46	1.52	1.20
	3.0%	2.10	1.53	1.98	1.44	1.80	1.31	1.53	1.11
	4.0%	1.86	1.30	1.77	1.24	1.63	1.14	1.42	1.00
	5.0%	1.63	1.11	1.56	1.07	1.46	1.00	1.29	0.88
	6.0%	1.44	0.96	1.39	0.93	1.31	0.88	1.17	0.79
	8.0%	1.15	0.74	1.11	0.72	1.06	0.69	0.97	0.63
	10.0%	0.93	0.58	0.91	0.57	0.88	0.55	0.81	0.51
	12.0%	0.78	0.46	0.76	0.46	0.73	0.44	0.69	0.41
CZ 12	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.87	1.23	0.79	1.11	0.68	0.95	0.53	0.74
	2.0%	1.85	1.45	1.72	1.34	1.53	1.20	1.26	0.98
	3.0%	1.74	1.24	1.64	1.17	1.49	1.06	1.27	0.90
	4.0%	1.52	1.01	1.44	0.96	1.33	0.89	1.16	0.77
	5.0%	1.30	0.83	1.25	0.79	1.17	0.74	1.03	0.66
	6.0%	1.12	0.67	1.08	0.65	1.02	0.61	0.91	0.55
	8.0%	0.83	0.43	0.81	0.42	0.77	0.40	0.70	0.37
	10.0%	0.61	0.27	0.59	0.26	0.57	0.25	0.53	0.23
	12.0%	0.45	0.15	0.44	0.14	0.42	0.14	0.40	0.13
CZ 14	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	1.34	1.80	1.21	1.62	1.04	1.39	0.81	1.09
	2.0%	2.57	2.00	2.38	1.85	2.12	1.65	1.74	1.35
	3.0%	2.38	1.66	2.24	1.57	2.04	1.43	1.73	1.21
	4.0%	2.03	1.39	1.94	1.33	1.79	1.23	1.56	1.07
	5.0%	1.76	1.17	1.69	1.12	1.58	1.05	1.40	0.93
	6.0%	1.54	0.99	1.48	0.96	1.40	0.90	1.25	0.81
	8.0%	1.19	0.74	1.16	0.72	1.10	0.69	1.01	0.63
	10.0%	0.95	0.57	0.93	0.55	0.89	0.53	0.83	0.49
	12.0%	0.77	0.44	0.76	0.43	0.73	0.42	0.69	0.39

Table 17: Case2-Warehouse B/C Ratios

Case 2: Warehouse, 15' ceiling ht, 1' light well, 1 LPD, Heat Only

		10,000 sq.ft		***8,000 sq.ft***		***6,000 sq.ft***		***6,000 sq.ft***	
		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio	
	SFR	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off
CZ 03	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.64	0.85	0.58	0.76	0.50	0.66	0.39	0.51
	2.0%	1.97	1.87	1.83	1.73	1.63	1.54	1.34	1.27
	3.0%	2.25	1.82	2.12	1.71	1.93	1.56	1.64	1.32
	4.0%	2.16	1.59	2.06	1.51	1.90	1.40	1.65	1.22
	5.0%	1.96	1.39	1.88	1.33	1.76	1.25	1.55	1.10
	6.0%	1.75	1.22	1.69	1.17	1.59	1.11	1.43	0.99
	8.0%	1.43	0.93	1.39	0.91	1.32	0.86	1.21	0.79
	10.0%	1.17	0.73	1.14	0.71	1.09	0.68	1.02	0.63
	12.0%	0.96	0.57	0.94	0.56	0.91	0.54	0.85	0.51
	SFR								
CZ 07	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.95	1.15	0.86	1.03	0.74	0.89	0.57	0.69
	2.0%	2.58	2.43	2.39	2.25	2.13	2.01	1.75	1.65
	3.0%	2.98	2.38	2.81	2.24	2.56	2.04	2.17	1.73
	4.0%	2.84	2.15	2.71	2.04	2.50	1.89	2.18	1.64
	5.0%	2.62	1.92	2.51	1.84	2.35	1.72	2.08	1.52
	6.0%	2.38	1.72	2.30	1.66	2.17	1.56	1.94	1.40
	8.0%	2.00	1.40	1.94	1.36	1.85	1.30	1.69	1.19
	10.0%	1.70	1.17	1.66	1.15	1.60	1.10	1.48	1.02
	12.0%	1.47	1.01	1.44	0.99	1.39	0.95	1.30	0.89
CZ 10	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.88	1.05	0.79	0.95	0.68	0.81	0.53	0.63
	2.0%	2.41	2.21	2.23	2.05	1.99	1.83	1.64	1.50
	3.0%	2.70	2.08	2.54	1.96	2.31	1.79	1.97	1.52
	4.0%	2.51	1.84	2.39	1.75	2.21	1.62	1.92	1.40
	5.0%	2.27	1.61	2.18	1.54	2.04	1.44	1.80	1.28
	6.0%	2.04	1.42	1.97	1.37	1.86	1.29	1.67	1.16
	8.0%	1.67	1.12	1.62	1.09	1.55	1.04	1.42	0.95
	10.0%	1.39	0.91	1.36	0.89	1.31	0.86	1.21	0.79
	12.0%	1.18	0.76	1.16	0.74	1.12	0.72	1.05	0.67
CZ 12	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.72	0.86	0.65	0.78	0.56	0.67	0.43	0.52
	2.0%	1.99	1.85	1.85	1.71	1.65	1.53	1.35	1.25
	3.0%	2.24	1.74	2.11	1.64	1.92	1.50	1.63	1.27
	4.0%	2.09	1.52	1.99	1.45	1.84	1.34	1.60	1.17
	5.0%	1.90	1.30	1.82	1.25	1.70	1.17	1.51	1.03
	6.0%	1.69	1.12	1.63	1.08	1.53	1.02	1.38	0.91
	8.0%	1.33	0.83	1.29	0.80	1.23	0.77	1.13	0.70
	10.0%	1.07	0.60	1.04	0.59	1.00	0.57	0.93	0.53
	12.0%	0.86	0.44	0.84	0.43	0.81	0.42	0.76	0.39
CZ 14	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	1.13	1.31	1.02	1.18	0.88	1.02	0.69	0.79
	2.0%	2.88	2.53	2.67	2.35	2.38	2.09	1.95	1.72
	3.0%	3.05	2.35	2.87	2.21	2.62	2.02	2.22	1.71
	4.0%	2.84	2.01	2.70	1.91	2.50	1.77	2.17	1.54
	5.0%	2.51	1.74	2.41	1.67	2.25	1.56	1.99	1.38
	6.0%	2.22	1.52	2.14	1.46	2.02	1.38	1.81	1.24
	8.0%	1.80	1.17	1.75	1.14	1.66	1.09	1.52	0.99
	10.0%	1.47	0.93	1.43	0.91	1.38	0.88	1.28	0.81
	12.0%	1.23	0.76	1.20	0.74	1.16	0.72	1.09	0.67

Table 18: Case3-Warehouse B/C Ratios

Case 3: Warehouse, 15' ceiling ht, 1' light well, 0.7 LPD, Unconditioned

		10,000 sq.ft		8,000 sq.ft		6,000 sq.ft		4,000 sq.ft	
		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio	
	SFR	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off
CZ 03	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.78	1.09	0.70	0.98	0.60	0.85	0.47	0.66
	2.0%	1.94	1.70	1.80	1.57	1.60	1.40	1.32	1.15
	3.0%	2.07	1.63	1.95	1.54	1.78	1.40	1.51	1.19
	4.0%	1.97	1.47	1.87	1.40	1.73	1.30	1.51	1.13
	5.0%	1.81	1.33	1.73	1.28	1.62	1.20	1.43	1.06
	6.0%	1.66	1.20	1.60	1.16	1.51	1.09	1.35	0.98
	8.0%	1.41	1.00	1.37	0.97	1.31	0.92	1.20	0.85
	10.0%	1.22	0.85	1.19	0.83	1.14	0.80	1.06	0.74
	12.0%	1.07	0.74	1.05	0.73	1.01	0.70	0.95	0.66
	SFR								
CZ 07	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.91	1.33	0.82	1.20	0.70	1.03	0.55	0.80
	2.0%	2.20	1.92	2.04	1.78	1.82	1.59	1.49	1.30
	3.0%	2.32	1.78	2.18	1.68	1.99	1.53	1.69	1.30
	4.0%	2.16	1.58	2.05	1.51	1.90	1.39	1.65	1.21
	5.0%	1.95	1.41	1.87	1.35	1.75	1.27	1.55	1.12
	6.0%	1.77	1.26	1.71	1.22	1.61	1.15	1.45	1.03
	8.0%	1.49	1.04	1.45	1.01	1.38	0.96	1.26	0.88
	10.0%	1.27	0.88	1.24	0.86	1.19	0.83	1.11	0.77
	12.0%	1.11	0.77	1.09	0.75	1.05	0.73	0.99	0.68
CZ 10	SFR								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.92	1.31	0.83	1.18	0.71	1.02	0.55	0.79
	2.0%	2.19	1.87	2.03	1.73	1.81	1.54	1.49	1.27
	3.0%	2.27	1.73	2.13	1.63	1.94	1.48	1.65	1.26
	4.0%	2.08	1.53	1.98	1.45	1.83	1.34	1.59	1.17
	5.0%	1.88	1.36	1.81	1.30	1.69	1.22	1.49	1.08
	6.0%	1.71	1.22	1.65	1.18	1.55	1.11	1.39	1.00
	8.0%	1.44	1.01	1.40	0.98	1.33	0.94	1.22	0.86
	10.0%	1.23	0.86	1.21	0.84	1.16	0.81	1.08	0.75
	12.0%	1.08	0.75	1.06	0.74	1.02	0.71	0.96	0.67
CZ 12	SFR								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.85	1.17	0.77	1.05	0.66	0.91	0.51	0.71
	2.0%	1.99	1.71	1.84	1.59	1.64	1.41	1.35	1.16
	3.0%	2.06	1.65	1.94	1.56	1.77	1.42	1.50	1.20
	4.0%	1.97	1.48	1.88	1.41	1.74	1.31	1.51	1.14
	5.0%	1.83	1.34	1.75	1.29	1.64	1.20	1.45	1.07
	6.0%	1.68	1.22	1.61	1.17	1.52	1.11	1.37	0.99
	8.0%	1.43	1.01	1.39	0.98	1.32	0.94	1.21	0.86
	10.0%	1.24	0.86	1.21	0.84	1.16	0.81	1.08	0.75
	12.0%	1.08	0.75	1.05	0.74	1.02	0.71	0.96	0.67
CZ 14	SFR								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	1.16	1.62	1.05	1.46	0.90	1.26	0.70	0.98
	2.0%	2.55	2.10	2.36	1.94	2.11	1.73	1.73	1.42
	3.0%	2.53	1.87	2.38	1.77	2.17	1.61	1.84	1.37
	4.0%	2.28	1.64	2.17	1.56	2.01	1.44	1.75	1.25
	5.0%	2.03	1.44	1.94	1.38	1.82	1.29	1.61	1.15
	6.0%	1.84	1.29	1.77	1.24	1.67	1.17	1.50	1.05
	8.0%	1.51	1.05	1.47	1.02	1.40	0.98	1.28	0.89
	10.0%	1.29	0.89	1.26	0.87	1.21	0.84	1.12	0.78
	12.0%	1.12	0.78	1.10	0.76	1.06	0.74	1.00	0.69

Table 19: Case4-Warehouse B/C Ratios

Case 4: Warehouse, 15' ceiling ht, 1' light well, 1 LPD, Unconditioned

		10,000 sq.ft		8,000 sq.ft		6,000 sq.ft		4,000 sq.ft	
		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio	
	SFR	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off
CZ 03	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.38	0.76	0.34	0.68	0.29	0.59	0.23	0.46
	2.0%	1.73	1.88	1.60	1.74	1.43	1.55	1.17	1.28
	3.0%	2.36	2.01	2.22	1.89	2.02	1.72	1.72	1.46
	4.0%	2.39	1.91	2.28	1.82	2.11	1.68	1.83	1.46
	5.0%	2.31	1.75	2.21	1.68	2.07	1.57	1.83	1.39
	6.0%	2.16	1.61	2.08	1.55	1.97	1.46	1.76	1.31
	8.0%	1.88	1.37	1.83	1.33	1.74	1.27	1.60	1.16
	10.0%	1.66	1.18	1.62	1.15	1.56	1.11	1.45	1.03
	12.0%	1.47	1.04	1.44	1.02	1.39	0.98	1.30	0.92
	SFR								
CZ 07	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.54	0.88	0.49	0.79	0.42	0.68	0.33	0.53
	2.0%	2.10	2.14	1.95	1.98	1.74	1.76	1.43	1.45
	3.0%	2.67	2.25	2.52	2.12	2.29	1.93	1.95	1.64
	4.0%	2.70	2.09	2.57	1.99	2.38	1.84	2.07	1.60
	5.0%	2.53	1.90	2.43	1.82	2.27	1.70	2.01	1.50
	6.0%	2.36	1.72	2.28	1.66	2.15	1.56	1.93	1.40
	8.0%	2.02	1.44	1.96	1.40	1.87	1.34	1.71	1.22
	10.0%	1.76	1.23	1.71	1.20	1.65	1.16	1.53	1.07
	12.0%	1.54	1.08	1.51	1.05	1.46	1.02	1.37	0.96
CZ 10	SFR								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.51	0.89	0.46	0.80	0.40	0.69	0.31	0.54
	2.0%	2.08	2.12	1.93	1.97	1.72	1.75	1.41	1.44
	3.0%	2.64	2.20	2.49	2.07	2.26	1.89	1.92	1.60
	4.0%	2.63	2.01	2.50	1.92	2.31	1.77	2.01	1.54
	5.0%	2.46	1.83	2.36	1.75	2.21	1.64	1.95	1.45
	6.0%	2.29	1.66	2.20	1.60	2.08	1.50	1.87	1.35
	8.0%	1.95	1.39	1.89	1.35	1.80	1.29	1.65	1.18
	10.0%	1.69	1.20	1.65	1.17	1.59	1.12	1.47	1.04
	12.0%	1.50	1.05	1.46	1.03	1.42	0.99	1.33	0.93
CZ 12	SFR								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.49	0.82	0.44	0.74	0.38	0.64	0.30	0.50
	2.0%	1.85	1.93	1.71	1.79	1.53	1.59	1.25	1.31
	3.0%	2.42	2.00	2.28	1.88	2.08	1.72	1.76	1.46
	4.0%	2.41	1.91	2.29	1.82	2.12	1.68	1.84	1.47
	5.0%	2.33	1.77	2.24	1.70	2.09	1.59	1.85	1.40
	6.0%	2.19	1.62	2.11	1.57	1.99	1.48	1.79	1.32
	8.0%	1.89	1.38	1.84	1.34	1.75	1.28	1.61	1.17
	10.0%	1.67	1.20	1.63	1.17	1.57	1.12	1.46	1.04
	12.0%	1.49	1.04	1.46	1.02	1.41	0.99	1.32	0.93
CZ 14	SFR								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.81	1.13	0.73	1.02	0.63	0.87	0.49	0.68
	2.0%	2.57	2.47	2.38	2.29	2.12	2.04	1.74	1.68
	3.0%	3.03	2.45	2.85	2.31	2.60	2.10	2.21	1.79
	4.0%	2.95	2.21	2.81	2.10	2.60	1.95	2.26	1.69
	5.0%	2.73	1.97	2.61	1.88	2.45	1.76	2.16	1.56
	6.0%	2.48	1.78	2.39	1.72	2.26	1.62	2.03	1.45
	8.0%	2.09	1.47	2.03	1.43	1.94	1.36	1.77	1.25
	10.0%	1.80	1.25	1.75	1.22	1.69	1.17	1.57	1.09
	12.0%	1.57	1.09	1.54	1.07	1.49	1.03	1.40	0.97

Table 20: Case5-Warehouse B/C Ratios

Case 5: Warehouse, 15' ceiling ht, 1' light well, 0.7 LPD, AC and Heat

		10,000 sq.ft		8,000 sq.ft		6,000 sq.ft		4,000 sq.ft	
		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio	
	SFR	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off
CZ 03	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.64	0.95	0.57	0.85	0.49	0.73	0.38	0.57
	2.0%	1.66	1.33	1.54	1.24	1.37	1.10	1.13	0.90
	3.0%	1.60	1.12	1.51	1.05	1.37	0.96	1.17	0.81
	4.0%	1.39	0.88	1.32	0.84	1.22	0.77	1.06	0.67
	5.0%	1.16	0.69	1.11	0.66	1.04	0.62	0.92	0.55
	6.0%	0.97	0.52	0.94	0.50	0.88	0.48	0.79	0.43
	8.0%	0.67	0.28	0.65	0.27	0.62	0.26	0.57	0.24
	10.0%	0.45	0.10	0.44	0.10	0.42	0.10	0.39	0.09
	12.0%	0.28	(0.03)	0.27	(0.03)	0.27	(0.03)	0.25	(0.03)
	SFR								
CZ 07	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.86	1.38	0.78	1.25	0.67	1.07	0.52	0.84
	2.0%	2.30	1.90	2.13	1.76	1.90	1.57	1.56	1.29
	3.0%	2.27	1.58	2.14	1.49	1.95	1.35	1.66	1.15
	4.0%	1.96	1.25	1.86	1.19	1.72	1.10	1.50	0.96
	5.0%	1.65	0.99	1.58	0.95	1.48	0.88	1.31	0.78
	6.0%	1.38	0.76	1.33	0.74	1.25	0.69	1.12	0.62
	8.0%	0.97	0.44	0.94	0.42	0.90	0.40	0.82	0.37
	10.0%	0.67	0.21	0.65	0.21	0.63	0.20	0.58	0.18
	12.0%	0.45	0.04	0.44	0.04	0.42	0.04	0.40	0.04
CZ 10	SFR								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.63	1.09	0.57	0.98	0.49	0.85	0.38	0.66
	2.0%	1.88	1.41	1.75	1.31	1.56	1.17	1.28	0.96
	3.0%	1.72	1.02	1.62	0.96	1.47	0.87	1.25	0.74
	4.0%	1.33	0.66	1.27	0.63	1.17	0.58	1.02	0.50
	5.0%	1.01	0.37	0.96	0.36	0.90	0.33	0.80	0.30
	6.0%	0.73	0.15	0.70	0.14	0.66	0.13	0.59	0.12
	8.0%	0.31	(0.19)	0.30	(0.18)	0.29	(0.17)	0.26	(0.16)
	10.0%	0.02	(0.42)	0.01	(0.41)	0.01	(0.39)	0.01	(0.36)
	12.0%	(0.21)	(0.59)	(0.20)	(0.57)	(0.20)	(0.56)	(0.18)	(0.52)
CZ 12	SFR								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.48	0.86	0.44	0.78	0.37	0.67	0.29	0.52
	2.0%	1.53	1.10	1.42	1.02	1.27	0.91	1.04	0.75
	3.0%	1.33	0.76	1.25	0.71	1.14	0.65	0.97	0.55
	4.0%	1.02	0.41	0.97	0.39	0.89	0.36	0.78	0.31
	5.0%	0.71	0.14	0.68	0.13	0.64	0.12	0.56	0.11
	6.0%	0.45	(0.08)	0.44	(0.08)	0.41	(0.07)	0.37	(0.07)
	8.0%	0.06	(0.41)	0.05	(0.40)	0.05	(0.38)	0.05	(0.35)
	10.0%	(0.23)	(0.64)	(0.23)	(0.63)	(0.22)	(0.60)	(0.20)	(0.56)
	12.0%	(0.45)	(0.81)	(0.44)	(0.79)	(0.43)	(0.77)	(0.40)	(0.72)
CZ 14	SFR								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.67	1.23	0.60	1.11	0.52	0.96	0.40	0.75
	2.0%	1.98	1.34	1.84	1.24	1.64	1.10	1.34	0.91
	3.0%	1.61	0.76	1.52	0.72	1.38	0.65	1.18	0.55
	4.0%	1.10	0.29	1.05	0.28	0.97	0.25	0.84	0.22
	5.0%	0.66	(0.08)	0.63	(0.07)	0.59	(0.07)	0.52	(0.06)
	6.0%	0.32	(0.36)	0.31	(0.35)	0.29	(0.33)	0.26	(0.30)
	8.0%	(0.21)	(0.78)	(0.20)	(0.75)	(0.19)	(0.72)	(0.18)	(0.66)
	10.0%	(0.57)	(1.06)	(0.56)	(1.03)	(0.53)	(0.99)	(0.50)	(0.92)
	12.0%	(0.83)	(1.26)	(0.82)	(1.23)	(0.79)	(1.19)	(0.74)	(1.12)

Table 21: Case6-Warehouse B/C Ratios

Case 6: Warehouse, 15' ceiling ht, 1' light well, 1 LPD, AC and Heat

		10,000 sq.ft		8,000 sq.ft		6,000 sq.ft		4,000 sq.ft	
		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio	
	SFR	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off	2 Level + Off	2/3 on/off
CZ 03	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.20	0.63	0.18	0.57	0.15	0.49	0.12	0.38
	2.0%	1.58	1.70	1.46	1.58	1.30	1.40	1.07	1.15
	3.0%	2.10	1.65	1.97	1.55	1.80	1.42	1.53	1.20
	4.0%	1.98	1.43	1.88	1.36	1.74	1.26	1.51	1.09
	5.0%	1.79	1.19	1.71	1.14	1.60	1.07	1.42	0.95
	6.0%	1.57	0.99	1.51	0.96	1.43	0.90	1.28	0.81
	8.0%	1.20	0.68	1.16	0.66	1.11	0.63	1.02	0.58
	10.0%	0.92	0.45	0.90	0.44	0.87	0.42	0.80	0.39
	12.0%	0.70	0.28	0.68	0.27	0.66	0.26	0.62	0.25
	SFR								
CZ 07	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.41	0.83	0.37	0.75	0.32	0.64	0.25	0.50
	2.0%	2.24	2.24	2.07	2.08	1.85	1.85	1.52	1.52
	3.0%	2.80	2.24	2.64	2.10	2.41	1.92	2.04	1.63
	4.0%	2.73	1.93	2.60	1.84	2.40	1.70	2.09	1.48
	5.0%	2.43	1.63	2.33	1.56	2.18	1.46	1.93	1.29
	6.0%	2.15	1.36	2.07	1.31	1.95	1.23	1.75	1.11
	8.0%	1.66	0.95	1.61	0.92	1.53	0.88	1.40	0.81
	10.0%	1.28	0.65	1.25	0.63	1.20	0.61	1.12	0.57
	12.0%	0.99	0.43	0.97	0.42	0.93	0.41	0.88	0.38
CZ 10	SFR								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.11	0.60	0.10	0.54	0.09	0.46	0.07	0.36
	2.0%	1.82	1.84	1.69	1.71	1.50	1.52	1.23	1.25
	3.0%	2.30	1.68	2.16	1.59	1.97	1.44	1.67	1.23
	4.0%	2.10	1.30	2.00	1.24	1.85	1.15	1.61	1.00
	5.0%	1.77	0.98	1.70	0.94	1.59	0.87	1.40	0.77
	6.0%	1.47	0.70	1.41	0.67	1.33	0.64	1.20	0.57
	8.0%	0.96	0.29	0.93	0.28	0.89	0.26	0.81	0.24
	10.0%	0.58	(0.01)	0.56	(0.01)	0.54	(0.01)	0.50	(0.01)
	12.0%	0.29	(0.23)	0.29	(0.23)	0.28	(0.22)	0.26	(0.20)
CZ 12	SFR								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.04	0.47	0.03	0.42	0.03	0.36	0.02	0.28
	2.0%	1.48	1.52	1.37	1.41	1.22	1.26	1.00	1.03
	3.0%	1.91	1.32	1.80	1.24	1.64	1.13	1.40	0.96
	4.0%	1.69	1.01	1.61	0.96	1.49	0.89	1.29	0.78
	5.0%	1.43	0.71	1.37	0.68	1.28	0.64	1.13	0.56
	6.0%	1.14	0.45	1.10	0.43	1.04	0.41	0.93	0.37
	8.0%	0.65	0.05	0.63	0.05	0.61	0.05	0.55	0.04
	10.0%	0.31	(0.24)	0.30	(0.23)	0.29	(0.22)	0.27	(0.21)
	12.0%	0.04	(0.46)	0.04	(0.45)	0.03	(0.44)	0.03	(0.41)
CZ 14	SFR								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.21	0.63	0.19	0.56	0.17	0.48	0.13	0.38
	2.0%	2.09	1.92	1.93	1.78	1.72	1.59	1.41	1.30
	3.0%	2.38	1.57	2.24	1.48	2.04	1.35	1.73	1.14
	4.0%	2.05	1.06	1.95	1.01	1.80	0.93	1.57	0.81
	5.0%	1.60	0.62	1.54	0.60	1.44	0.56	1.27	0.49
	6.0%	1.18	0.29	1.14	0.28	1.07	0.26	0.96	0.24
	8.0%	0.54	(0.24)	0.53	(0.23)	0.50	(0.22)	0.46	(0.20)
	10.0%	0.08	(0.59)	0.08	(0.58)	0.08	(0.56)	0.07	(0.52)
	12.0%	(0.26)	(0.86)	(0.26)	(0.84)	(0.25)	(0.81)	(0.23)	(0.76)

Table 22: Case7-Retail B/C Ratios

Case 7: Retail, 15' ceiling ht, 1' light well, 1.6 LPD, AC and Heat

		10,000 sq.ft		8,000 sq.ft		6,000 sq.ft		4,000 sq.ft	
		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio	
	SFR	2/3 on/off	Dim 20%	2/3 on/off	Dim 20%	2/3 on/off	Dim 20%	2/3 on/off	Dim 20%
CZ 03	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	1.00	2.38	0.90	2.14	0.77	1.84	0.60	1.44
	2.0%	2.76	3.52	2.56	3.26	2.28	2.90	1.87	2.38
	3.0%	3.03	3.44	2.85	3.24	2.60	2.95	2.21	2.51
	4.0%	2.88	3.09	2.74	2.94	2.53	2.72	2.20	2.36
	5.0%	2.58	2.71	2.48	2.60	2.32	2.43	2.05	2.15
	6.0%	2.29	2.38	2.21	2.29	2.08	2.16	1.87	1.94
	8.0%	1.83	1.85	1.78	1.79	1.69	1.71	1.55	1.57
	10.0%	1.46	1.46	1.43	1.42	1.37	1.37	1.27	1.27
	12.0%	1.18	1.16	1.15	1.14	1.11	1.10	1.04	1.03
	SFR								
CZ 07	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	1.17	2.79	1.06	2.52	0.91	2.16	0.71	1.69
	2.0%	3.27	4.06	3.03	3.76	2.70	3.35	2.22	2.75
	3.0%	3.60	3.89	3.39	3.67	3.09	3.34	2.62	2.84
	4.0%	3.23	3.40	3.07	3.23	2.84	2.99	2.47	2.60
	5.0%	2.86	2.92	2.74	2.80	2.56	2.62	2.27	2.32
	6.0%	2.48	2.51	2.39	2.42	2.25	2.28	2.02	2.05
	8.0%	1.88	1.87	1.83	1.81	1.74	1.73	1.60	1.59
	10.0%	1.42	1.41	1.39	1.37	1.34	1.32	1.24	1.23
	12.0%	1.09	1.07	1.06	1.04	1.03	1.01	0.96	0.95
CZ 10	SFR								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	1.00	2.54	0.90	2.29	0.78	1.97	0.61	1.54
	2.0%	2.94	3.68	2.72	3.41	2.43	3.04	1.99	2.50
	3.0%	3.11	3.40	2.92	3.20	2.67	2.92	2.26	2.48
	4.0%	2.64	2.82	2.51	2.69	2.32	2.49	2.02	2.16
	5.0%	2.22	2.30	2.12	2.21	1.99	2.06	1.76	1.83
	6.0%	1.83	1.87	1.77	1.80	1.67	1.70	1.50	1.52
	8.0%	1.20	1.21	1.17	1.18	1.12	1.12	1.02	1.03
	10.0%	0.76	0.75	0.74	0.73	0.71	0.70	0.66	0.65
	12.0%	0.42	0.41	0.42	0.40	0.40	0.39	0.38	0.36
CZ 12	SFR								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.91	2.38	0.82	2.15	0.71	1.85	0.55	1.44
	2.0%	2.69	3.46	2.49	3.21	2.22	2.86	1.82	2.35
	3.0%	2.78	3.22	2.62	3.03	2.38	2.76	2.02	2.34
	4.0%	2.54	2.72	2.41	2.58	2.23	2.39	1.94	2.08
	5.0%	2.13	2.24	2.04	2.14	1.91	2.01	1.69	1.78
	6.0%	1.74	1.83	1.68	1.76	1.59	1.66	1.42	1.49
	8.0%	1.17	1.19	1.14	1.16	1.08	1.10	0.99	1.01
	10.0%	0.72	0.72	0.71	0.70	0.68	0.68	0.63	0.63
	12.0%	0.38	0.36	0.37	0.36	0.36	0.35	0.34	0.32
CZ 14	SFR								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	1.09	2.73	0.98	2.46	0.84	2.12	0.66	1.65
	2.0%	3.13	3.83	2.90	3.55	2.58	3.16	2.12	2.59
	3.0%	3.05	3.29	2.87	3.10	2.62	2.82	2.22	2.40
	4.0%	2.44	2.54	2.32	2.42	2.15	2.24	1.87	1.95
	5.0%	1.87	1.91	1.79	1.83	1.67	1.71	1.48	1.51
	6.0%	1.39	1.39	1.34	1.34	1.26	1.27	1.13	1.14
	8.0%	0.64	0.63	0.62	0.61	0.59	0.58	0.54	0.53
	10.0%	0.11	0.10	0.11	0.09	0.11	0.09	0.10	0.08
	12.0%	(0.27)	(0.29)	(0.27)	(0.29)	(0.26)	(0.28)	(0.24)	(0.26)

Table 23: Case8-Retail B/C Ratios

Case 8: Retail, 12' ceiling ht, 4'+Splays light well, 1.6 LPD, AC and Heat

		10,000 sq.ft		***8,000 sq.ft***		***6,000 sq.ft***		***4,000 sq.ft***	
		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio	
	SFR	2/3 on/off	Dim 20%	2/3 on/off	Dim 20%	2/3 on/off	Dim 20%	2/3 on/off	Dim 20%
CZ 03	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.15	0.38	0.15	0.37	0.15	0.36	0.14	0.34
	2.0%	0.55	0.70	0.54	0.69	0.52	0.67	0.50	0.64
	3.0%	0.70	0.80	0.69	0.78	0.67	0.77	0.64	0.73
	4.0%	0.74	0.80	0.73	0.79	0.72	0.77	0.69	0.74
	5.0%	0.72	0.76	0.72	0.75	0.70	0.74	0.68	0.71
	6.0%	0.69	0.71	0.68	0.70	0.67	0.69	0.64	0.67
	8.0%	0.61	0.61	0.60	0.61	0.59	0.60	0.57	0.58
	10.0%	0.52	0.52	0.51	0.51	0.51	0.51	0.49	0.49
	12.0%	0.44	0.44	0.44	0.43	0.43	0.43	0.42	0.42
	SFR								
CZ 07	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.19	0.45	0.19	0.44	0.18	0.43	0.17	0.40
	2.0%	0.65	0.81	0.64	0.79	0.62	0.77	0.59	0.74
	3.0%	0.83	0.90	0.82	0.89	0.80	0.87	0.77	0.83
	4.0%	0.83	0.88	0.82	0.87	0.81	0.85	0.77	0.81
	5.0%	0.80	0.82	0.79	0.81	0.78	0.80	0.75	0.77
	6.0%	0.74	0.75	0.73	0.74	0.72	0.73	0.70	0.71
	8.0%	0.62	0.62	0.61	0.61	0.61	0.60	0.59	0.58
	10.0%	0.51	0.50	0.50	0.50	0.49	0.49	0.48	0.47
	12.0%	0.41	0.40	0.40	0.40	0.40	0.39	0.39	0.38
CZ 10	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.16	0.40	0.15	0.40	0.15	0.39	0.14	0.37
	2.0%	0.58	0.73	0.58	0.72	0.56	0.70	0.53	0.67
	3.0%	0.72	0.79	0.71	0.78	0.69	0.76	0.66	0.73
	4.0%	0.68	0.73	0.67	0.72	0.66	0.70	0.63	0.68
	5.0%	0.62	0.65	0.62	0.64	0.60	0.63	0.58	0.60
	6.0%	0.55	0.56	0.54	0.55	0.53	0.54	0.52	0.53
	8.0%	0.40	0.40	0.39	0.40	0.39	0.39	0.38	0.38
	10.0%	0.27	0.27	0.27	0.26	0.26	0.26	0.26	0.25
	12.0%	0.16	0.15	0.16	0.15	0.16	0.15	0.15	0.15
CZ 12	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.14	0.38	0.14	0.37	0.13	0.36	0.13	0.34
	2.0%	0.53	0.69	0.52	0.68	0.51	0.66	0.48	0.63
	3.0%	0.64	0.74	0.63	0.73	0.62	0.72	0.59	0.69
	4.0%	0.65	0.70	0.64	0.69	0.63	0.68	0.60	0.65
	5.0%	0.60	0.63	0.59	0.62	0.58	0.61	0.56	0.59
	6.0%	0.52	0.55	0.52	0.54	0.51	0.53	0.49	0.51
	8.0%	0.39	0.39	0.38	0.39	0.38	0.38	0.36	0.37
	10.0%	0.26	0.26	0.25	0.25	0.25	0.25	0.24	0.24
	12.0%	0.14	0.14	0.14	0.14	0.14	0.13	0.13	0.13
CZ 14	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.17	0.43	0.17	0.43	0.16	0.41	0.15	0.39
	2.0%	0.62	0.76	0.61	0.75	0.60	0.73	0.57	0.70
	3.0%	0.71	0.76	0.70	0.75	0.68	0.73	0.65	0.70
	4.0%	0.63	0.66	0.62	0.65	0.61	0.64	0.59	0.61
	5.0%	0.52	0.54	0.52	0.53	0.51	0.52	0.49	0.50
	6.0%	0.42	0.42	0.41	0.41	0.40	0.41	0.39	0.39
	8.0%	0.21	0.21	0.21	0.21	0.21	0.20	0.20	0.20
	10.0%	0.04	0.03	0.04	0.03	0.04	0.03	0.04	0.03
	12.0%	(0.10)	(0.11)	(0.10)	(0.11)	(0.10)	(0.11)	(0.10)	(0.10)

Table 24: Case9-Retail B/C Ratios

Case 9: Retail, 10' ceiling ht, 4'+Splays light well, 1.6 LPD, AC and Heat

		10,000 sq.ft		***8,000 sq.ft***		***6,000 sq.ft***		***4,000 sq.ft***	
		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio	
	SFR	2/3 on/off	Dim 20%	2/3 on/off	Dim 20%	2/3 on/off	Dim 20%	2/3 on/off	Dim 20%
CZ 03	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.13	0.30	0.13	0.29	0.12	0.28	0.12	0.28
	2.0%	0.45	0.56	0.44	0.54	0.42	0.53	0.42	0.52
	3.0%	0.58	0.65	0.56	0.63	0.55	0.62	0.54	0.61
	4.0%	0.62	0.66	0.60	0.64	0.59	0.63	0.59	0.62
	5.0%	0.62	0.64	0.60	0.62	0.59	0.61	0.58	0.61
	6.0%	0.59	0.61	0.57	0.59	0.56	0.58	0.56	0.57
	8.0%	0.53	0.53	0.52	0.52	0.51	0.51	0.50	0.51
	10.0%	0.46	0.46	0.45	0.45	0.44	0.44	0.44	0.44
	12.0%	0.39	0.39	0.39	0.38	0.38	0.38	0.38	0.37
	SFR								
CZ 07	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.15	0.35	0.15	0.34	0.14	0.33	0.14	0.33
	2.0%	0.53	0.65	0.52	0.63	0.50	0.61	0.50	0.61
	3.0%	0.69	0.74	0.67	0.71	0.65	0.70	0.65	0.69
	4.0%	0.70	0.73	0.68	0.71	0.66	0.69	0.66	0.69
	5.0%	0.68	0.69	0.66	0.67	0.65	0.66	0.64	0.65
	6.0%	0.64	0.64	0.62	0.62	0.61	0.61	0.60	0.61
	8.0%	0.54	0.54	0.53	0.52	0.52	0.51	0.52	0.51
	10.0%	0.45	0.44	0.44	0.43	0.43	0.42	0.43	0.42
	12.0%	0.36	0.36	0.36	0.35	0.35	0.34	0.35	0.34
CZ 10	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.13	0.32	0.13	0.31	0.12	0.30	0.12	0.30
	2.0%	0.48	0.59	0.47	0.57	0.45	0.55	0.45	0.55
	3.0%	0.60	0.65	0.58	0.62	0.56	0.61	0.56	0.60
	4.0%	0.57	0.61	0.55	0.59	0.54	0.57	0.54	0.57
	5.0%	0.53	0.55	0.51	0.53	0.50	0.52	0.50	0.51
	6.0%	0.47	0.48	0.46	0.47	0.45	0.46	0.45	0.45
	8.0%	0.35	0.35	0.34	0.34	0.33	0.33	0.33	0.33
	10.0%	0.24	0.24	0.23	0.23	0.23	0.23	0.23	0.23
	12.0%	0.14	0.14	0.14	0.14	0.14	0.13	0.14	0.13
CZ 12	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.12	0.30	0.11	0.29	0.11	0.28	0.11	0.28
	2.0%	0.44	0.56	0.42	0.54	0.41	0.52	0.41	0.52
	3.0%	0.53	0.61	0.52	0.59	0.50	0.58	0.50	0.57
	4.0%	0.55	0.58	0.53	0.57	0.52	0.55	0.52	0.55
	5.0%	0.51	0.53	0.49	0.51	0.48	0.50	0.48	0.50
	6.0%	0.45	0.47	0.44	0.45	0.43	0.44	0.43	0.44
	8.0%	0.34	0.34	0.33	0.33	0.32	0.33	0.32	0.33
	10.0%	0.23	0.23	0.22	0.22	0.22	0.22	0.22	0.22
	12.0%	0.13	0.12	0.13	0.12	0.12	0.12	0.12	0.12
CZ 14	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.15	0.34	0.14	0.33	0.14	0.32	0.13	0.32
	2.0%	0.51	0.61	0.50	0.59	0.48	0.58	0.48	0.57
	3.0%	0.59	0.63	0.57	0.60	0.55	0.59	0.55	0.58
	4.0%	0.53	0.55	0.51	0.53	0.50	0.52	0.50	0.51
	5.0%	0.45	0.45	0.43	0.44	0.42	0.43	0.42	0.43
	6.0%	0.36	0.36	0.35	0.35	0.34	0.34	0.34	0.34
	8.0%	0.19	0.18	0.18	0.18	0.18	0.17	0.18	0.17
	10.0%	0.04	0.03	0.04	0.03	0.04	0.03	0.04	0.03
	12.0%	(0.09)	(0.10)	(0.09)	(0.09)	(0.08)	(0.09)	(0.08)	(0.09)

Table 25: Case10-Office B/C Ratios

Case 10: Office, 10' ceiling ht, 4'+Splays light well, 1.1 LPD, AC and Heat

		10,000 sq.ft		***8,000 sq.ft***		***6,000 sq.ft***		***4,000 sq.ft***	
		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio		15 year B/C Ratio	
	SFR	2/3 on/off	Dim 20%	2/3 on/off	Dim 20%	2/3 on/off	Dim 20%	2/3 on/off	Dim 20%
CZ 03	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.11	0.20	0.10	0.20	0.10	0.19	0.10	0.19
	2.0%	0.28	0.33	0.27	0.31	0.26	0.31	0.26	0.30
	3.0%	0.32	0.34	0.31	0.33	0.30	0.32	0.30	0.32
	4.0%	0.31	0.33	0.30	0.32	0.29	0.31	0.29	0.31
	5.0%	0.29	0.30	0.28	0.29	0.28	0.28	0.27	0.28
	6.0%	0.27	0.27	0.26	0.26	0.25	0.26	0.25	0.26
	8.0%	0.21	0.21	0.20	0.20	0.20	0.20	0.20	0.20
	10.0%	0.16	0.15	0.15	0.15	0.15	0.15	0.15	0.15
	12.0%	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	SFR								
CZ 07	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.13	0.24	0.13	0.23	0.12	0.23	0.12	0.23
	2.0%	0.33	0.37	0.32	0.36	0.31	0.35	0.31	0.35
	3.0%	0.35	0.37	0.34	0.36	0.33	0.35	0.33	0.35
	4.0%	0.33	0.34	0.32	0.33	0.31	0.32	0.31	0.32
	5.0%	0.29	0.30	0.28	0.29	0.28	0.28	0.28	0.28
	6.0%	0.25	0.25	0.25	0.24	0.24	0.24	0.24	0.24
	8.0%	0.17	0.17	0.17	0.17	0.17	0.16	0.16	0.16
	10.0%	0.10	0.10	0.10	0.10	0.10	0.09	0.10	0.09
	12.0%	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
CZ 10	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.10	0.21	0.10	0.20	0.09	0.19	0.09	0.19
	2.0%	0.27	0.31	0.26	0.30	0.25	0.29	0.25	0.29
	3.0%	0.26	0.28	0.25	0.27	0.24	0.26	0.24	0.26
	4.0%	0.21	0.22	0.21	0.22	0.20	0.21	0.20	0.21
	5.0%	0.16	0.16	0.15	0.16	0.15	0.16	0.15	0.15
	6.0%	0.10	0.11	0.10	0.10	0.10	0.10	0.10	0.10
	8.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10.0%	(0.08)	(0.09)	(0.08)	(0.09)	(0.08)	(0.08)	(0.08)	(0.08)
	12.0%	(0.16)	(0.16)	(0.16)	(0.16)	(0.15)	(0.16)	(0.15)	(0.16)
CZ 12	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.08	0.18	0.07	0.18	0.07	0.17	0.07	0.17
	2.0%	0.23	0.27	0.22	0.26	0.21	0.26	0.21	0.26
	3.0%	0.23	0.25	0.22	0.24	0.21	0.24	0.21	0.23
	4.0%	0.19	0.20	0.18	0.19	0.18	0.19	0.17	0.19
	5.0%	0.13	0.14	0.13	0.14	0.12	0.13	0.12	0.13
	6.0%	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	8.0%	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
	10.0%	(0.11)	(0.12)	(0.11)	(0.11)	(0.11)	(0.11)	(0.11)	(0.11)
	12.0%	(0.19)	(0.20)	(0.19)	(0.19)	(0.19)	(0.19)	(0.18)	(0.19)
CZ 14	**SFR**								
	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0%	0.10	0.21	0.09	0.21	0.09	0.20	0.09	0.20
	2.0%	0.25	0.28	0.24	0.27	0.23	0.26	0.23	0.26
	3.0%	0.20	0.21	0.19	0.21	0.19	0.20	0.19	0.20
	4.0%	0.12	0.12	0.12	0.12	0.11	0.12	0.11	0.12
	5.0%	0.04	0.04	0.04	0.03	0.04	0.03	0.03	0.03
	6.0%	(0.05)	(0.05)	(0.04)	(0.05)	(0.04)	(0.05)	(0.04)	(0.04)
	8.0%	(0.19)	(0.19)	(0.18)	(0.19)	(0.18)	(0.18)	(0.18)	(0.18)
	10.0%	(0.31)	(0.31)	(0.30)	(0.31)	(0.30)	(0.30)	(0.29)	(0.30)
	12.0%	(0.41)	(0.41)	(0.40)	(0.41)	(0.40)	(0.40)	(0.39)	(0.40)

Appendix 2: Market Response to Skylights and Photocontrol Adoption

Summary of Results

Phone interviews of 60 building departments found the following implementation information concerning the skylighting and daylighting controls in the 2005 standards:

- Approximately 30% of large open spaces with high ceilings are not installing skylighting because they are shell building that may have lower ceilings as part of the tenant finish. Another 17% are not sure why these large buildings are not installing skylights.
- Of all the bldg departments interviewed, none was aware of anyone using astronomical time switches to comply with the daylighting requirement in Section 131(c). Of the few building plans we reviewed with completed lighting plans, none were showing an astronomical time switch.
- Of all the bldg departments interviewed, only 17% of total permits with skylights had multilevel photocontrols. In the remaining 83%, plan checkers couldn't identify whether they had controls or not.
- Of the 14 building permit documents that were reviewed, only 2 'whole building permits' had photocontrols in 100% of their daylit spaces. The remaining 12 were 'shell only' permits with skylights but no lighting controls or Title 24 documentation.
- Of the 14 building permit document reviews, the skylight area on an average was 2.5% of the total building area.
- Of the 14 building permit document reviews, none of the buildings with skylights had submitted the ENV-4-C skylight area support worksheet as part of their documentation submittal to building departments.

Introduction

The 2005 standards have introduced a new compliance for large buildings like warehouses with spaces greater than 25,000 SF of area and a ceiling height of greater than 15 feet – the prescriptive requirement for skylights and automatic controls. Though skylights and photocontrols have been embraced by several national big box retailers, overall the market for photocontrols is small. It is believed that the market for astronomical time clocks is larger than photocontrols as the product is easy to specify and install, even though they are estimated to save about half the amount of lighting energy as photocontrols. The current 2005 code allows the astronomical time clocks as one option for large spaces with skylights.

The main aim of this study was to research what fraction of the current market is using skylights in large space like warehouses and big box retail, what fraction of the designers are using photocontrols for compliance and how well the overall skylighting requirement is working. We interviewed plan checkers by telephone in building departments that typically see a lot of large open building plans submitted. We identified building departments that had permits with skylights and were willing to let us examine plan submittals. We then did a detailed analysis of those plans that were identified as large spaces with skylights. This report summarizes the methodology, findings and analysis of the phone interviews and building permit document reviews of building departments across California.

Methodology

The sections below describe the methodology that we used to conduct the phone interviews and building permit document reviews to collect information on large spaces with skylights under the 2005 compliance.

Selection Criteria for Building Departments

The following criteria used for selecting building departments for phone interviews to identify buildings with Skylights and lighting controls:

1. Square Feet of Area for large retail/industrial buildings: The counties with the largest square feet of area for retail and warehouses were chosen for building department interview. This information is based on the Dodge Construction Database[4]

2. Number of Nonresidential Permits: The cities that have maximum number of nonresidential permits within the selected counties were short listed .This information on nonresidential permits is based on a phone interview conducted by HMG for Doug Beaman and Associates for the PG&E Codes enhancement study.

3. Accessibility: Cities within the chosen counties that are easily accessible for on-site visits were selected for the phone interviews

4. Population density/size of City: Some cities within the chosen counties (counties with largest area) were selected based on their size and density

5. Referred by other departments: While we were conducting phone interviews, some building departments suggested additional departments to contact. About 15 of these building departments were added later for the interview.

The final building department phone interview list had a total of 60 building departments out of which 57 completed the interview. There were 24 building departments interviewed from Southern California and 33 from Northern California.

Building Department Phone Interview

The phone interview was developed for the purpose of short listing about 10 building departments to visit and physically view the plans and Title 24 documents of those permits that have used skylights for compliance with the 2005 energy standards. A total of 60 building departments were interviewed on the phone to retrieve the following information (either based on actual figures or estimates based on plan checker's experience). Out of these, 57 departments completed the interview. The five broad questions in the phone interview are outlined below (for detailed interview questions, refer to Appendix 2):

1. Total number of building permit applications for buildings with spaces greater than 25,000 SF of area and ceiling height greater than 15 feet that were submitted after October 1st 2005

2. Number of those building permits that have skylights

3. Type of buildings that have applied for skylights, Percentage and area of that building type

4. Type of daylighting controls in the skylit spaces

5. When skylights and controls are not required to comply with the code, what are the reasons for exemption

Document Review Data Collection

Out of the 16 building departments that had large building permits with skylights, we conducted on-site document reviews in 13 building departments. Out of those, only eight building departments qualified under our study (permits

[4] RLW, 1999. "Final Report – Nonresidential New Construction Baseline Study." RLW Analytics. California State-Level Market Assessment and Evaluation Study. This database contains nonresidential construction activity by occupancy type for each of the counties in California.

that have large spaces with skylights under 2005 compliance). We requested building departments to provide us with plans and Title 24 documents of permits that had applied for skylighting under 2005 compliance. In most case, they were able to identify two or three building plan sets with energy compliance documents for HMG review.

The selection criteria for on-site document reviews were based on:

- Willingness of building departments to take time out to identify the plans specific to our needs
- Ease with which plans can be retrieved. Most building departments don't track skylighting as part of their tracking system and are unable to trace documentation of permits that have had tailored lighting since October 1, 2005.
- Availability of plans. Most permits are either under plan review through outside consultants, or are with owners for revision, or sent for imaging after they are issued. We selected departments that had plans available in their department at the time of our study.

We created document review forms with information pertaining to skylights and lighting controls. This was used by the surveyor to input information based on each building surveyed. Most of the information in the on-site document review form was based on the 2005 Title 24 compliance forms ENV-2-C (envelope component method) and ENV-4-C (skylight area support worksheet). We also referred to building plans to check all the information that was in the compliance documents or whatever was missing from the compliance documentation. The following list provides a brief summary of information that was in the on-site document review forms:

Skylight Properties:

- Type of Skylight and type of frame
- Number of panes
- U-factor and SHGC values
- Percent Skylight
- Manufacturer name and model number
- Skylight dimensions and number of skylights

Skylight Area Calculation:

- Type of skylight area calculation method (effective aperture or daylight fraction method)
- Floor area and proposed daylit area
- Lighting Power Density
- Skylight to daylight fraction
- Proposed skylight area

Results

The sections below summarize the results and analysis of the phone interviews and on-site document review conducted at the building departments.

Phone Interview Results

- Number of building permits with skylights: Out of 57 interviews, 26 building departments had large warehouse/big box retail type permit applications (area >25,000SF and submitted after October 1st 2005. Out of the 26 building department, 17 of them had permit applications with skylights. Out of a total of 236 permits that were submitted under large space applications, **51%** of them had skylights as part of their

design submittal. The remaining 49% had given the following three reasons for buildings with large spaces to be exempt from skylights:

- When they are "shell only" permit application: Based on the building department, here the applicant is not required to submit Title 24 compliance documentation or install skylights because the owner is not installing any lighting or mechanical equipment. Two building departments said that they request letters from the owner that would indicate that the owner of shell only permit will not install skylights but will leave it up to the tenant improvement owner to put in skylights if required.

- Designer used performance (software) method: In this case, the designer can choose to install other energy efficient measures, through California Energy Commission approved software that can prove that skylighting is not required in this building if it can be traded off with other measures like high performance windows, energy efficient heating and cooling equipment and higher insulation levels.

- Permits with "other" reasons. The three main reasons for buildings not having skylights were "don't know the reason", "the plan checker was not sure if the area was more than 25,000 SF or ceiling height >15 feet", or the "permit application was for a TI in an existing large warehouse".

Figure 10 shows the fraction of large buildings (with spaces >25,000 SF and ceiling height >15 feet) that had skylights and fraction of those that were exempt from using skylights. This is based on the information collected from plan checkers through phone interviews.

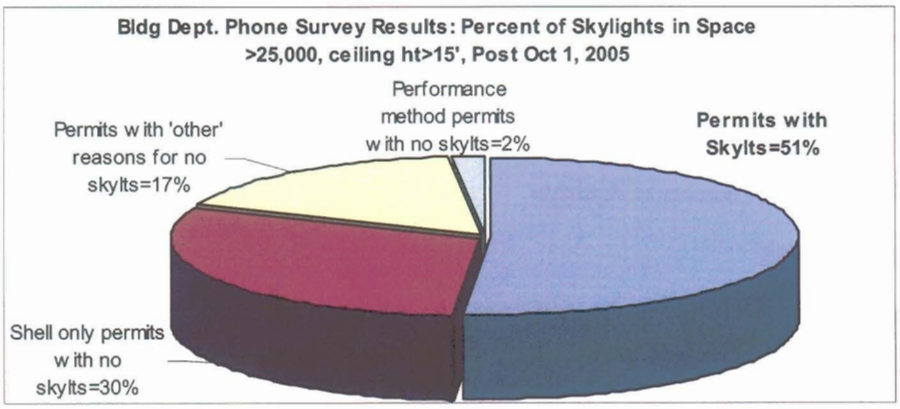


Figure 10: Phone Interview Results: Fraction of large Building Application that had skylights and Fraction of those that were Exempt from using Skylights

- Type of buildings that had skylights: Out of those buildings that had skylights, 89% of those were warehouse permit applications and 11% were big box retail stores. See Figure 11.

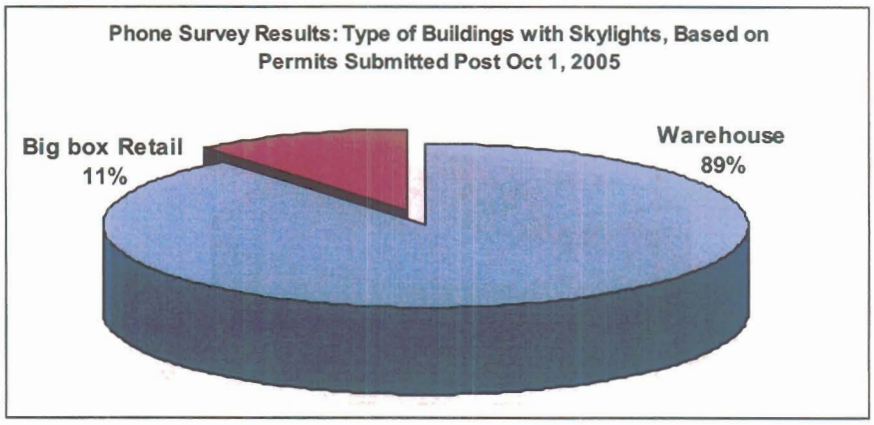


Figure 11: Fraction of Building Types that have used Tailored Method for Compliance with 2005 Standards redraw this so that names are on the percentage values not as a lengend at the bottom

- Fraction of buildings with skylights with daylighting controls: According to the plan checkers through the phone interviews, only **17%** of the total permits with skylights had "multilevel photocontrol" as daylighting controls in skylit spaces. In the remaining 83% of the permits with skylights, the plan checkers indicated "don't know" as the answer. This could be because they don't track skylights and photocontrols as part of their tracking system and daylighting control is a very detailed part of the plan check that most of the times they may not remember. None of the building departments interviewed had come across buildings with skylights that had installed astronomical time clocks. Some plan checkers were not even aware of such a product available as part of daylighting controls.

Document Review Results

The surveyor conducted a total of 73 document reviews in 13 building departments. Out of those, only eight building departments with a total of 14 building permits qualified under our criteria (permits that have large spaces with skylights under 2005 compliance). The remaining building departments (with a total of 59 permits) did not meet our criteria for the following reasons:

- 67% of the total permits that didn't meet our criteria were "No skylights with Spaces <25000 SF and <15' ceiling"
- 10% were "No skylights, TI permit applications submitted in 2005 on existing 2001 shell"
- 3% were "No skylights, and had used Performance Method under 2005 compliance"
- 8% were "No skylights as they were shell only permit applications under 2005 compliance"
- 7% were "No skylights and met 2001 compliance"
- 5% were "with skylights but were under 2001 compliance"

Figure 12 shows the fraction of those building plans that did not meet the criteria of this study.

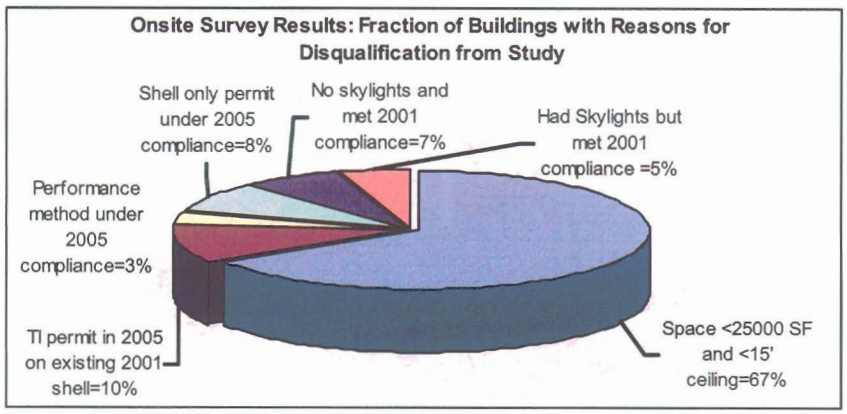


Figure 12: On-site Document Review Results: Fraction of Buildings that did not meet the Criteria for the Study

According to the surveyor, the number of warehouses and those with skylights indicated by plan checkers during phone interviews was different from what the surveyor counted when on site. From the plan reviews, the fraction of large spaces with skylights as per the 2005 compliance was **38%** of the total warehouse/big box type of large space permits, while the phone interview indicated **51%** of the total large spaces that had skylights.. This difference could be due to several reasons, for instance, the plan checkers may include spaces with skylights under 2001 compliance permits as part of their estimate of buildings with skylights under 2005 compliance, or may have included 'small shelving/rack addition permits to warehouses as part of the total number of warehouse.

The following analysis is based on the **14** building permits reviewed and that qualified under our criteria (spaces >25,000SF and ceiling height >15 feet and under 2005 compliance):

- Out of the 14 building permits that met our criteria of qualified plans, 2 were big box retail permits and the rest of the 12 were all warehouse shell only permits
- Out of the total building permit document review, only **2 had indicated lighting controls in building plans** and both of these were making use of photocontrols to satisfy the daylighting control requirements. These 2 buildings were both big box retail permit applications. This indicates that **100%** of the plans surveyed with lighting documentation had photocontrols. However, this is a tiny sample. The remaining buildings did not install any automatic photocontrols or astronomical time clocks as part of their design. This could be because all those buildings were "shell only" permits and were not required by the building department to submit Title 24 documentation. Also, in shell only situations, owners don't install any type of mechanical or lighting equipment As a result, no lighting control was indicated as part of the permit submittals.
- Out of the 12 "shell only" buildings permits that had skylights, 9 permits had building areas greater than 50,000 SF. According to the plan checkers, any building greater than 50,000 SF is required to install "Smoke Hatch" as part of the building code. It is possible that all the 9 buildings that applied for skylights were not required by building departments to install skylights but they chose to do so since they had to install smoke hatch as part of their design.
- None of the 12 building permits had any ENV-2-C or ENV-4-C forms available for review. The building department didn't require them to submit these documents for plan check. The remaining 2 buildings that were big box retail permits had submitted only the ENV-2-C form for review, but none of them had filled out the ENV-4-C form that is the skylight area support worksheet. The plan checkers for both these projects were unaware of the 2005 ENV-4-C skylight are support worksheet.
- Typical features of the skylights based on the 14 buildings is as follows:
    - Skylight dimensions: 4 feet x 8 feet for all warehouses. One big box retail had specified a 5'x5' skylight and the other had specified 6'x 6' skylight dimensions

- On an average, skylight area in warehouses was 2.5% of the total building area
- Most spaces had used double pane skylights with aluminum frame
- Fiberglass and acrylic were the predominant materials used for skylights

Summary

- On an average the total number of warehouse/retail applications submitted after October 1, 2005 has been relatively low. This could be because of the short time frame since the new code took into effect. Also, many plan checkers indicated that there was a rush of applications for warehouses/big box retail permits just prior to October 1, 2005 in order to avoid the new 2005 requirements of skylights in such spaces
- Only 51% of the total warehouse/big box retail permits were with skylights. This is mainly because most of the permits under these requirements were 'shell only" applications and did not require skylights as per the building departments. Those that had skylights did not submit any compliance documents related to Title 24 standards as they were not required by the building department to do so. The building plans for all these projects indicated some basic information about the skylights that the surveyor was able to document.
- According to the building permits document review, a very small fraction of those buildings with skylights have used photocontrols. This indicates that most of the permits that were submitted with skylights were "shell only" permits and thus didn't need to install photocontrols as part of their design. There is a possibility that these shell only buildings may install lighting controls later when the tenant improvement lighting design is submitted.
- According to the phone interviews to building departments, only 17% of buildings with skylights had photocontrols as part of their plan submittal. In the remaining 83%, the plan checkers couldn't identify whether the permits with skylights had lighting controls or not.
- Astronomical time clocks were not encountered at all during this study either through phone interviews or on-site document reviews.