CODE CHANGE PROPOSAL FOR

Updates to Title 24 Treatment of Skylights:

- Definition of Skylit Zone
- Definitions of Effective Aperture and Well Efficiency
- Requirements for Automatic Multi-Level Daylighting Controls
- Revised Power Adjustment Factors
- Mandatory Automatic Controls under Skylights
- Skylighting as Base Case for Large Low-Rise Nonresidential Buildings

FINAL REPORT 5/14/02

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Overview

This proposal seeks to incorporate skylighting and automatic daylighting controls as code requirements for large low rise nonresidential buildings. This code proposal would shift the emphasis of Title 24's treatment of skylights from a building feature that is accommodated by the standards to an efficiency measure that is actively promoted by the standards.

This proposal follows on the precedent set by the Statewide Savings By Design (SBD) nonresidential new construction program, that skylights and daylighting controls are a significant source of energy efficiency in new nonresidential buildings. Daylighting controls incentivized by SBD are saving at least 8.7 GWh/yr, or 22% of all of the energy from the Statewide nonresidential new construction programs (see the "Energy Savings from Daylighting in New Construction Program" section in the Appendix). This commonly applied measure from the utility efficiency program can be added to the California Building Efficiency Standards to yield cost-effective energy savings for a larger population of buildings.

Description

Six proposed changes to Title 24 are recommended to improve how the building efficiency standards are applied to skylights:

1) Modifying the description of the daylit zone under skylights (for simplicity's sake we call the daylit zone under skylights the "skylit zone"). The current definition allows all electric lighting within one ceiling height of the skylight "footprint" to be considered part of the skylit zone. This defines too large of an area to be on a single control or alternatively allows the skylight spacing to be too large to provide uniform illumination. The current definition allows what the lighting designers call a "spacing criterion" of at least 2.0; in contrast most luminaires with electric sources have a spacing criterion of 1.5 or less. The new definition results in a spacing criterion of at least 1.4.

2) Correcting errors in the definitions of effective aperture and well efficiency. The calculation method for well efficiency should be updated and use the same terms as in most recent version (ninth edition) of the IESNA Handbook. Correctly calculating effective aperture is more important in this code change proposal because we propose that effective aperture be used to calculate the Power Adjustment Factors (PAF) credit for lighting controlled by daylighting controls.

3) Adding requirements for Automatic Daylighting Control Devices so that they are easy to adjust initially and over time. To qualify, the photocontrol would have to be readily accessible, have well marked gradations on adjustment mechanisms, and be remote from the light sensor so that the field of view of the sensor will not blocked by the commissioning agent during adjustment. The light sensor would be required to have a linear response so that the combination of the sensor and the controller produce a predictable response (i.e. it is easy to adjust the settings to some fraction or multiple of the illuminance level encountered during commissioning).

4) Adding a mandatory requirement that light fixtures in the daylit area be controlled by photosensors or timeclocks. While not as effective as photosensors, timeclocks can easily save substantial lighting energy, and are cheaper and easier to use. This requirement is clearly cost-effective for skylit areas. This requirement will be apply for enclosed spaces that have a combined area of skylit zones greater than 2,500 ft^2. Photocontrols would qualify for an additional compliance credit through the Power Adjustment Factor (see below).

5) Revising the Power Adjustment Factors (PAF's in Table 1-L) to give more credit to automatic stepped daylighting controls under skylights. This Power Adjustment Factor credit would only apply to skylighting systems that use diffusing skylights and would not be available for daylighting controls under clear skylights.

6) Updating the prescriptive requirements for large (greater than 25,000 square feet) low-rise nonresidential buildings to require skylights for floor areas directly under roofs. This prescriptive requirement for large low-

rise nonresidential buildings would also be incorporated into the base case of the alternative compliance method (ACM).

Benefits

Thoughtful design of buildings using daylight can improve lighting quality, increase productivity (HMG 1999, Heschong et al 2001) and reduce energy consumption (McHugh et al 1998). Since over 60% of commercial building floorspace is single story or on a top floor[1], toplighting with skylights or other rooftop apertures will be the method of choice for daylighting much of the commercial building stock.

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.

Type of Change

This section identifies how each of the components of the proposed code change affects the standards. Major categories include:

Mandatory Measure The change would add or modify a mandatory measure. Mandatory measures are required on all buildings where they apply and cannot be traded away. This proposal contains revisions to a mandatory measure in the "Mandatory Automatic Lighting Controls in the Daylit Zone under Skylights" section.

Prescriptive Requirement The change would add or modify a prescriptive requirement. The prescriptive requirements are code measures that can be applied as they are written in the standard and can be applied without running a performance method computer simulation. These requirements are not mandatory and can be traded-off in the performance method by adding other building features that result in the same energy consumption as an equivalent building that minimally meets the prescriptive requirements. Adding prescriptive requirements impacts the "base case" building in the performance method. The section of this proposal entitled "Prescriptive Requirements for Skylights in Large Low-Rise Nonresidential Buildings" falls under the prescriptive category.

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. We are proposing an update to the energy credits for automatic daylighting controls in the proposal "Revised Power Adjustment Factors."

Modeling The change would modify the Standard Design and 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. No specific algorithmic change is recommended in this proposal.

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[1] Table BC-11, 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)

Daylit Zone under Skylights

This change affects the definition of the daylit zone. In the current standard this would affect the calculation of the Power Adjustment Factors (PAF's) which in turn affects the amount of lighting credits one can claim when calculating installed lighting power density. This definition also affects the code proposal for mandatory photocontrols, as a daylit zone area over 2,500 square feet triggers the requirement. This definition also affects the prescriptive requirements for skylights in large low-rise buildings, since large enclosed areas would be required to have at least 50% of the floor area in the daylit zone.

Definitions of Effective Aperture and Well Efficiency

This change is primarily a "clean-up" measure. The equation for effective aperture was incorrect in the Standard but effective aperture is correctly calculated in the Nonresidential Manual. We propose to change the calculation for well efficiency to reflect the most recent version of the Illuminating Engineering Society of North America (IESNA) Handbook. This change simply updates the terminology to that used by the lighting design community; it does not affect the numerical results. Also included in this proposal is a change in the definition of skylight area from the surface area of the skylight to the rough opening of the skylight. This is consistent with the way that window areas are calculated in Title 24, and is consistent with the way that rated U-factors for skylights are applied to skylight areas. This is also in line with the definition of skylight area used in the ASHRAE Handbooks and is consistent with the calculation method used in the IESNA Handbook.

Requirements for Automatic Daylighting Controls

This refines the mandatory characteristics of automatic daylighting control devices in Section 119(e) to assure that photocontrols have the features that allow them to be easily commissioned. This affects the standard and the Nonresidential Manual but has no impact on the performance method or the ACM.

Revised Power Adjustment Factors

The revised PAF's provide encouragement for designers to use more sophisticated controls to automatically turn off the electric lighting in the skylit area during daylit hours. This will affect the current calculation method in the ACM. Currently the ACM applies the PAF's to the lighting power in the proposed building model. For prescriptive compliance, the methodology will remain the same although the values (PAF's) will change.

Mandatory Automatic Lighting Controls in the Daylit Zone under Skylights

This recommendation would expand the scope of Section 131c from simply requiring additional switches in daylit zones over 250 square feet to requiring automatic controls in spaces containing total daylit zone area over 2,500 square feet. Either a photocontrol system or a timeclock control will meet the automatic control requirement. This impacts the Power Adjustment Factors for photocontrols since the incentive amount would now be compared relative to the minimally compliant timeclock control. This requirement cannot be traded away for other measures.

Prescriptive Requirements for Skylights in Large Low-Rise Nonresidential Buildings

This proposal would create a requirement for skylights or other toplighting in low rise buildings having enclosed spaces over 25,000 square feet that are directly under a roof (with exceptions for spaces that cannot tolerate daylighting, such as auditoriums, movie theatres, museums, and refrigerated warehouses). This would be incorporated into the Prescriptive Envelope Criteria for Nonresidential Buildings (Section 143, Table 1-H). Since the performance method Standard Design is based on the prescriptive requirements, this would necessitate changes to the ACM and the compliance software. Skylights and daylighting would be part of the Standard Design for buildings where the new requirements apply.

Technology Measures

This proposal is 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 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 specialty lighting market for over a decade.

As an alternative to photocontrols one can use the familiar timeclock control technology. Such a timeclock would need to have the astronomical calculation algorithms built in such as are currently required for outdoor lighting controls. These algorithms automatically adjust the timeclock settings for the length of the day, saving more energy in the summer than in the winter.

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 $770/ea for a double-glazed skylights[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 s 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

[2] Values from 1995 Means Building Construction Cost data and increased by the recommended 20% for California cost and wage conditions, figures adjusted up by 10% from 1995 according to NASA inflation calculator. These estimates are somewhat (as much as 50%) higher than those quoted by installers – thus the estimates of benefit cost ratio are conservative.

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 $2,000.

The bottom half of Table 1 shows the area covered by a single lighting circuit with a 90% fill factor (circuit has a load that is 90% of its allowable rating). Lighting circuits are derated to 80% of ampacity since they are continuous duty circuits. If you multiply the areas by 3, one can readily see that a three-circuit photocontrol can cover several thousand square feet of floor area at the code maximum lighting power densities. Most nonresidential lighting circuits are 277V, so the larger areas in the second column of the table apply. Thus a single photocontrol can cover large areas if these areas are fairly uniform in terms of how they distribute daylight from skylights and the general lighting needed.

Table 1: Coverage area of a single lighting circuit for single story occupancies

Assumptions			
Volts	**277**	**120**	
12 ga wire nom. Ampacity	20	20	
Circuit fill	90%	90%	
Continuous duty de-rating	80%	80%	
Amps/circuit	14.4	14.4	
Watt/circuit	3,989	1,728	
Volts	**277**	**120**	**LPD**
Whole building	**SF/circuit**	**SF/circuit**	**W/sf**
Comm Hi bay	3,324	1,440	1.20
Comm low bay	3,989	1,728	1.00
Grocery	2,659	1,152	1.50
Storage Bldg	5,698	2,469	0.70
Office	3,324	1,440	1.20
Retail	2,346	1,016	1.70
Schools	2,849	1,234	1.40

Useful Life, Persistence and Maintenance

The power savings and benefits of photocontrols are well established and are recognized in the Advanced Lighting Guidelines.[3] The largest unknown is the calibration and performance of automatic daylighting controls. Our interviews with market players have recorded mixed results, with a relatively higher rate of failed systems. As a result, we have focussed this proposal on daylighting controls for the electric lighting under skylights because these controls are less likely to fail than daylighting controls applied to sidelighting. Simple open loop photocontrols in skylit spaces perform much in the same way that photocontrols work on streetlights; they sense only daylight and

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

turn off electric lighting when the daylight level is above a given threshold.[4] For those designers who resist using a technology that they perceive as new or unfamiliar, the requirements allow the use of the very familiar timeclock to control lights in the skylit zone. This controls requirement for the skylit area mirrors the mandatory requirements for automatic controls for outdoor lighting (Title 24 §131f).

However, we think greater savings can be achieved with photocontrols – thus the proposal retains Power Adjustment Factors for automatic photocontrols to encourage their use. Some of the complaints heard about photocontrols is that they are hard to calibrate. This proposal includes requirements for automatic daylighting control devices in Section 119(e) that would make photocontrols easier to calibrate, and hence less prone to failure due to unsatisfactory behavior.

Performance Verification

Photocell controls require calibration to deliver savings. These controls must be enabled before final inspection so the inspector can see that lights are responding to available daylight. Beyond that, we do not feel that extensive performance verification procedures are necessary.

Cost Effectiveness

All the measures proposed here that need a cost-effectiveness determination are cost-effective. To evaluate cost-effectiveness of the Power Adjustment Factors, we have applied the TDV methodology so that our results will be in concordance with implementation of TDV in the ACM programs.

Some measures do not directly require a cost-effectiveness analysis. For example, redefining effective aperture does not have a cost-effectiveness calculation. But cost-effectiveness is calculated for the requirements that are based on the new “effective aperture” definition. A similar situation exists for the proposal, which places additional requirements on the specification of automatic daylighting controls. The cost-effectiveness of these new requirements have not been evaluated in isolation, but the cost of photocontrols that meet the new acceptance requirements are embedded in the cost effectiveness analysis for mandatory automatic daylighting controls. Thus the combined measure of the new specification requirements and mandatory photocontrols are cost -effective.

The cost-effectiveness analysis for each measure is described in the Results section.

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 the complexity of the DOE-2 daylighting algorithms, the rule sets for the ACM programs would have to be carefully thought out to assure that daylighting modeled by these programs would have sufficient fidelity to the building design. Given the potential for the DOE-2 daylighting algorithms to be misapplied and the sufficient accuracy of the existing PAF method, we propose that the PAF method of calculating daylight savings be used but with revised PAF’s as contained in this proposal.

Relationship to Other Measures

Within this proposal several measures are interrelated:

[4] This is in marked contrast to the complexity of closed loop controls used in conjunction with sidelighting from windows. Closed loop controls have to account for the differences in the spectral and spatial distribution of electric lighting from above and daylight from the side and to be reliable are configured to avoid sensing locations that might have their reflectances change.

- The power adjustment factors for photocontrols are cut in half because automatic controls would become a mandatory requirement for most of the daylit zones encountered (over 2,500 square feet). The PAF is retained to encourage the use of the more efficient photocontrol over the less efficient and less dependable timeclock compliance method.

- Redefinition of the effective aperture will yield the same result as the method shown in the Nonresidential Manual. The definition of the effective aperture is more important under this proposal because it is directly used in calculating the Power Adjustment Factors for automatic daylighting controls and it is used in exempting a building from mandatory daylighting controls requirements.

Methodology

Several different methods were used to evaluate the wide range of skylighting measures we considered for inclusion in the Standards. We used the results of skylight photometric testing to determine the appropriate spacing of skylights – and by extension the appropriate definition of the daylit zone under skylights.

We made use of the electric lighting savings calculation method contained in the SkyCalc[5] software to calculate the appropriate Power Adjustment Factors for different types of photocontrol systems as well as the minimum daylit area required for a photocontrol system to be cost effective. These calculations were performed on an hourly basis so the hourly time dependent valuation (TDV) factors could be applied to the energy savings.

Finally, to evaluate the cost-effectiveness of requiring skylights for some single story occupancies, we performed DOE-2.2 simulations. This detailed model was needed to accurately model the thermal processes as well as the daylighting and photocontrol performance.

Daylit Zone under Skylights

The method used to evaluate the appropriate spacing for skylights was the use of the calculated spacing criterion (SC). These spacing criterions were calculated from measurements of the luminous intensity distributions from white skylights under clear skies[6]. The method used to calculate the spacing criterion is described in the IESNA Handbook and compares the illuminance between two luminaires (skylights) to that directly below a single luminaire (skylight). This method provides a simple method of evaluating the appropriate spacing of skylights for uniform illumination. This method provides a conservative (overly large) metric for spacing skylights because, "When other criteria are considered, such as overlap between luminaires, vertical illuminance, shadowing and illuminance distribution above the workplane, it generally is found that luminaires be installed at some spacing-to-mounting-height ratio less than the value of the luminaire spacing criterion."[7]

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[5] Heschong, L. & McHugh, J. "Skylights: Calculating Illumination Levels and Energy Impacts," *Journal of the Illumination Engineering Society*, Winter 2000, Vol. 29, No. 1, pp. 90-100. SkyCalc accounts for well efficiency, lighting technology and control strategies that is hard to replicate in other energy modeling programs. SkyCalc accounts for interaction effects between HVAC and the daylighting system and calculates total energy impact of skylights.

[6] Available from the New Buildings Institute, http://www.newbuildings.org/pier/ Heschong Mahone Group. Construction and Calibration of Skylight Photometric Test Facility: Final Report for Task 5.3.5a Skylight Photometry Lab and Calibration. PIER Integrated Design of Commercial Building Ceiling Systems project report.

[7] P. 9-50 to 9-51 IESNA 2000. IESNA Lighting Handbook Ninth Edition, New York.

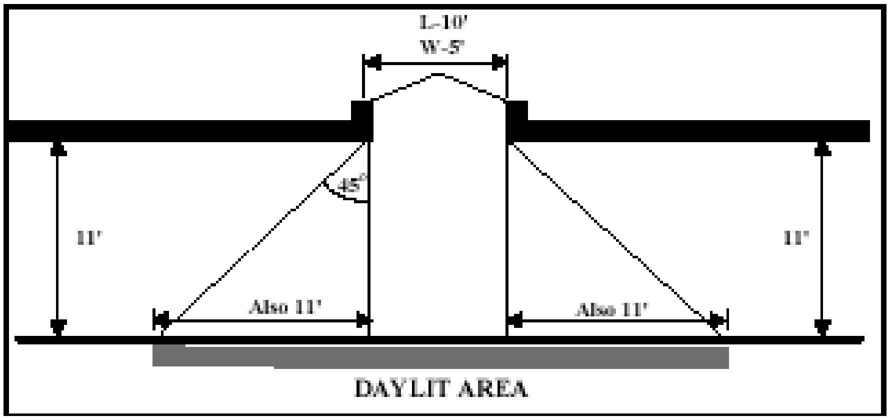


Figure 1: Existing Daylit Area Figure in the 2001 Title 24 Nonresidential Manual.

The current code language defines a horizontal (or plan) daylit zone as the "footprint" of the skylight plus the ceiling height in each direction from the side of the skylight. This expansion of the daylit zone under skylights is illustrated in the 2001 Title 24 Nonresidential Manual (see Figure 1) with a "spread angle" of 45 degrees. We desired a similar level of simplicity so a desired outcome would have a ratio of spacing width to ceiling height that would be a simple decimal (multiples of 5%) with a "spread angle" that is a multiple of 5 degrees.

The existing definition of the daylit area implicitly has a spacing criterion of 2.0. From comparing the spacing criterions of diffusing light fixtures which have spacing criterions around 1.5, it was our hypothesis that the spacing criterion for skylights would also be around 1.5 – substantially less the current value in the building efficiency standards.

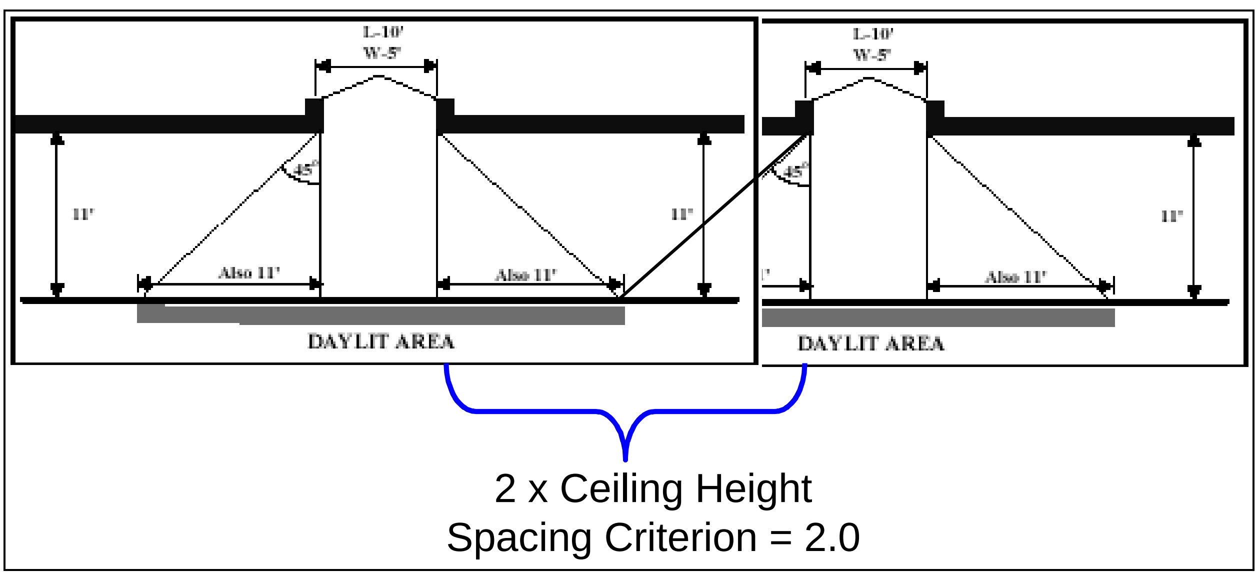


Figure 2: Relationship between the existing definition of daylit zone and its spacing criterion

Revised Power Adjustment Factors

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 2005 Title 24 standards. The resulting output units from this calculation procedure are present valued dollar savings that include energy and capacity costs. Before daylighting controls were applied, the retail store had 5,293 full load hours or 8.5 kWh/ft^2·yr of lighting consumption per square foot of store area. Similarly, warehouse lighting was operating 4,428 full load hours and consuming 3.1 kWh/ft^2·yr of electricity.

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 cut in half to account for the savings that could result from the minimum mandatory requirement of electric lighting on an astronomical timeclock control (which we propose as a mandatory minimum requirement for all skylit spaces). This factor of one half is not a calculated value but rather recognizes that correctly applied timeclock controls can save a substantial fraction of energy while making it relatively easy to calculate the total benefit from photocontrols (double the PAF amount).

Two similar models were created for this analysis: a big box retail or grocery store with relatively high lighting power densities (2 W/SF) and a warehouse space with lower lighting power densities (0.7 W/SF). In the retail store it was assumed that 80% of the LPD would be allocated to general lighting that might be displaced by daylight and that 20% of the lighting was display lighting that would be unaffected by the amount daylight available. All of the warehouse lighting was treated as ambient lighting and could be displaced by daylighting. In both models, 10% of general lighting was not controlled – it was considered to be emergency or other lighting outside of the daylit zone. Thus the retail model has a controlled LPD of 1.44 W/SF and the warehouse had a controlled LPD of 0.63 W/SF.

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. In both building models we modeled two light sources: fluorescent industrial strip pendants and metal halide hi-bay downlights. Fluorescent fixtures were assumed to have T-8 lamps and electronic ballasts for a maintained luminous efficacy of 78 lumens/Watt. Metal halide fixtures were assumed to have standard (not pulse start) lamps and ballasts with an overall maintained luminous efficacy of 52 lumens/Watt. As a result, the retail store with an ambient LPD of 1.6 W/SF, had ambient lighting design footcandles of 65 fc with fluorescent lighting and 40 fc with metal halide lighting. The retail store with an ambient LPD of 0.7 W/SF, had a ambient lighting design footcandles of 20 fc with fluorescent lighting and 13 fc with metal halide lighting. The maintained luminous efficacy of pulse start metal halide is equivalent to that of the fluorescent lighting system.

The PAF analysis uses the SkyCalc lighting schedules which come from calibrated DOE-2 models used to create the Unit Energy Savings (UES) tables – tables that all the California investor owned utilities are using to estimate savings in their nonresidential new construction programs. Figure 3 plots the weekday, Saturday and Sunday lighting schedules for the warehouse and retail models used in this analysis. 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.

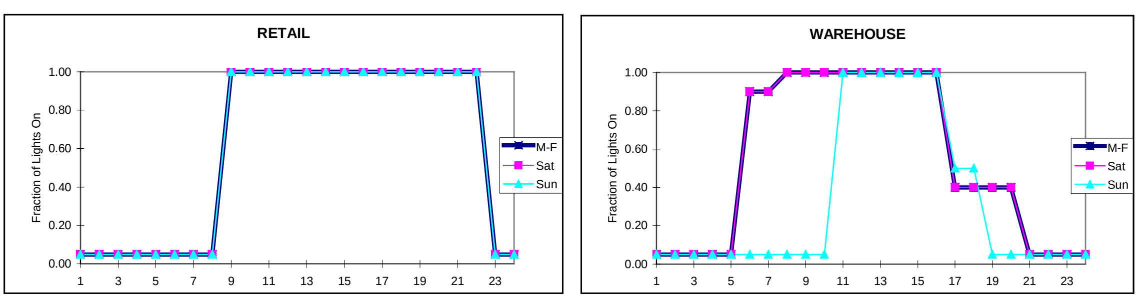


Figure 3: Lighting Schedules Used in PAF Analysis

We evaluated four switching control schemes that are common to all lighting technologies, as well as dimming and step dimming technologies that have power reduction factors that are specific to the lighting technology used. Figure 4 plots for each control type, the fraction of rated lighting power (% power) consumed by a lighting system in response to the fraction of design illuminance (% of setpoint) provided by daylight. The control types considered are:

- On/Off. This switching control turns off all of the lights when interior daylight illuminance exceeds the target illuminance for the space. Power consumption is proportional to electric light output.

- 2 Level + Off. This switching control turns off half of the lights when interior daylight illuminance exceeds one half of the target illuminance for the space and turns off all of the lights when interior daylight illuminance exceeds the target illuminance for the space. Power consumption is proportional to electric light output.

- ½ Controlled On/Off. This switching control turns off half of the lights when interior daylight illuminance exceeds one half of the target illuminance for the space. The other half of the lights always remain on. Power consumption is proportional to electric light output.

- 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.

- Dimming Min 25% Light (Metal Halide). This dimming control continuously dims the metal halide lighting system in proportion to the fraction of the target illuminance provided by daylight. Since the minimum dimming level of the metal halide system is 25%, the metal halide system is fully dimmed when daylight is providing 75% of the target illuminance. At minimum light output the lighting system consumes 56% of rated power.

- Hi/Lo Ballast (Metal Halide). This step ballast control dims all of the lamps to 22% of light output when interior daylight illuminance exceeds 78% of the target illuminance for the space. At 22% of rated light output the lighting system consumes 48% of rated power.

- Dimming Min 10% Light (Fluorescent). This dimming control continuously dims the fluorescent lighting system in proportion to the fraction of the target illuminance provided by daylight. Since the minimum dimming level is 10%, the fluorescent lighting system is fully dimmed when daylight is providing 90% of the target illuminance. At minimum light output the lighting system consumes 19% of rated power.

It should be noted that fluorescent light sources are more amenable to reducing power consumption from dimming than Metal Halide. Fluorescent lamps dimmed to 10% consume about 20% of rated power, whereas Metal Halide lamps dimmed to 25% of light output consume over 40% of power. Later on we will be discussing multi-level control which are defined to consume less than 35% of rated power at minimum light output. Neither Metal Halide dimming control (Hi/Lo Ballast and Dimming Min 25% Light) would qualify since they both use more than 35% of rated power at lowest light output. All other control strategies save simple On/Off control would qualify as multi-level controls.

Savings from each control type were evaluated for retail and warehouse buildings with 1%, 3% and 5% of roof area covered with skylights. We expected there would be an interaction between LPD (and its inferred design illuminance), skylight-to-floor ratio, and the fraction of savings from each control strategy. These results would then help us decide on appropriate Power Adjustment Factors (PAF's) for daylighting controls under skylights.

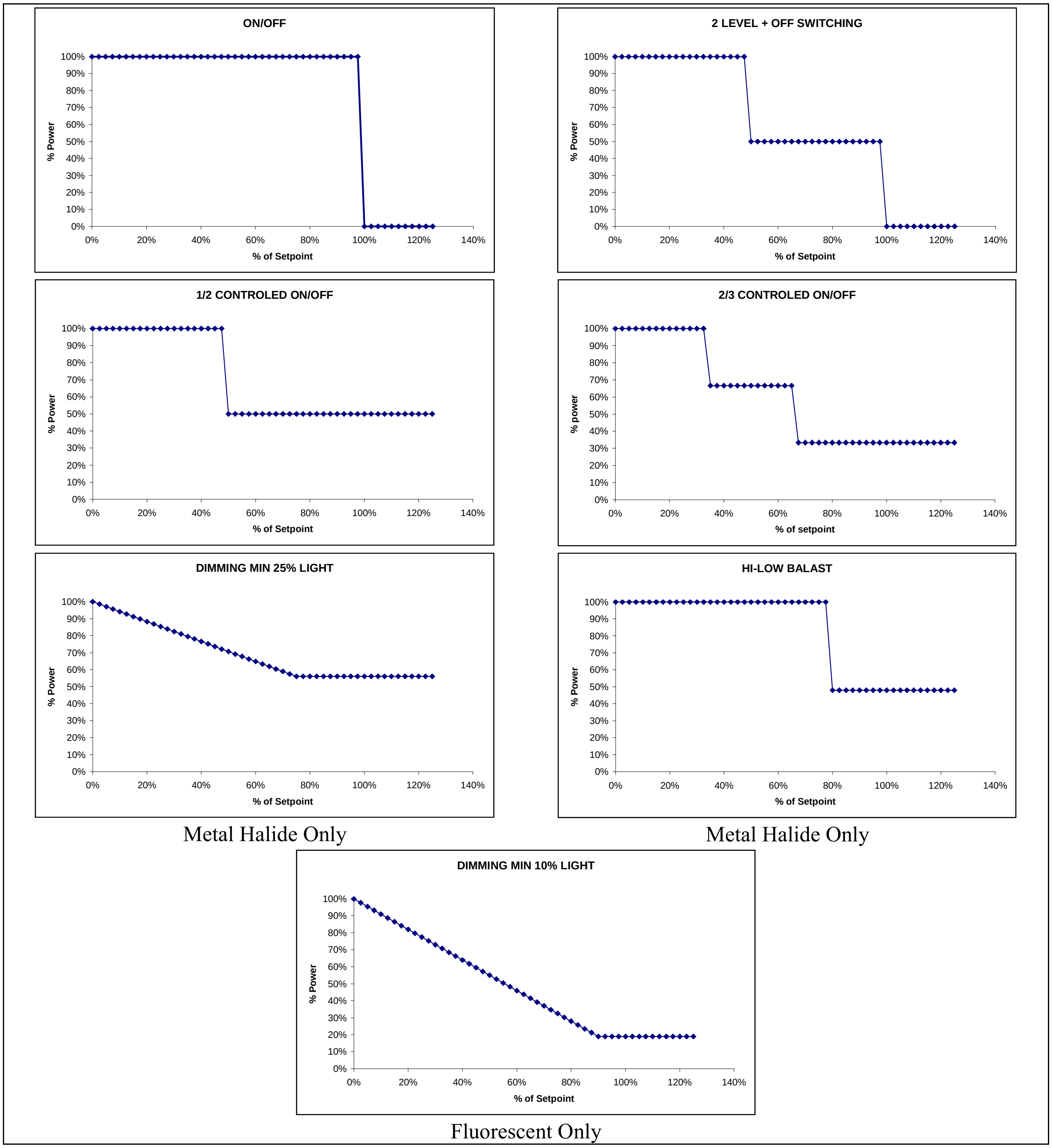


Figure 4: Lighting Power in Response to Photocontrols

Mandatory Automatic Lighting Controls in the Daylit Zone under Skylights

This analysis makes use of the previous analysis for the present value of energy savings from each control type to define the minimum daylit area required to render photocontrols cost-effective. If the results are only slightly different between climate zones, a single threshold value can be used for the minimum area under which photocontrols can be required. If this cost-effectiveness metric is widely varied a climate zone specific minimum area could be adopted. We were expecting that a single value would be appropriate for the entire state.

Prescriptive Requirements for Skylights in Large Low-Rise Nonresidential Buildings

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. This is in marked contrast to the analysis for evaluating the cost-effectiveness for mandatory automatic daylighting controls - where it is assumed that the skylights are already in place and savings estimates need only consider lighting energy. The two major building types under consideration are warehouses and big box retail. The analysis here was performed with the SkyCalc analysis tool with many built 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. An example of a default lighting schedule is given in Figure 3 in the previous section describing the PAF analysis methodology. Our prototypical warehouse had a conditioned area of 50,000 square feet and a 25-foot ceiling height. This warehouse is modeled with 15 foot tall and 8 feet wide shelves that are evenly spaced by 12-foot wide aisles.

The skylights are described as typical medium white acrylic skylights. Two types of skylights are used in the parametric runs – single white and double-glazed (clear over white). The height of the skylight wells is 1ft – this is essentially the depth of the skylight curb and framing. The single glazed skylight has a visible transmittance of 42%, a SHGC of 0.33, and a U-factor of 1.52 Btu/h·°F·sq. ft. 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.

The unit installed costs for 4 foot by 8 foot skylights (the skylight size used for the 3% SFR scenario) including contractor overhead and profit are estimated to be $610 for single glazed and $770 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 per 25,000 SF space or $5,000 for the 50,000 SF warehouse. The costs of the skylights used for the warehouse analysis are shown in Table 2. This analysis assumes that skylights are spaced appropriately to provide acceptable uniformity (i.e. the entire space is within the daylit zone under skylights). Thus all of the skylit buildings have 49 skylights but as the skylight to floor ratio (SFR) increases the skylight area increases as well.

Table 2: Installed Costs of Skylights 49 skylights on a 50,000 SF warehouse

			Single		**Double**	
SFR	Total area	Area/skylight	Cost/skylight	Total Cost	Cost/skylight	Total Cost
0.0%	0	0	$ -	$ -	$ -	$ -
1.0%	500	10	$ 230.33	$ 16,286.00	$ 282.86	$ 18,860.00
2.0%	1000	20	$ 406.78	$ 24,932.00	$ 515.34	$ 30,251.60
3.0%	1500	31	$ 610.16	$ 34,898.00	$ 773.01	$ 42,877.40
4.0%	2000	41	$ 778.53	$ 43,148.00	$ 961.71	$ 52,124.00
5.0%	2500	51	$ 973.16	$ 52,685.00	$ 1,202.14	$ 63,905.00
6.0%	3000	61	$ 1,167.80	$ 62,222.00	$ 1,442.57	$ 75,686.00
8.0%	4000	82	$ 1,557.06	$ 81,296.00	$ 1,923.43	$ 99,248.00
10.0%	5000	102	$ 1,946.33	$ 100,370.00	$ 2,404.29	$ 122,810.00
12.0%	6000	122	$ 2,335.59	$ 119,444.00	$ 2,885.14	$ 146,372.00

Three lighting control strategies were used with each type of skylight. 1) On/Off, 2) Two level plus off switching, and 3) 2/3 controlled on/off. Each of these control strategies is graphed in Figure 4 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 17 footcandles and for a LPD of 1.0 W/SF, a setpoint of 25 fc.

By applying the approved 15 year present valued electricity and gas rates[8] 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.

Retail Analysis

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

- The modeled zone was 25,000 SF
- general lighting had a lighting power density of 1.66 W/SF and used the retail lighting schedule (see Figure 3)
- the luminaire mounting height was 15 feet and the design illuminance was 65 fc,
- the ceiling height was 20 feet
- shelving had a back to back width of 6 feet, a height of 7 feet and was separated by 10 feet wide aisles
- lighting controls considered were fluorescent dimming and 2/3 on/off switching control (see Figure 4)

[8] Eley Associates, March 11, 2002. *Life Cycle Cost Methodology, 2005 California Building Energy Efficiency Standards*, California Energy Commission Contract Number 400-00-061

- 36 skylights are used to calculate the first cost of the skylighting system.

The skylights have to be closer together than in the warehouse model because the ceiling is lower. The costs used for skylights plus $2,500 for the photocontrol system are shown in Table 3.

Table 3: Installed Costs of Skylights 36 Skylights On A 25,000 SF Big Box Retail Store

			Single		**Double**	
SFR	Total area	Area/skylight	Cost/skylight	Total Cost	Cost/skylight	Total Cost
0.0%	0	0	$ -		$ -	
1.0%	250	7	$ 156.75	$ 8,143.00	$ 192.50	$ 9,430.00
2.0%	500	14	$ 276.83	$ 12,466.00	$ 350.72	$ 15,125.80
3.0%	750	21	$ 415.25	$ 17,449.00	$ 526.08	$ 21,438.70
4.0%	1000	28	$ 529.83	$ 21,574.00	$ 654.50	$ 26,062.00
5.0%	1250	35	$ 662.29	$ 26,342.50	$ 818.13	$ 31,952.50
6.0%	1500	42	$ 794.75	$ 31,111.00	$ 981.75	$ 37,843.00
8.0%	2000	56	$ 1,059.67	$ 40,648.00	$ 1,309.00	$ 49,624.00
10.0%	2500	69	$ 1,324.58	$ 50,185.00	$ 1,636.25	$ 61,405.00
12.0%	3000	83	$ 1,589.50	$ 59,722.00	$ 1,963.50	$ 73,186.00

Results and Discussion

Cost-effectiveness calculations are provided for the mandatory automatic daylighting controls requirement and the prescriptive requirements for skylights in low rise nonresidential buildings for enclosed spaces directly below roofs.

Some measures do not directly require a cost-effectiveness analysis. For example, redefining effective aperture does not have a cost-effectiveness calculation. But cost-effectiveness is calculated for the requirements that are based on effective aperture. A similar situation exists for the proposal that places additional requirements on the specification of automatic daylighting controls. The cost-effectiveness of these new requirements have not been evaluated in isolation but the cost of photocontrols that meet the new acceptance requirements are embedded in the cost effectiveness analysis for mandatory automatic daylighting controls and the prescriptive skylighting requirement. Thus the combined measure of the new specification requirements and mandatory photocontrols are cost -effective.

This section also includes a discussion of the rationale for all of the proposed code changes.

Daylit Zone under Skylights

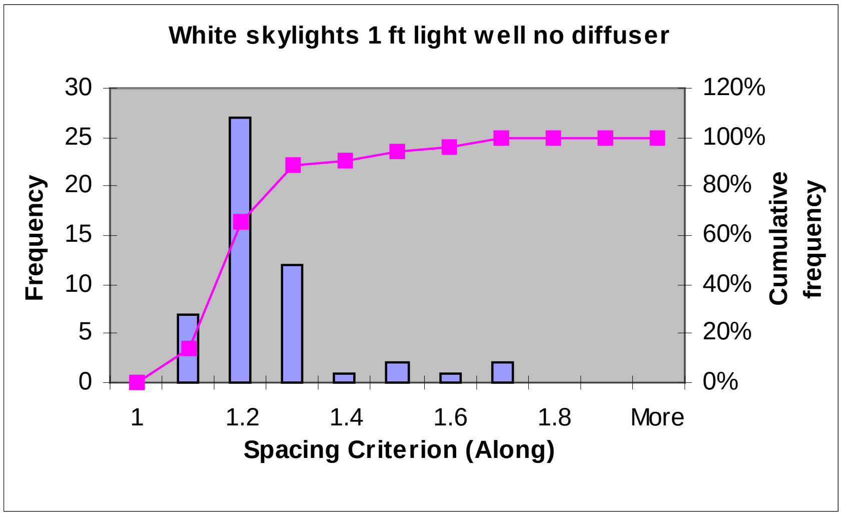
The metric used to characterize the correct definition of the daylit zone under skylights is the spacing criterion. The spacing criterion is readily available for most area lighting luminaires with electric light sources. The spacing criterion is calculated from the luminous intensity distributions that are measured during photometric testing of luminaires. In the past this information has not been available for skylights. However, photometric testing of skylights was performed within the last year for the CEC sponsored Public Interest Energy Research (PIER) program. Since the distribution of light emitted from a skylight changes when the sun position changes, a separate photometric test was performed for each 10 degree increment in solar elevation (angle of sun above the horizon). Thus for each skylight tested, there would be photometric measurements made for when the sun was at 10 degrees, 20 degrees etc. to the maximum solar elevation on the day of the test (all measurements were in the summer or early fall). The data from these tests was compiled into IES LM 63-1995 photometric files and processed into photometric reports that include the spacing criterion. Unlike electric lighting fixtures, a skylight has more than one set of spacing criterions based upon the sun angle. Thus this evaluation of spacing criterion for skylights is based upon the spacing criterion for several skylights over a range of sun angles.

Figure 5: Compound parabolic skylight

The graphs in Figure 6 display the distribution of Spacing Criterion in the direction along the primary axis of the skylight (North-South) and across this axis (East-West) for four foot wide by four foot long white skylights above a minimal one-foot light well. The skylights tested were a single glazed white acrylic dome skylight, a double-glazed clear over white acrylic dome skylight, and a single glazed white PET compound parabolic skylight. The compound parabolic skylight was rotated so that the "ribs" of the skylight were parallel to the major axis in one set of tests and perpendicular in the other set of tests. An example of a compound parabolic skylight shape is shown in Figure 5

Each spacing criterion data point is for one of the four skylight conditions (single glazed white dome, double glazed white dome, and PET compound parabolic white dome in two orientations) and for each 10 degree increment in solar elevation over the course of a clear sky day from sunup to sundown.

The distribution of spacing criterions in Figure 6, clearly indicates that for these typical white diffusing skylights, the spacing criterion most of the time is 1.4 or less. The spacing criterion is a basic indication that for uniform light distribution the luminaires (in this case skylights) should be spaced no further apart than around 1.4 times the mounting height.



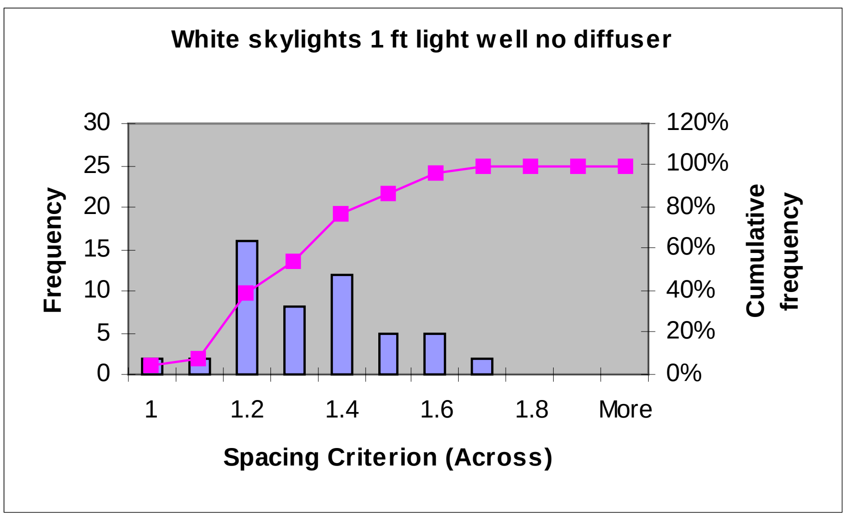
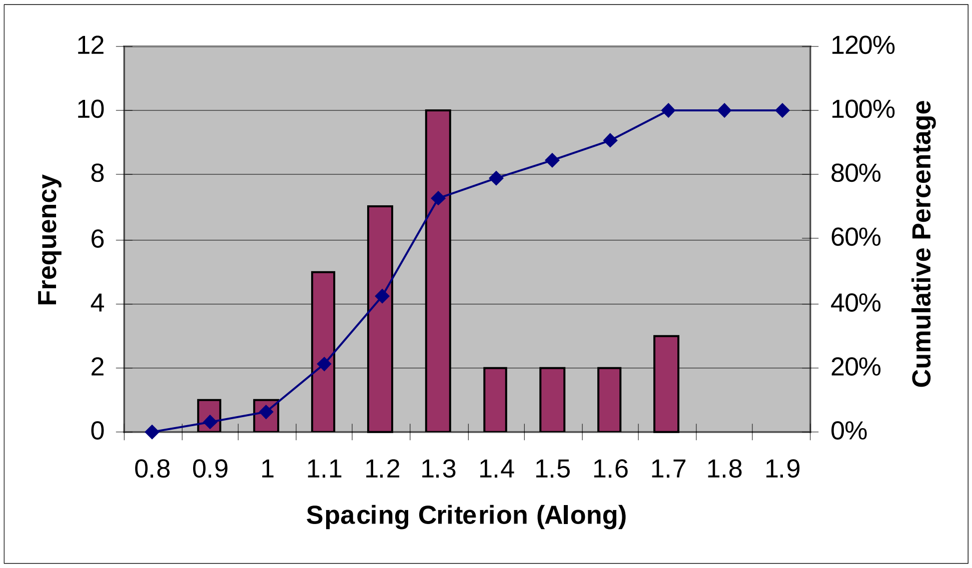


Figure 6: Frequency distribution of spacing criterions for white skylights

A second set of skylight photometric test results was also evaluated for its spacing criterions. This second set of skylights contained skylights having a prismatic diffuser at the bottom of a 3 foot or 6 foot light well. The skylight and well combinations were: a glass skylight with a 6 foot tall light well with white painted walls, a white acrylic dome with a 3 foot tall light well with a specular (metallic foil) surface and a white acrylic dome with a 6 foot tall light well with a specular (metallic foil) surface.

The graphs in Figure 7 plot the frequency distribution of spacing criterions in the across and along directions for skylight configurations that have a flat bottom diffuser. These results are similar to Figure 6, in that most of the time the spacing criterions for skylights with bottom diffusers are equal to or less than 1.4.

Thus the area that can be controlled together as a "daylit zone" under skylights should be based on this definition. If we modify the existing definition of daylit zone as the skylight “footprint” plus additional distance in each longitudinal and lateral dimension – that additional distance would be one half of the spacing criterion or 70% of the floor to ceiling height. The "spread angle" that describes how the skylit area increases with ceiling height is the arctangent of 0.7 or 35 degrees.



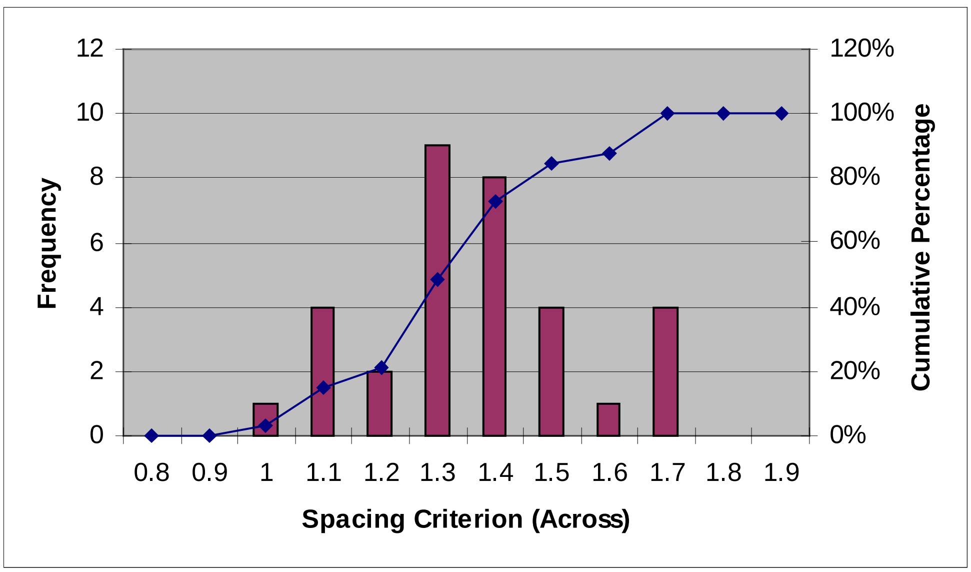


Figure 7: Frequency distribution of spacing criterions for skylights with diffuser at bottom of light well

Definitions of Effective Aperture and Well Efficiency

The current standards contain a series of inaccuracies in the definitions and calculations for skylights in Section 101 "Definitions and Rules of Construction." The offending passages are quoted below:

> **Existing definition: EFFECTIVE APERTURE** (EA) is (1) for windows, the visible light transmittance (VLT) times the window wall ratio; and (2) for skylights, the well index times the VLT times the skylight area times 0.85 divided by the gross exterior roof area.
>
> **Existing definition: SKYLIGHT AREA** is the area of the surface of a skylight, plus the area of the frame, sash, and mullions.
>
> **Existing definition: WELL INDEX** is the ratio of the amount of visible light leaving a skylight well to the amount of visible light entering the skylight well and is calculated as follows: ….(equations given in Recommendations section).

The equation for effective aperture would be correct if the skylight area was defined in terms of the rough opening of the skylight and the term "well index" was replaced with "well efficiency".

The equation for well index is correct in the current standard but its definition as written is incorrect. "The ratio of the amount of visible light leaving a skylight well to the amount of visible light entering the skylight well" is the correct definition of *well efficiency* not *well index*. The well index is an intermediary term used to calculate the well efficiency. The well index was discontinued upon issuance of the 1993 IESNA(Illuminating Engineering Society of North America) Handbook[9]. Well index was replaced by the newer term "well cavity ratio" (WCR).

The ninth edition of the IESNA Handbook contains the basic Lumen Method equation for calculating indoor illuminances under skylights from exterior illumination as follows:[10]

$$E_i = E_{xh}\,\tau\,CU\,\frac{A_S}{A_W}$$

where,

E_{xh} = exterior horizontal illumination, lux (or foot-candles)

τ = net transmittance of skylight and light well, including losses from solar control devices and maintenance factors

CU = coefficient of utilization, ratio of luminous flux received on the work plane to the total luminous flux emitted from the bottom of the skylight well.

A_S = gross projected horizontal area of all of the skylights, m^2 (or ft^2)

A_W = area of the workplane, m^2 (or ft^2)

9 Note there are many errors in the daylighting chapter of the 8th edition of the IESNA Handbook (including the definition of the well cavity ratio); these errors were fixed in the Ninth edition of the IESNA Handbook. Thus if the IESNA Handbook is referenced be sure to reference the Ninth Edition.

10 Equation 8-28, IESNA Handbook, Ninth ed. 2000, p. 8-11.

The net transmittance (τ) is the product of the glazing transmittance, the fraction of skylight area that is glazed, the light well efficiency and losses due to dirt factors or blinds in the light well. The gross projected horizontal area of all of the skylights (,A_S), is the same as saying the plan area of the skylight, which is essentially the rough opening area of the skylight.

If 1) the skylight area is the rough opening area of the skylight and 2) the effective aperture definition uses well efficiency instead of well index and 3) the 0.85 term is the dirt depreciation factor, the lumen method equation can be rewritten:

$$E_i = E_{xh}\ CU \left[\tau\ \frac{A_S}{A_W} \right] = E_{xh}\ CU\ [EA]$$

From the discussion above, skylight performance will be more accurately described if the rough opening area is used for the proxy for the gross horizontal projection of skylight area.

Changing the skylight area definition will also have the added benefit of creating consistency in the units used to define skylight thermal performance. The default U-factor for single glazed skylights in the standard is 1.72; this is substantially higher than the default U-factor of 1.28 for single glazed windows. [11] The reason for this difference in U-factor is explained in the Fenestration chapter in the ASHRAE Handbook of Fundamentals. "Note that garden window and skylight U-factors are approximately twice those of other products. While this difference is partially due to the differences in slope in the skylights, it is largely because these products project from the surface of the wall or roof. For instance, the skylight surface area, which includes the curb, can vary from 13 to 240% greater than the rough opening area, depending on the size and mounting method."[12] The default U-factor tables in the 2001 Building Energy Standards are very similar to ASHRAE's default tables, which are based upon heat transfer per unit area of rough opening. Thus to be consistent with the methods used to define U-factors and to predict light transmittance, the definition of skylight area of a skylight should be the rough opening of the skylight.

While updating the skylighting definitions, we proposed to use the current IESNA nomenclature for describing light well geometry. The old term for describing the ratios of height length and width of light wells was the well index – the current Title 24 Standards are still using this obsolete term. This is very similar to the room cavity ratio concept used by the lighting community in lumen method calculations except that for the same geometry the well index was formulated to be 10 times lower than the room cavity ratio. The use of the well index was discontinued by the Illuminating Engineering Society of North America (IESNA) by 1993 and was replaced with the well cavity ratio (WCR). The well cavity ratio uses the same equations as the room cavity ratio (RCR) – a formula frequently used by lighting designers. Thus the well cavity ratio equation is the same as the well index equation multiplied by a factor of 10. As applied to the same light well with the same geometry and surface reflectances, the newer well efficiency nomograph as a function of well cavity ratio yields the same results as the older well efficiency nomograph with respect to well index. The only difference between the proposed and older nomographs is the intermediary value used to look up well efficiency; the proposed nomograph uses the well cavity ratio which is 10 times greater than the obsolete well index term used in the older nomograph. Thus the same well efficiency will result from both calculations. Nevertheless we propose that the Standards make use of the updated terminology and calculation procedures that are currently used by the lighting industry.

Requirements for Automatic Daylighting Controls

The purpose of this part of the proposal is to assure that photocontrol systems are adequately commissioned initially and that they are easy to re-commission in response to changes in the use of a space or changes to the lighting system being controlled. Photocontrols without correct commissioning save significantly less energy than those

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[11] 2001 Building Standards Section 116 Table 1D "*Default Fenestration Product U-Factors*"

[12] p 29.6. 1997 ASHRAE Fundamentals Handbook

calibrated correctly and may be disabled by unsatisfied building occupants, eliminating all energy savings potential. The additional requirements for automatic daylighting controls in this proposal were added to address each of the following issues.

First, from discussions with people who commission photocontrols, photocontrols with the adjustment knobs mounted on the light sensor were hard to commission for the following reasons:

- The photosensor is often mounted up high – attached to the ceiling or up in a skylight well. This makes it hard to access initially and even harder to access later on when furniture or machinery blocks easy access to the ceiling. In many of the skylit zones discussed in this code change proposal, ceiling heights are 20 feet or more.

- The body of the commissioning agent is shielding the photosensor. What might be a correct adjustment while the commissioning agent is on the ladder in front of the sensor is an incorrect adjustment once that agent is on the ground.

Second, because the adjustments to the photocontrol system may be remote from the lights being controlled, an indicator for the status of the lights is needed so the system can be easily commissioned.

Third, as part of commissioning the system one needs to obtain immediate feedback on how an adjustment to the control settings affects the operation of the lighting controls. Thus the time delay must have a capability to be overridden or set to a very small value (such as 5 seconds or less).

Fourth, since commissioning of open loop switching systems will likely occur under daylight illuminance conditions that are not at the threshold of a control step, one must have a way of adjusting the setpoint relative to what is being sensed at the time of commissioning. To accomplish this, one needs two conditions. 1) a fairly linear[13] response from the photosensor and 2) a setpoint control that has enough gradations to identify with sufficient accuracy the illuminance setpoint that causes a change of control state (lights on or lights off) during commissioning and allows sufficient accuracy to specify a desired setpoint relative to the illuminance at time of commissioning.

The focus for of these requirements are for "open loop" controls that are commonly used with skylighting systems. Additional requirements for "closed loop" lighting control systems, such as those used for sidelighting from windows ware not addressed in this report.[14]

Revised Power Adjustment Factors

Savings from photocontrols did not change substantially between climate zones. All climate zones have lots of light in the middle of the day and declining amounts in the early morning and late afternoons. Sizing of skylights with regard to climate is related to trade-offs between lighting savings and thermal gains and losses through the skylights. The results specific to climate zones 2, 3, 7, 10 and 12 are contained in Table 13 and Table 14 in the Appendix of this report. Since the climate zones had little impact on the results, we ran more sizing parametrics on just climate zone 3 (Bay Area). Table 4 contains the summary results of the TDV energy savings from different control strategies. The results are given in terms of the SFR (skylight to floor ratio) and effective aperture.

As described in Section 101 of the Standards the effective aperture is, "for skylights the well index times the VLT times the skylight area times 0.85 divided by the gross exterior roof area". This is incorrect in the Standards, but is

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[13] Linear here means that illuminance sensed is directly proportional to the output signal from the sensor. If 50 fc sensed by the photosensor results in a 1 Volt signal, then 100 fc sensed should result in a 2 Volt signal.

[14] Open loop refers to lighting controls that do not receive any control signal from the lighting they are controlling. An example of an open loop control is a photocontrol where the sensor faces up in the light well and "sees" only light from the skylight. In contrast a closed loop control receives feedback from the lighting system controlled. An example of a closed loop control is a photocontrol where the light sensor is mounted on the ceiling facing down – it receives reflected light from both the daylighting source and the electric lighting system.

correctly calculated in the Nonresidential manual. The correct equation for effective aperture is the well efficiency (calculated from well index and well reflectance) times VLT times skylight area times 0.85 (dirt factor) divided by the gross exterior roof area.

The results are for sample runs of medium white skylights which had a visible light transmittance (VLT) of 0.42, a one foot deep light well with a well efficiency of 87%, and a dirt factor of 0.85. Thus in this case the effective aperture is 0.31 times the skylight to floor ratio (SFR).

Table 4: Fraction of TDV Energy Savings from Photocontrols in Climate Zone 3.

		Warehouse LPD = 0.7										
Climate zone 3		Fluorescent setpoint = 20 fc					Metal Halide setpoint = 13 fc					
SFR	Effective Aperture	On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 10% light	On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 25% light	hi/lo ballast
1.9%	0.6%	24%	37%	25%	31%	41%	39%	47%	28%	37%	28%	23%
2.6%	0.8%	36%	47%	29%	37%	47%	49%	56%	31%	41%	30%	28%
3.2%	1.0%	44%	53%	31%	40%	51%	54%	60%	33%	44%	31%	30%
3.9%	1.2%	50%	58%	33%	42%	53%	59%	64%	34%	46%	32%	32%
4.5%	1.4%	54%	61%	34%	44%	55%	62%	66%	35%	47%	33%	34%
5.2%	1.6%	57%	63%	35%	46%	57%	64%	68%	36%	48%	33%	35%
5.8%	1.8%	60%	65%	35%	47%	58%	66%	70%	37%	49%	34%	36%
6.4%	2.0%	62%	67%	36%	48%	59%	68%	71%	37%	50%	34%	36%
7.1%	2.2%	65%	70%	37%	49%	60%	69%	72%	38%	51%	35%	38%
7.7%	2.4%	65%	70%	37%	49%	60%	70%	73%	38%	51%	35%	38%
		Retail LPD = 1.6										
Climate zone 3		Fluorescent setpoint = 65 fc					Metal Halide setpoint = 40 fc					
SFR	Effective Aperture	On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 10% light	On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 25% light	hi/lo ballast
1.9%	0.6%	0%	5%	5%	9%	18%	2%	17%	16%	21%	18%	7%
2.6%	0.8%	0%	12%	12%	17%	24%	17%	29%	20%	26%	21%	13%
3.2%	1.0%	3%	17%	15%	22%	30%	25%	36%	23%	30%	23%	17%
3.9%	1.2%	12%	24%	18%	25%	34%	31%	41%	25%	33%	24%	20%
4.5%	1.4%	19%	30%	21%	28%	37%	37%	45%	26%	35%	25%	22%
5.2%	1.6%	24%	35%	22%	30%	39%	41%	48%	28%	36%	26%	24%
5.8%	1.8%	29%	38%	24%	32%	41%	44%	50%	28%	37%	27%	25%
6.4%	2.0%	32%	41%	25%	34%	43%	46%	52%	29%	38%	27%	26%
7.1%	2.2%	35%	43%	26%	35%	44%	48%	54%	30%	39%	28%	27%
7.7%	2.4%	38%	45%	26%	36%	45%	50%	55%	30%	40%	28%	28%

Several conclusions can be drawn from these results:

- Power Adjustment Factors do not need to be climate specific (see Table 13 and Table 14 in the Appendix).
- Lighting savings is negligible for retail areas with skylight to floor ratios (SFR) less than 1%.
- For a given skylight to floor ratio, percentage savings (not energy savings) are greater for spaces with low LPD's (under 1 W/SF) as compared to spaces with higher LPD's.
- Metal halide dimming saves comparable amounts or less than switching control strategies. Metal halide dimming as modeled here, which draws 56% of rated power at minimum light level, would not qualify as a "multi-level control" which consumes less than 35% of power at minimum light output.
- Fluorescent dimming saves more than switching when the design illuminance is high and the skylight to floor ratio is low.

- Two level switching saves substantially more energy than on/off switching when the skylight to floor ratio is low.

The proposal was originally in the format of a lookup table with respect to LPD and effective aperture of the space. However given the range a results that depends upon these variables one has the trade-off of an overly complex table and accuracy. This initial table, shown in Table 5 below kept the number of cells to a minimum. However, it was felt that this format created excessive discontinuities between less than 1 W/SF and those above 1 W/SF. The values for less than 1 W/SF were based upon the warehouse calculations with a 0.7W/SF LPD. The values for greater than 1 W/SF were based upon the big box retail calculations with a 1.6 W/SF LPD.

Table 5: Initial proposed PAF's for Automatic Multi-level Daylighting Controls with skylights

Effective Aperture	LPD	
	< 1W/SF	> 1W/SF
0.6% < EA ≤ 1.0%	19%	7%
1% < EA ≤ 1.5%	25%	13%
1.5% < EA	28%	18%

The proposed solution to this dilemma was to write a continuous equation that had several simple coefficients so it would be easy to apply and would not have any discontinuities. Thus the following simple linear equation gives a reasonably close approximation of the Power Adjustment Factors (PAF's) for skylighting controls.

$$\text{PAF} = 10 \times \text{Effective Aperture} - \frac{\text{Lighting Power Density}}{10} + 0.2$$

The graph in Figure 8 compares the results that were in Table 5 for LPD's of 0.7 and 1.6 W/SF with the calculated values from the previously mentioned PAF equation. As can be readily seen, the results of the equations match well the values in the lookup table without the table's corresponding discontinuities.

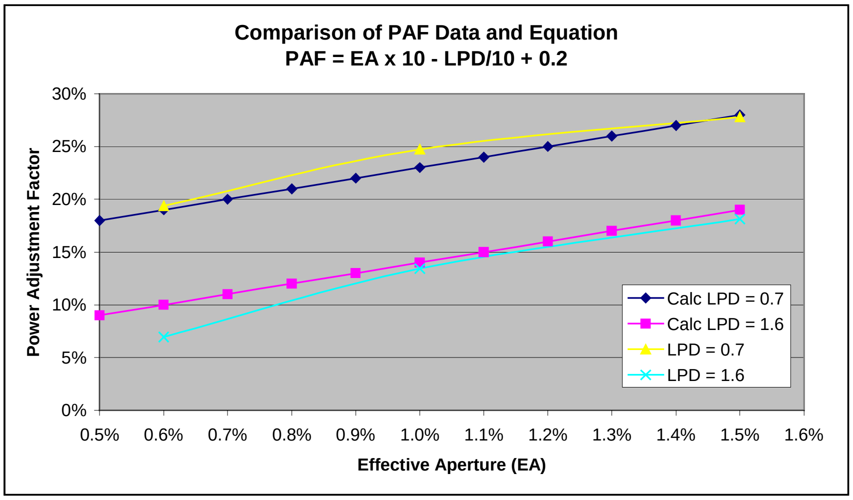

Figure 8: Comparison of results from PAF calculation and tabular data

Mandatory Automatic Lighting Controls in the Daylit Zone under Skylights

The analysis is this section considers the minimum daylit area needed on a single photocontrol before the photocontrol is cost-effective. The cost-effective area is a function of both the lighting power density of the daylit zone and the effective aperture of the skylighting system. As described in the Measure Availability and Cost section, the incremental cost of photocontrols is approximately $2,000 for a multi-level daylighting control. Because a lighting control panel is already needed to satisfy the automatic shut-off requirement (Section 131d), the cost of the photocontrol is essentially independent of lighting area controlled.

Following on the analysis of the power adjustment factors the energy savings from photocontrols was converted to present valued dollar savings. This analysis was performed using two methods: 1) total energy savings multiplied by the 15 year discounted electricity rates recommended for the 2005 Standards cost-effectiveness analysis[15]; and 2) hourly energy savings multiplied by the (time dependent valuation) TDV energy factors to yield a present valued savings. As can be seen in Table 15 and Table 16 in the appendix, the variation in savings between climate zones was negligible. Further parametric analysis by effective aperture for climate zone 3 only is given here in Table 6 using fixed rates for electricity and in Table 7 using the time varying costs of electricity contained in the TDV method. The results from both tables are very close to each other. It should be noted that the savings are in terms of present valued dollar savings (15 year period of analysis with a 3% real discount rate) per square foot of daylit area beneath the skylights.

[15] $1.37/kWh 15 year discounted value for electricity. From Eley Associates, March 11, 2002. *Life Cycle Cost Methodology, 2005 California Building Energy Efficiency Standards*

Table 6: Fixed Rate LCC Cost Savings per Square Foot of Daylit Area from Photocontrols

		Warehouse LPD = 0.7										
Climate zone 3		Fluorescent setpoint = 20 fc					Metal Halide setpoint = 13 fc					
SFR	Effective Aperture	On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 10% light	On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 25% light	hi/lo ballast
1.9%	0.6%	$0.77	$1.25	$0.87	$1.08	$1.45	$1.31	$1.63	$0.97	$1.32	$0.99	$0.79
2.6%	0.8%	$1.23	$1.63	$1.01	$1.31	$1.68	$1.69	$1.96	$1.12	$1.48	$1.08	$0.97
3.2%	1.0%	$1.53	$1.88	$1.11	$1.42	$1.82	$1.91	$2.13	$1.18	$1.58	$1.13	$1.07
3.9%	1.2%	$1.74	$2.04	$1.17	$1.52	$1.92	$2.09	$2.28	$1.23	$1.65	$1.17	$1.15
4.5%	1.4%	$1.90	$2.17	$1.22	$1.59	$2.00	$2.22	$2.39	$1.28	$1.72	$1.20	$1.21
5.2%	1.6%	$2.02	$2.26	$1.25	$1.65	$2.06	$2.31	$2.47	$1.32	$1.75	$1.22	$1.25
5.8%	1.8%	$2.13	$2.35	$1.28	$1.69	$2.11	$2.38	$2.54	$1.35	$1.79	$1.24	$1.28
6.4%	2.0%	$2.22	$2.43	$1.32	$1.73	$2.15	$2.44	$2.59	$1.37	$1.83	$1.26	$1.31
7.1%	2.2%	$2.29	$2.53	$1.36	$1.76	$2.19	$2.50	$2.64	$1.39	$1.85	$1.27	$1.34
7.7%	2.4%	$2.34	$2.53	$1.36	$1.78	$2.21	$2.54	$2.68	$1.40	$1.87	$1.28	$1.37
		Retail LPD = 1.6										
Climate zone 3		Fluorescent setpoint = 65 fc					Metal Halide setpoint = 40 fc					
SFR	Effective Aperture	On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 10% light	On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 25% light	hi/lo ballast
1.9%	0.6%	$0.00	$0.48	$0.48	$0.88	$1.70	$0.17	$1.56	$1.48	$1.95	$1.70	$0.64
2.6%	0.8%	$0.00	$1.08	$1.08	$1.61	$2.33	$1.54	$2.74	$1.97	$2.53	$2.03	$1.24
3.2%	1.0%	$0.23	$1.57	$1.45	$2.09	$2.86	$2.35	$3.41	$2.24	$2.94	$2.23	$1.60
3.9%	1.2%	$1.10	$2.30	$1.75	$2.42	$3.26	$2.96	$3.91	$2.43	$3.22	$2.37	$1.93
4.5%	1.4%	$1.74	$2.88	$2.01	$2.71	$3.58	$3.50	$4.35	$2.60	$3.43	$2.49	$2.17
5.2%	1.6%	$2.22	$3.29	$2.18	$2.98	$3.82	$3.91	$4.69	$2.73	$3.56	$2.57	$2.33
5.8%	1.8%	$2.67	$3.63	$2.29	$3.17	$4.03	$4.25	$4.94	$2.82	$3.70	$2.64	$2.45
6.4%	2.0%	$3.01	$3.92	$2.42	$3.30	$4.20	$4.48	$5.13	$2.89	$3.81	$2.70	$2.58
7.1%	2.2%	$3.32	$4.17	$2.51	$3.43	$4.35	$4.67	$5.29	$2.95	$3.92	$2.75	$2.68
7.7%	2.4%	$3.66	$4.44	$2.60	$3.51	$4.46	$4.87	$5.44	$3.00	$4.00	$2.79	$2.79

Table 7: TDV Cost Savings per Square Foot of Daylit Area from Photocontrols

		Warehouse LPD = 0.7										
Climate zone 3		Fluorescent setpoint = 20 fc					Metal Halide setpoint = 13 fc					
SFR	Effective Aperture	On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 10% light	On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 25% light	hi/lo ballast
1.9%	0.6%	$ 0.90	$ 1.40	$ 0.95	$ 1.19	$ 1.57	$ 1.47	$ 1.79	$ 1.05	$ 1.42	$ 1.05	$ 0.88
2.6%	0.8%	$ 1.39	$ 1.79	$ 1.10	$ 1.41	$ 1.80	$ 1.86	$ 2.12	$ 1.19	$ 1.58	$ 1.13	$ 1.05
3.2%	1.0%	$ 1.69	$ 2.03	$ 1.19	$ 1.53	$ 1.93	$ 2.07	$ 2.29	$ 1.25	$ 1.68	$ 1.18	$ 1.16
3.9%	1.2%	$ 1.90	$ 2.19	$ 1.24	$ 1.61	$ 2.03	$ 2.24	$ 2.42	$ 1.30	$ 1.74	$ 1.22	$ 1.23
4.5%	1.4%	$ 2.06	$ 2.32	$ 1.29	$ 1.68	$ 2.11	$ 2.37	$ 2.53	$ 1.34	$ 1.80	$ 1.25	$ 1.28
5.2%	1.6%	$ 2.18	$ 2.41	$ 1.32	$ 1.73	$ 2.16	$ 2.45	$ 2.60	$ 1.38	$ 1.83	$ 1.27	$ 1.32
5.8%	1.8%	$ 2.28	$ 2.49	$ 1.35	$ 1.78	$ 2.21	$ 2.52	$ 2.67	$ 1.41	$ 1.87	$ 1.29	$ 1.35
6.4%	2.0%	$ 2.37	$ 2.56	$ 1.38	$ 1.81	$ 2.24	$ 2.58	$ 2.72	$ 1.43	$ 1.90	$ 1.30	$ 1.38
7.1%	2.2%	$ 2.49	$ 2.66	$ 1.42	$ 1.86	$ 2.28	$ 2.63	$ 2.76	$ 1.44	$ 1.92	$ 1.31	$ 1.43
7.7%	2.4%	$ 2.49	$ 2.66	$ 1.42	$ 1.86	$ 2.30	$ 2.67	$ 2.79	$ 1.46	$ 1.94	$ 1.32	$ 1.43
		Retail LPD = 1.6										
Climate zone 3		Fluorescent setpoint = 65 fc					Metal Halide setpoint = 40 fc					
SFR	Effective Aperture	On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 10% light	On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 25% light	hi/lo ballast
1.9%	0.6%	$ -	$ 0.56	$ 0.56	$ 1.00	$ 1.86	$ 0.19	$ 1.75	$ 1.66	$ 2.17	$ 1.85	$ 0.75
2.6%	0.8%	$ -	$ 1.24	$ 1.24	$ 1.79	$ 2.55	$ 1.79	$ 3.05	$ 2.16	$ 2.78	$ 2.19	$ 1.42
3.2%	1.0%	$ 0.28	$ 1.77	$ 1.63	$ 2.33	$ 3.13	$ 2.69	$ 3.78	$ 2.44	$ 3.18	$ 2.39	$ 1.79
3.9%	1.2%	$ 1.27	$ 2.57	$ 1.93	$ 2.67	$ 3.54	$ 3.32	$ 4.28	$ 2.62	$ 3.47	$ 2.54	$ 2.12
4.5%	1.4%	$ 2.03	$ 3.21	$ 2.19	$ 2.96	$ 3.88	$ 3.86	$ 4.72	$ 2.78	$ 3.68	$ 2.65	$ 2.37
5.2%	1.6%	$ 2.56	$ 3.66	$ 2.38	$ 3.22	$ 4.12	$ 4.29	$ 5.06	$ 2.91	$ 3.82	$ 2.73	$ 2.53
5.8%	1.8%	$ 3.03	$ 4.01	$ 2.49	$ 3.42	$ 4.33	$ 4.64	$ 5.32	$ 3.00	$ 3.95	$ 2.80	$ 2.66
6.4%	2.0%	$ 3.37	$ 4.30	$ 2.61	$ 3.56	$ 4.50	$ 4.88	$ 5.52	$ 3.08	$ 4.06	$ 2.86	$ 2.78
7.1%	2.2%	$ 3.69	$ 4.55	$ 2.71	$ 3.68	$ 4.65	$ 5.07	$ 5.67	$ 3.14	$ 4.17	$ 2.91	$ 2.87
7.7%	2.4%	$ 4.02	$ 4.80	$ 2.79	$ 3.77	$ 4.76	$ 5.26	$ 5.82	$ 3.19	$ 4.24	$ 2.95	$ 2.98

If we use the same 1% effective aperture (EA) metric that was required in Section 131 for requiring separate daylit zone switching controls, we can see that in all but one case, this type of control saves at least $1.00/SF. The one outlier is On/Off control when the design illuminance is 65 fc (retail, fluorescent lighting). This outlier is important and must be addressed in how the requirements for controls are structured. It would suggest that when automatic daylighting controls are required that they should be the multi-level type of control. Given the cost savings are greater than $1.00/SF for all types of multi-level photocontrols when the effective aperture is over 1% and the incremental cost of a photocontrol system is $2,000, automatic photocontrols are cost-effective whenever the daylit area is over 2,000 square feet.

From reviewing these results the following observations can be made:

- Turning off 2/3s of the lamps (100%, 67%, and 33% steps are available) outperforms metal halide dimming under all circumstances shown here.
- Turning off 2/3s of the lamps yields a significant benefit over controlling half of the lights with an on/off control.
- Two level plus off switching is comparable to fluorescent dimming at higher SFR's when the design illuminance is low (i.e. when there is full daylighting for most of the daylit hours).
- At moderate skylight to floor ratios On/Off control performs worse than most other strategies.

From the above, the following conclusions can be drawn.

- Multi-level controls save more energy than a control that turns off all the lights in one step. These controls have the added advantage of being less obtrusive in that the light level jumps less per control step.
- Significant savings result from shifting minimum power draw from one half of rated power to one third of rated power.
- Energy savings from multi-level switching controls that turn completely off are comparable to dimming controls at moderate to high skylight to floor ratios.

Prescriptive Requirements for Skylights in Large Low-Rise Nonresidential Buildings

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. Runs were performed for 6 cases:

1. A big box retail store with a heating and air conditioning system, 1.66 W/SF of general lighting, 1W/SF display lighting (not controlled) and a design illuminance of 65 fc.
2. A warehouse with a heating and air conditioning system, 1.0 W/SF of general lighting and a design illuminance of 25 fc.
3. A warehouse with a heating only system (no air conditioning), 1.0 W/SF of general lighting and a design illuminance of 25 fc.
4. A warehouse with a heating and air conditioning system, 0.7 W/SF of general lighting and a design illuminance of 17 fc.

5. A warehouse with a heating only system (no air conditioning), 0.7 W/SF of general lighting and a design illuminance of 17 fc.

6. An unconditioned warehouse (no heating or cooling), 0.7 W/SF of general lighting and a design illuminance of 17 fc.

This analysis is designed to define the conditions under which adding skylights and automatic daylighting controls provide cost-effective energy savings. The variables in this analysis are:

- Climate zones 1, 3, 7, 12, 14, and 16
- the skylight to floor ratio (SFR)
- number of glazings - single versus double
- the lighting power density (LPD) from 0.7 to 1.66
- the lighting control algorithms

The results for the first two cases (retail and warehouse with 0.7 W/SF LPD and air conditioning) are given in this section. The remainders of the results are contained in the Appendix of this report.

Cost Savings Figures

The cost savings for single glazed and double glazed skylights from a high LPD (retail) to a low LPD (warehouse) are shown in Figure 9 to Figure 14. There are some key patterns that can be discerned here:

- The skylight area producing maximum savings is greater in a building with a high lighting power density than one with a low LPD. (Compare Figure 10 with Figure 12.)
- Double glazing produces more savings in most climate zones except climate zone 7. Because the climate is so mild in climate zone 7, the added layer of glazing produces little savings due to heat loss or gain while the extra layer of glazing reduces the visible transmittance of the skylight.

Whether increasing the number of skylight glazings from single to double glazing is cost-effective will be evaluated in the next section in the Benefit/Cost Tables.

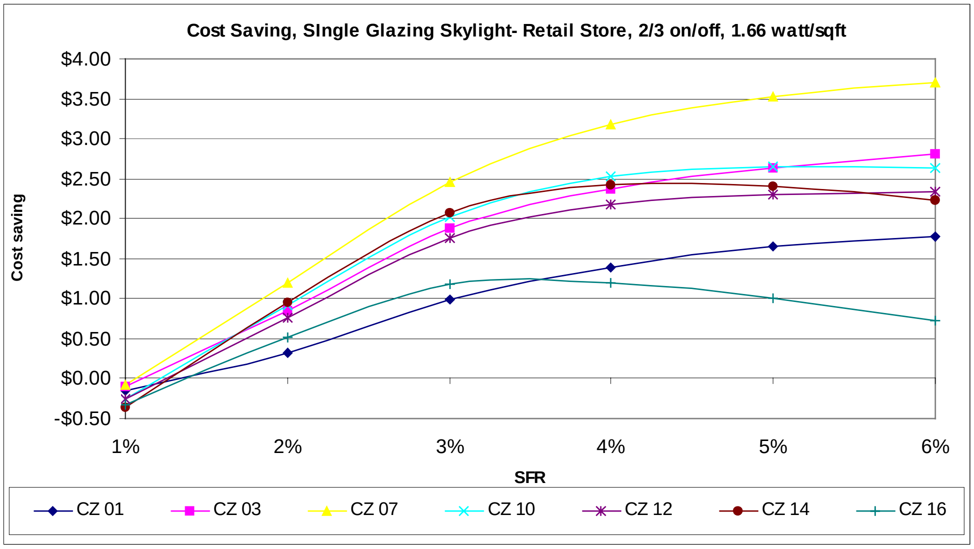

Figure 9: Big Box Retail Cost Savings ($/SF) – Single Glazed Skylights

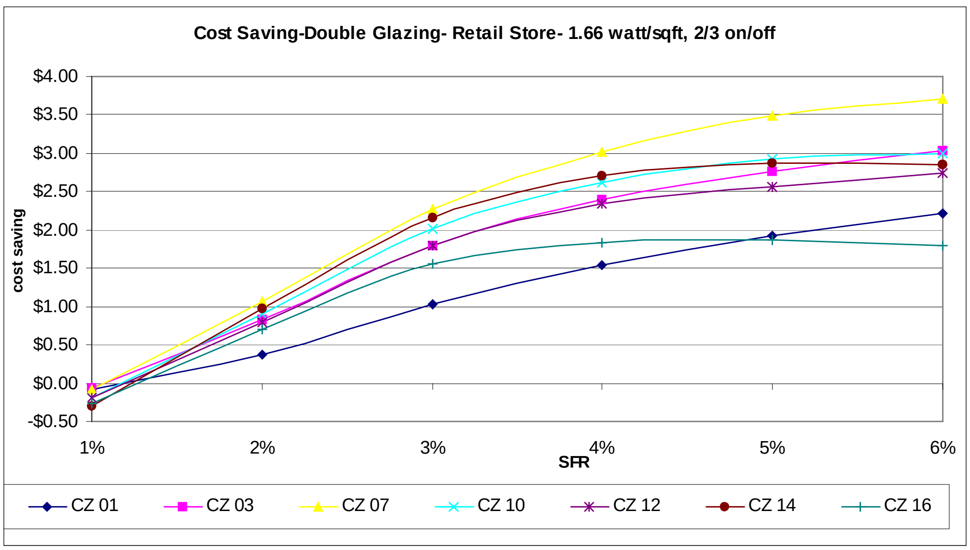

Figure 10: Big Box Retail Cost Savings ($/SF) – Double Glazed Skylights

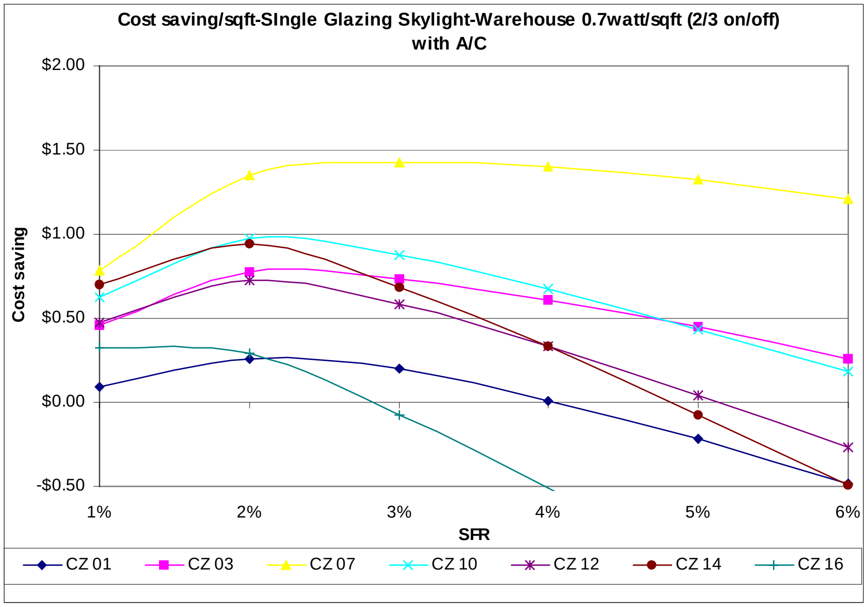

Figure 11: Warehouse 0.7 LPD Energy Cost Savings ($/SF) – Single Glazed Skylights

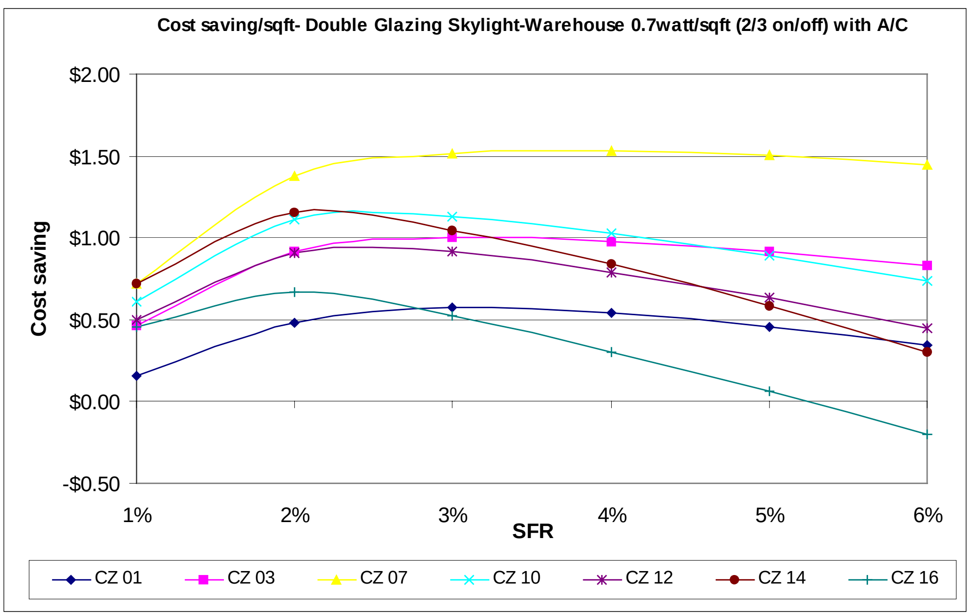

Figure 12: Warehouse 0.7 LPD Energy Cost Savings ($/SF) – Double Glazed Skylights

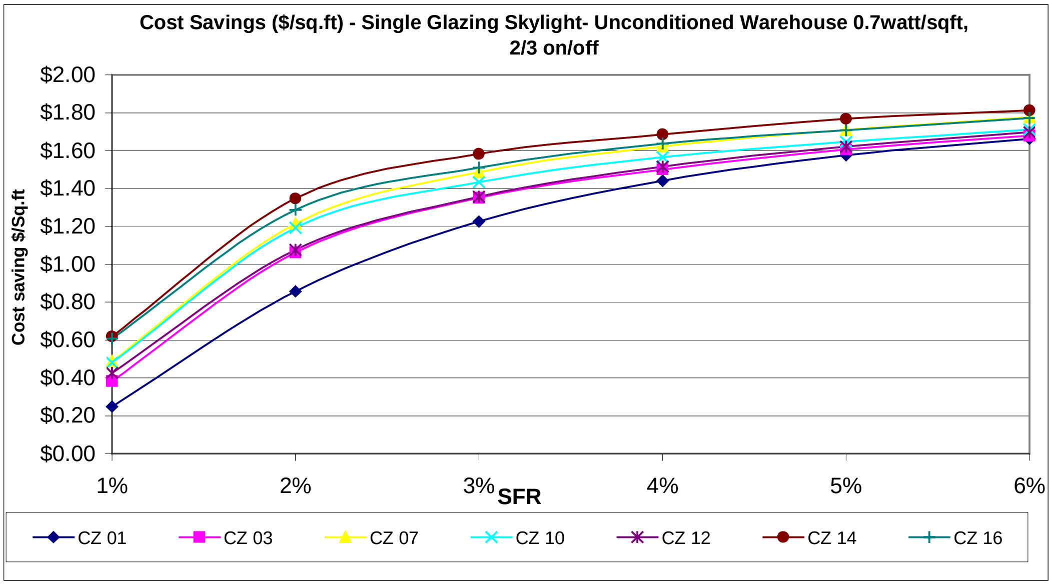

Figure 13: Warehouse, Unconditioned 0.7 LPD Energy Cost Savings ($/SF) – Single Glazed Skylights

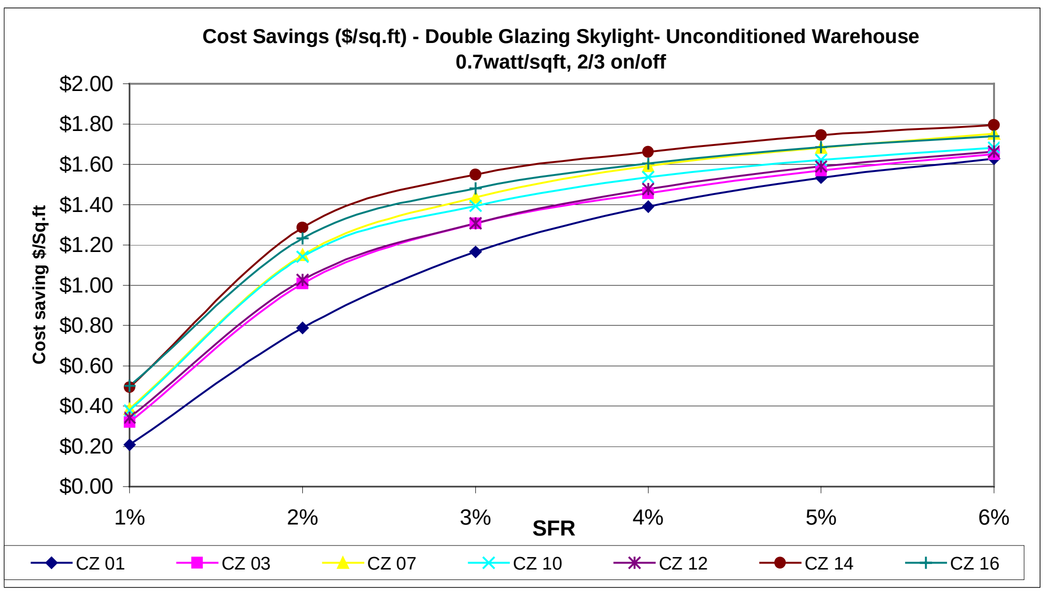

Figure 14: Warehouse, Unconditioned 0.7 LPD Energy Cost Savings ($/SF) – Double Glazed Skylights

Benefit/Cost Tables

Table 8 has the benefit/cost ratios for big box retail stores in climate zones 1, 3, 7, 12, 14, and 16 for different skylight areas described in terms of a skylight to floor area ratio. The retail store is 25,000 SF, thus each percent of SFR represents 250 SF of skylight area. The tables are split into three major columns: Single Glazing options, Double Glazing Options and B/C Ratio of going from Single to Double Glazed. The first two major headings describe the benefit/cost ratio relative to no skylights or controls, the third major heading compares the incremental savings and costs between the savings from a given SFR of single glazed skylights to double glazed skylights.

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 and a 30 year period of analysis.

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.

From briefly glancing at Table 8 through Table 10, it is obvious that there is a range of SFR's that skylighting is cost-effective for the range of lighting power densities if we exclude climate zones 1 and 16. The relatively low savings in climate zones 1 and 16 are more evident in warehouses with lower lighting power densities such as in Table 9.

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

- Skylights are very cost-effective in most climate zones
- Skylights increase in cost-effectiveness as lighting power density increases
- The optimal skylight area increases as lighting power density increases

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

- Skylights need to be diffusing to effectively save energy and not cause glare
- Multi-level controls are needed to maximize savings
- The initial costs of skylighting systems are reduced with taller ceilings – skylights can be spaced further apart while maintaining lighting uniformity

Table 8: Retail Benefit Cost Ratios for Skylights and Photocontrols

CZ	SFR	***Single*** *Glazed Acrylic*				***Double*** *Glazed Acrylic*				***B/C Ratio Single to Double Glaz.***			
		2/3 on/off		Dimming 20%		2/3 on/off		Dimming 20%		2/3 on/off		Dimming 20%	
		15 year	30 year	15 year	30 year	15 year	30 year	15 year	30 year	15 year	30 year	15 year	30 year
1	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	(0.45)	(0.65)	0.38	0.53	(0.23)	(0.34)	0.37	0.53	1.16	2.02	0.09	0.38
	2%	0.63	0.75	0.81	1.14	0.62	0.81	0.80	1.14	0.57	1.12	0.19	0.54
	3%	1.42	1.87	1.20	1.68	1.19	1.64	1.21	1.74	0.18	0.55	0.51	1.06
	4%	1.61	2.15	1.42	1.96	1.49	2.08	1.51	2.15	0.88	1.71	1.11	2.08
	5%	1.57	2.09	1.52	2.08	1.50	2.11	1.70	2.42	1.19	2.22	1.47	2.67
	6%	1.42	1.88	1.54	2.06	1.46	2.07	1.83	2.59	1.64	2.97	1.80	3.21
	8%	1.04	1.31	1.39	1.77	1.23	1.73	1.93	2.68	2.10	3.72	2.24	3.93
	10%	0.69	0.79	1.13	1.29	1.01	1.40	1.89	2.59	2.42	4.24	2.47	4.33
	12%	0.41	0.36	0.78	0.69	0.81	1.11	1.78	2.38	2.60	4.53	2.63	4.59
3	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	(0.32)	(0.46)	0.57	0.82	(0.19)	(0.27)	0.52	0.76	0.67	1.19	-0.73	-0.95
	2%	1.71	2.25	1.21	1.74	1.36	1.86	1.11	1.62	-0.25	-0.22	-0.63	-0.79
	3%	2.69	3.70	1.78	2.56	2.10	2.96	1.69	2.45	-0.50	-0.60	-0.22	-0.17
	4%	2.75	3.83	2.07	2.97	2.31	3.29	2.04	2.96	0.20	0.51	0.35	0.75
	5%	2.51	3.52	2.21	3.15	2.16	3.11	2.24	3.24	0.52	1.04	0.69	1.30
	6%	2.26	3.18	2.26	3.19	2.00	2.90	2.36	3.40	0.82	1.51	0.96	1.73
	8%	1.71	2.41	2.19	3.06	1.63	2.37	2.45	3.51	1.24	2.19	1.28	2.26
	10%	1.30	1.79	2.03	2.76	1.33	1.93	2.43	3.46	1.46	2.55	1.48	2.58
	12%	0.99	1.34	1.80	2.38	1.10	1.59	2.37	3.34	1.58	2.75	1.61	2.80
7	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	(0.25)	(0.33)	0.72	1.05	(0.22)	(0.29)	0.64	0.94	-0.02	0.03	-1.44	-2.14
	2%	2.41	3.25	1.53	2.23	1.75	2.42	1.36	1.99	-1.31	-1.95	-1.46	-2.17
	3%	3.53	4.93	2.24	3.27	2.65	3.77	2.05	2.99	-1.19	-1.77	-0.96	-1.42
	4%	3.68	5.23	2.62	3.81	2.90	4.17	2.46	3.59	-0.87	-1.27	-0.50	-0.69
	5%	3.36	4.82	2.82	4.10	2.73	3.98	2.69	3.93	-0.20	-0.23	-0.16	-0.16
	6%	2.98	4.31	2.91	4.23	2.44	3.58	2.81	4.11	-0.02	0.05	0.04	0.13
	8%	2.38	3.48	2.96	4.30	1.99	2.94	2.92	4.26	0.21	0.41	0.26	0.48
	10%	1.91	2.81	2.90	4.19	1.63	2.42	2.92	4.26	0.37	0.65	0.39	0.68
	12%	1.56	2.30	2.79	4.01	1.36	2.02	2.87	4.17	0.44	0.76	0.47	0.82
10	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	(0.76)	(1.01)	0.61	0.88	(0.49)	(0.65)	0.57	0.83	1.27	2.05	-0.40	-0.51
	2%	1.85	2.47	1.29	1.87	1.50	2.06	1.22	1.77	-0.14	-0.10	-0.35	-0.42
	3%	2.90	4.02	1.88	2.72	2.35	3.32	1.83	2.66	-0.08	0.00	0.14	0.33
	4%	2.94	4.13	2.12	3.06	2.51	3.60	2.15	3.13	0.46	0.85	0.83	1.43
	5%	2.52	3.58	2.17	3.12	2.28	3.31	2.28	3.32	1.16	1.95	1.20	2.01
	6%	2.12	3.02	2.12	3.03	1.98	2.88	2.31	3.35	1.33	2.20	1.40	2.32
	8%	1.50	2.13	1.89	2.66	1.51	2.20	2.24	3.23	1.54	2.55	1.62	2.67
	10%	1.03	1.44	1.57	2.17	1.16	1.69	2.08	2.97	1.73	2.85	1.73	2.85
	12%	0.67	0.91	1.21	1.61	0.88	1.28	1.87	2.66	1.79	2.95	1.80	2.96
12	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	(0.78)	(1.05)	0.55	0.79	(0.48)	(0.66)	0.52	0.76	1.42	2.35	-0.21	-0.16
	2%	1.52	1.99	1.18	1.70	1.32	1.80	1.13	1.64	0.40	0.78	-0.11	0.00
	3%	2.53	3.47	1.72	2.46	2.09	2.95	1.70	2.47	0.20	0.48	0.41	0.81
	4%	2.52	3.50	1.92	2.74	2.26	3.22	2.00	2.89	0.98	1.73	1.15	2.00
	5%	2.18	3.04	1.94	2.75	2.01	2.89	2.12	3.06	1.22	2.12	1.54	2.63
	6%	1.87	2.61	1.88	2.63	1.82	2.62	2.16	3.11	1.57	2.68	1.80	3.05
	8%	1.24	1.69	1.60	2.17	1.39	2.01	2.09	2.98	2.08	3.50	2.12	3.56
	10%	0.76	0.98	1.22	1.56	1.03	1.48	1.91	2.69	2.25	3.78	2.28	3.82
	12%	0.43	0.49	0.79	0.88	0.78	1.10	1.69	2.33	2.31	3.88	2.36	3.96
14	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	(1.08)	(1.42)	0.63	0.91	(0.78)	(1.04)	0.61	0.89	1.10	1.80	0.13	0.32
	2%	1.90	2.53	1.34	1.94	1.62	2.21	1.30	1.90	0.29	0.56	0.18	0.40
	3%	2.98	4.13	1.89	2.73	2.52	3.57	1.92	2.79	0.54	0.94	0.89	1.48
	4%	2.82	3.96	2.01	2.89	2.60	3.72	2.16	3.15	1.53	2.48	1.77	2.86
	5%	2.28	3.22	1.92	2.76	2.24	3.24	2.20	3.20	2.07	3.33	2.15	3.45
	6%	1.79	2.54	1.75	2.49	1.88	2.73	2.14	3.10	2.29	3.67	2.33	3.74
	8%	1.02	1.42	1.27	1.76	1.29	1.88	1.89	2.71	2.51	4.03	2.55	4.09
	10%	0.48	0.62	0.70	0.90	0.87	1.26	1.55	2.20	2.64	4.24	2.67	4.28
	12%	0.07	0.01	0.10	(0.01)	0.56	0.80	1.17	1.63	2.75	4.41	2.74	4.40
16	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	(1.00)	(1.48)	0.41	0.54	(0.71)	(1.04)	0.46	0.63	1.10	2.34	1.67	3.25
	2%	1.03	1.09	0.86	1.12	1.15	1.43	0.97	1.34	1.68	3.27	1.90	3.61
	3%	1.69	1.99	1.12	1.42	1.81	2.40	1.38	1.90	2.34	4.31	2.67	4.81
	4%	1.38	1.55	1.05	1.25	1.76	2.33	1.50	2.02	3.60	6.38	3.69	6.51
	5%	0.96	0.95	0.86	0.90	1.47	1.92	1.47	1.94	3.85	6.76	3.93	6.89
	6%	0.58	0.39	0.60	0.45	1.19	1.52	1.38	1.76	4.01	7.01	4.08	7.12
	8%	(0.03)	(0.51)	(0.01)	(0.58)	0.73	0.85	1.09	1.27	4.19	7.29	4.22	7.35
	10%	(0.45)	(1.15)	(0.68)	(1.70)	0.41	0.38	0.75	0.69	4.29	7.45	4.31	7.48
	12%	(0.75)	(1.60)	(1.37)	(2.85)	0.18	0.04	0.38	0.08	4.33	7.52	4.36	7.56

Table 9: Warehouse 0.7 W/SF LPD, Conditioned - B/C Ratios for Skylights and Photocontrols

CZ	SFR	***Single** Glazed Acrylic*				***Double** Glazed Acrylic*				***B/C Ratio Single to Double Glaz.***			
		2/3 on/off		Dimming 20%		2/3 on/off		Dimming 20%		2/3 on/off		Dimming 20%	
		15 year	30 year	15 year	30 year	15 year	30 year	15 year	30 year	15 year	30 year	15 year	30 year
1	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	(0.29)	(0.54)	0.28	0.18	(0.01)	(0.09)	0.42	0.46	1.79	3.29	1.31	2.58
	2%	0.44	0.33	0.53	0.44	0.68	0.81	0.80	0.97	1.82	3.35	2.10	3.77
	3%	0.46	0.33	0.28	0.09	0.76	0.93	0.67	0.80	2.09	3.77	2.38	4.18
	4%	0.34	0.15	0.01	(0.31)	0.76	0.92	0.52	0.58	2.75	4.87	2.97	5.18
	5%	0.15	(0.13)	(0.21)	(0.63)	0.64	0.75	0.36	0.35	2.91	5.10	3.01	5.24
	6%	(0.02)	(0.38)	(0.39)	(0.89)	0.51	0.57	0.22	0.16	2.98	5.20	3.05	5.31
	8%	(0.31)	(0.80)	(0.65)	(1.28)	0.30	0.27	0.03	(0.12)	3.04	5.29	3.09	5.35
	10%	(0.52)	(1.11)	(0.82)	(1.54)	0.14	0.04	(0.10)	(0.31)	3.07	5.34	3.10	5.37
	12%	(0.68)	(1.35)	(0.94)	(1.73)	0.02	(0.14)	(0.20)	(0.45)	3.10	5.37	3.10	5.37
3	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	0.59	0.66	1.40	1.68	0.58	0.71	1.22	1.54	0.50	1.12	0.08	0.50
	2%	1.82	2.30	1.55	1.93	1.65	2.20	1.52	2.01	0.85	1.68	1.37	2.48
	3%	1.56	2.00	1.05	1.28	1.53	2.09	1.16	1.56	1.39	2.52	1.66	2.91
	4%	1.26	1.58	0.71	0.80	1.37	1.87	0.93	1.24	1.91	3.37	2.03	3.54
	5%	0.94	1.14	0.42	0.40	1.12	1.53	0.72	0.94	1.98	3.48	2.10	3.64
	6%	0.69	0.78	0.21	0.09	0.93	1.26	0.55	0.70	2.05	3.58	2.11	3.67
	8%	0.32	0.25	(0.09)	(0.35)	0.65	0.86	0.31	0.36	2.13	3.69	2.14	3.71
	10%	0.07	(0.12)	(0.29)	(0.64)	0.45	0.56	0.16	0.14	2.15	3.72	2.15	3.73
	12%	(0.11)	(0.39)	(0.43)	(0.85)	0.31	0.35	0.05	(0.02)	2.15	3.73	2.16	3.74
7	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	1.23	1.55	2.41	3.06	0.96	1.24	1.90	2.48	-0.77	-1.07	-1.29	-1.86
	2%	3.05	4.10	2.70	3.62	2.43	3.36	2.27	3.13	-0.47	-0.60	0.25	0.50
	3%	2.82	3.90	2.05	2.82	2.34	3.31	1.77	2.49	0.23	0.48	0.53	0.94
	4%	2.41	3.38	1.62	2.26	2.09	2.99	1.47	2.10	0.52	0.95	0.73	1.28
	5%	1.98	2.79	1.26	1.75	1.75	2.53	1.18	1.69	0.70	1.23	0.78	1.35
	6%	1.64	2.32	0.97	1.35	1.48	2.15	0.95	1.37	0.78	1.36	0.86	1.46
	8%	1.15	1.63	0.60	0.82	1.10	1.60	0.64	0.93	0.83	1.44	0.85	1.46
	10%	0.82	1.14	0.35	0.45	0.83	1.20	0.45	0.64	0.87	1.49	0.88	1.50
	12%	0.58	0.79	0.18	0.20	0.64	0.92	0.31	0.43	0.89	1.52	0.89	1.52
10	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	0.79	0.96	1.92	2.39	0.75	0.95	1.61	2.07	0.46	0.92	-0.34	-0.30
	2%	2.42	3.19	1.96	2.56	2.10	2.87	1.84	2.50	0.62	1.17	1.29	2.20
	3%	2.04	2.75	1.25	1.65	1.90	2.65	1.32	1.82	1.28	2.18	1.59	2.65
	4%	1.55	2.08	0.78	1.00	1.59	2.23	0.99	1.37	1.78	2.99	1.97	3.28
	5%	1.12	1.49	0.41	0.48	1.26	1.77	0.70	0.96	1.91	3.18	2.02	3.35
	6%	0.78	1.00	0.15	0.09	0.99	1.40	0.48	0.65	2.00	3.32	2.05	3.39
	8%	0.30	0.31	(0.22)	(0.46)	0.61	0.85	0.19	0.22	2.03	3.36	2.07	3.42
	10%	(0.02)	(0.16)	(0.47)	(0.82)	0.36	0.48	0.00	(0.06)	2.07	3.42	2.10	3.46
	12%	(0.25)	(0.50)	(0.64)	(1.08)	0.18	0.21	(0.13)	(0.26)	2.09	3.45	2.10	3.47
12	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	0.49	0.52	1.45	1.76	0.55	0.68	1.32	1.67	0.98	1.83	0.47	-0.16
	2%	1.86	2.38	1.45	1.81	1.73	2.33	1.51	2.01	1.13	2.07	1.78	0.00
	3%	1.45	1.87	0.84	1.00	1.54	2.11	1.07	1.44	1.90	3.25	2.07	0.81
	4%	1.06	1.31	0.39	0.36	1.29	1.77	0.76	1.00	2.43	4.13	2.54	2.00
	5%	0.67	0.77	0.04	(0.14)	0.99	1.35	0.50	0.62	2.50	4.23	2.63	2.63
	6%	0.36	0.32	(0.21)	(0.51)	0.75	1.00	0.30	0.34	2.54	4.30	2.65	3.05
	8%	(0.08)	(0.34)	(0.58)	(1.06)	0.41	0.50	0.01	(0.08)	2.62	4.42	2.69	3.56
	10%	(0.39)	(0.79)	(0.82)	(1.42)	0.17	0.15	(0.17)	(0.36)	2.68	4.50	2.70	3.82
	12%	(0.61)	(1.13)	(0.98)	(1.67)	(0.00)	(0.11)	(0.30)	(0.56)	2.70	4.54	2.71	3.96
14	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	0.87	1.06	2.15	2.70	(0.83)	(1.12)	1.91	2.47	-11.62	-17.62	0.37	0.76
	2%	2.60	3.44	1.90	2.48	1.46	1.98	1.91	2.60	-3.88	-5.72	1.98	3.24
	3%	1.93	2.60	0.97	1.26	1.63	2.27	1.22	1.69	0.31	0.70	2.31	3.74
	4%	1.30	1.74	0.38	0.43	1.35	1.89	0.80	1.10	1.57	2.68	2.81	4.55
	5%	0.75	0.96	(0.07)	(0.22)	0.97	1.36	0.46	0.61	2.03	3.36	2.92	4.71
	6%	0.35	0.39	(0.39)	(0.69)	0.70	0.97	0.20	0.24	2.30	3.78	2.94	4.74
	8%	(0.23)	(0.47)	(0.83)	(1.35)	0.29	0.36	(0.14)	(0.27)	2.62	4.27	2.97	4.80
	10%	(0.61)	(1.03)	(1.11)	(1.78)	0.01	(0.05)	(0.36)	(0.60)	2.75	4.46	2.99	4.83
	12%	(0.88)	(1.44)	(1.31)	(2.08)	(0.19)	(0.35)	(0.52)	(0.83)	2.83	4.60	3.01	4.86
16	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	0.14	(0.09)	1.01	1.00	0.46	0.46	1.21	1.43	2.48	4.64	2.53	4.73
	2%	1.09	1.07	0.58	0.38	1.46	1.80	1.10	1.31	3.16	5.65	3.56	6.25
	3%	0.56	0.34	(0.11)	(0.59)	1.12	1.37	0.61	0.65	3.58	6.28	3.78	6.58
	4%	0.05	(0.42)	(0.59)	(1.30)	0.81	0.91	0.29	0.19	4.47	7.79	4.53	7.87
	5%	(0.34)	(0.97)	(0.92)	(1.79)	0.51	0.50	0.05	(0.17)	4.50	7.82	4.57	7.93
	6%	(0.64)	(1.42)	(1.16)	(2.16)	0.28	0.17	(0.13)	(0.43)	4.54	7.89	4.60	7.97
	8%	(1.05)	(2.04)	(1.49)	(2.67)	(0.03)	(0.29)	(0.38)	(0.81)	4.58	7.94	4.61	7.98
	10%	(1.33)	(2.47)	(1.70)	(3.00)	(0.24)	(0.61)	(0.54)	(1.05)	4.62	8.00	4.62	8.00
	12%	(1.53)	(2.78)	(1.85)	(3.24)	(0.40)	(0.84)	(0.66)	(1.22)	4.62	7.99	4.62	8.00

Table 10: Warehouse 0.7 W/SF LPD, Unconditioned- B/C Ratios for Skylights and Photocontrols

CZ	SFR	***Single*** *Glazed Acrylic*				***Double*** *Glazed Acrylic*				***B/C Ratio Single to Double Glaz.***			
		2/3 on/off		Dimming 20%		2/3 on/off		Dimming 20%		2/3 on/off		Dimming 20%	
		15 year	30 year	15 year	30 year	15 year	30 year	15 year	30 year	15 year	30 year	15 year	30 year
1	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	0.70	0.89	0.77	0.98	0.48	0.62	0.55	0.72	-0.93	-1.43	-0.81	-1.23
	2%	1.85	2.51	1.72	2.33	1.34	1.85	1.30	1.81	-1.04	-1.60	-0.65	-0.99
	3%	2.05	2.88	1.76	2.47	1.56	2.22	1.36	1.94	-0.60	-0.92	-0.38	-0.58
	4%	2.12	3.02	1.67	2.38	1.65	2.39	1.33	1.93	-0.57	-0.88	-0.28	-0.44
	5%	1.97	2.85	1.49	2.16	1.56	2.28	1.20	1.75	-0.37	-0.57	-0.18	-0.28
	6%	1.81	2.64	1.34	1.95	1.44	2.12	1.08	1.58	-0.26	-0.40	-0.13	-0.20
	8%	1.53	2.25	1.09	1.60	1.22	1.81	0.88	1.30	-0.16	-0.25	-0.06	-0.10
	10%	1.30	1.93	0.91	1.35	1.05	1.56	0.73	1.10	-0.09	-0.14	-0.06	-0.09
	12%	1.13	1.68	0.78	1.17	0.91	1.36	0.63	0.95	-0.06	-0.10	-0.02	-0.04
3	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	1.11	1.43	1.18	1.51	0.79	1.04	0.85	1.11	-1.24	-1.90	-1.24	-1.90
	2%	2.43	3.30	2.13	2.89	1.82	2.52	1.67	2.31	-1.03	-1.58	-0.51	-0.79
	3%	2.45	3.44	1.94	2.72	1.89	2.70	1.52	2.17	-0.56	-0.85	-0.28	-0.43
	4%	2.33	3.32	1.74	2.48	1.86	2.68	1.40	2.02	-0.39	-0.59	-0.24	-0.37
	5%	2.08	3.00	1.52	2.20	1.67	2.44	1.23	1.79	-0.24	-0.38	-0.16	-0.25
	6%	1.87	2.72	1.35	1.97	1.50	2.20	1.09	1.60	-0.23	-0.35	-0.11	-0.17
	8%	1.55	2.28	1.09	1.61	1.25	1.85	0.88	1.31	-0.11	-0.17	-0.07	-0.10
	10%	1.31	1.94	0.92	1.36	1.05	1.57	0.74	1.11	-0.09	-0.14	-0.05	-0.07
	12%	1.13	1.69	0.79	1.17	0.91	1.37	0.64	0.96	-0.06	-0.10	-0.02	-0.04
7	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	1.30	1.66	1.50	1.92	0.96	1.25	1.02	1.34	-1.19	-1.83	-2.01	-3.08
	2%	2.77	3.76	2.43	3.31	2.10	2.91	1.90	2.63	-1.01	-1.55	-0.60	-0.92
	3%	2.77	3.89	2.13	2.99	2.16	3.08	1.67	2.39	-0.52	-0.80	-0.32	-0.49
	4%	2.56	3.65	1.88	2.68	2.05	2.96	1.53	2.21	-0.40	-0.61	-0.16	-0.25
	5%	2.25	3.26	1.62	2.34	1.82	2.66	1.32	1.92	-0.21	-0.32	-0.12	-0.19
	6%	2.01	2.93	1.43	2.08	1.62	2.39	1.16	1.70	-0.18	-0.27	-0.09	-0.14
	8%	1.64	2.41	1.14	1.68	1.32	1.96	0.92	1.37	-0.11	-0.17	-0.05	-0.08
	10%	1.37	2.03	0.95	1.41	1.11	1.66	0.77	1.15	-0.04	-0.06	-0.04	-0.07
	12%	1.18	1.76	0.81	1.21	0.95	1.43	0.66	0.99	-0.05	-0.07	-0.02	-0.03
10	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	1.31	1.68	1.48	1.89	0.98	1.29	1.00	1.31	-1.08	-1.65	-2.01	-3.08
	2%	2.76	3.74	2.39	3.25	2.12	2.94	1.89	2.62	-0.87	-1.34	-0.47	-0.72
	3%	2.70	3.80	2.05	2.88	2.12	3.02	1.63	2.32	-0.45	-0.69	-0.25	-0.38
	4%	2.47	3.53	1.81	2.59	1.99	2.88	1.47	2.13	-0.32	-0.50	-0.16	-0.25
	5%	2.18	3.15	1.56	2.26	1.77	2.58	1.27	1.85	-0.19	-0.30	-0.11	-0.17
	6%	1.94	2.83	1.38	2.00	1.57	2.30	1.11	1.64	-0.15	-0.24	-0.11	-0.16
	8%	1.57	2.32	1.11	1.63	1.27	1.89	0.90	1.33	-0.10	-0.16	-0.06	-0.09
	10%	1.33	1.97	0.92	1.37	1.07	1.60	0.75	1.12	-0.06	-0.09	-0.04	-0.07
	12%	1.15	1.71	0.79	1.18	0.93	1.39	0.64	0.96	-0.05	-0.08	-0.03	-0.04
12	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	1.20	1.54	1.31	1.68	0.89	1.17	0.91	1.19	-1.07	-1.65	-1.63	-2.50
	2%	2.50	3.40	2.16	2.93	1.89	2.62	1.70	2.35	-0.98	-1.50	-0.47	-0.72
	3%	2.46	3.46	1.94	2.73	1.92	2.74	1.53	2.18	-0.46	-0.70	-0.30	-0.45
	4%	2.35	3.35	1.76	2.51	1.87	2.70	1.42	2.05	-0.43	-0.66	-0.21	-0.32
	5%	2.10	3.04	1.54	2.22	1.69	2.46	1.24	1.82	-0.26	-0.41	-0.14	-0.21
	6%	1.88	2.74	1.36	1.99	1.52	2.23	1.10	1.62	-0.17	-0.27	-0.13	-0.19
	8%	1.56	2.30	1.11	1.63	1.25	1.86	0.89	1.33	-0.12	-0.19	-0.07	-0.10
	10%	1.33	1.97	0.92	1.37	1.07	1.60	0.75	1.11	-0.09	-0.13	-0.04	-0.06
	12%	1.15	1.71	0.79	1.18	0.93	1.39	0.64	0.96	-0.05	-0.08	-0.02	-0.04
14	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	1.67	2.14	1.90	2.44	1.23	1.61	1.31	1.71	-1.59	-2.44	-2.45	-3.76
	2%	3.23	4.39	2.70	3.67	2.48	3.44	2.13	2.95	-1.05	-1.60	-0.57	-0.88
	3%	3.03	4.26	2.27	3.18	2.37	3.38	1.81	2.58	-0.55	-0.84	-0.21	-0.33
	4%	2.73	3.90	1.95	2.79	2.22	3.21	1.59	2.30	-0.25	-0.39	-0.13	-0.21
	5%	2.37	3.42	1.68	2.42	1.92	2.80	1.37	1.99	-0.19	-0.28	-0.10	-0.15
	6%	2.08	3.03	1.46	2.12	1.68	2.47	1.19	1.74	-0.14	-0.21	-0.06	-0.10
	8%	1.67	2.46	1.16	1.71	1.35	2.01	0.94	1.40	-0.07	-0.11	-0.05	-0.07
	10%	1.39	2.07	0.96	1.43	1.13	1.69	0.78	1.16	-0.05	-0.08	-0.04	-0.06
	12%	1.20	1.78	0.82	1.22	0.97	1.45	0.66	1.00	-0.04	-0.06	-0.03	-0.04
16	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	1.66	2.13	1.87	2.39	1.22	1.59	1.33	1.74	-1.61	-2.47	-2.08	-3.19
	2%	3.13	4.25	2.58	3.51	2.38	3.30	2.04	2.82	-1.11	-1.71	-0.52	-0.80
	3%	2.92	4.09	2.16	3.04	2.28	3.26	1.73	2.46	-0.47	-0.72	-0.18	-0.28
	4%	2.62	3.74	1.90	2.71	2.12	3.06	1.54	2.22	-0.31	-0.48	-0.18	-0.28
	5%	2.28	3.29	1.62	2.34	1.84	2.69	1.32	1.92	-0.21	-0.32	-0.10	-0.15
	6%	2.02	2.94	1.42	2.07	1.63	2.39	1.15	1.69	-0.16	-0.25	-0.11	-0.17
	8%	1.63	2.40	1.13	1.67	1.32	1.95	0.92	1.37	-0.10	-0.16	-0.04	-0.07
	10%	1.37	2.03	0.94	1.40	1.10	1.65	0.76	1.14	-0.07	-0.10	-0.04	-0.06
	12%	1.17	1.75	0.81	1.21	0.95	1.42	0.66	0.98	-0.05	-0.07	-0.03	-0.04

Specifying Diffusion for Skylights

All the analysis above was based upon a simulation model of a skylight that is perfectly diffusing. Without a method of diffusing the light emanating from skylights the results have deleterious effects on visibility and energy savings. If the skylighting system (skylight, light well, diffusers etc.) does not provide diffusion then:

- Excessive contrast is created between excessively bright areas directly under non-diffusing skylights and the rest of the space which will appear dark even with what is normally considered high interior light levels. The light levels directly under non-diffusing skylights can exceed 1,000 fc. Unless some method is found to diffuse the light, the skylights will be covered over thus defeating the purpose of the skylight[16].

- Areas between skylights, even in what we have defined as the "daylit zone," will be darker for a non-diffusing skylighting system than a diffusing skylighting system with the same transmittance.

Thus if the skylighting system is not diffusing, it is over-lighting some areas and under-lighting others. A non-diffusing skylighting system is providing sufficient light to a smaller area. Thus a minimum level of diffusion is considered necessary to yield the energy savings benefit of skylighting that is displacing electric lighting.

Finding a good metric for diffusion has been challenging. The metric we have settled on is the measurement of haze as is defined in ASTM D1003-00 "Standard Test Method for Haze and Luminous Transmittance of Transparent Plastics." This test is inexpensive to administer and gives a basic indication of its ability to diffuse light. Haze is the ratio of diffusely transmitted light to total transmitted light. Diffusely transmitted light is defined as all light that is scattered more than 2.5° from the directly transmitted beam. Luminous transmittance and haze can be tested on a single test instrument that has all the geometric aspects of this test standard designed in.

Materials having a haze value greater than 30% are considered diffusing, ASTM recommends that they be tested in accordance with Practice E167 "Practice for Goniophotometry of Objects and Materials" but testing according to E167 yields a distribution of luminous intensities. It does not yield a "diffusion index" similar to haze that can be used as a simple "Yes/No" test for determining whether a glazing is diffusing or not. Our conclusion is that the haze value from ASTM D1003 is a reasonably good proxy for diffusion and can be done repeatably.

As part of the PIER skylight testing program, glazing samples from a variety of different skylights were tested for visible transmittance and haze. The samples were sent to DSET Labs in Phoenix, AZ where visible transmittance, haze and clarity were measured on a BYK-Gardener Haze Gard #4725. The cost of these measurements was less than $10 per sample. The results from testing are presented in the Table 11 below. The key conclusion from examination of this data is that diffusing glazings have haze values that are clearly above 90%.

[16] An exception to this is in atria where the light level for an entire area is relatively uniform and substantially higher than most interior spaces.

Table 11: Measured visible transmittance and haze of plastic glazing materials

Description	Tvis	Haze
White Acrylic	62.6%	100.0%
Clear Acrylic	94.9%	0.3%
Bronze Acrylic	28.2%	1.5%
White PET	48.8%	100.0%
Thick Prismatic	84.8%	98.1%
Twinwall Polycarbonate	83.6%	33.2%
Fiberglass Assembly	29.2%	92.2%
Fiberglass Sheet	79.1%	69.0%
Prismatic Diffuser	85.8%	97.2%

Thus a requirement that skylight glazing or a skylight diffuser have a haze rating greater than 90% reasonably assures that skylights are not causing excessive glare while not placing a great burden on the skylight industry. The test is inexpensive, most diffusing skylights would pass the test without any changes in their design and those skylights that do not pass the 90% haze standard can install an inexpensive diffuser.

Recommendations

Proposed Standards Language

Daylit Zone under Skylights

Alter the second item (definition of daylit zone under skylights) in the definition of daylit zone in Section 101 – Definitions and Rules of Construction:

DAYLIT AREA is the space on the floor that is the larger of 1 plus 2, or 3;

2. For areas daylit by horizontal glazing, the daylit area is the footprint 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 opaque partition, or one half the horizontal distance to the edge of the closest skylight or vertical glazing.

The section in the Title 24 Nonresidential Manual would be updated to describe the revised definition of the daylit zone and would show the "spread angle" of the daylit zone to be 35°. An example of how this would be illustrated is given in Figure 15.

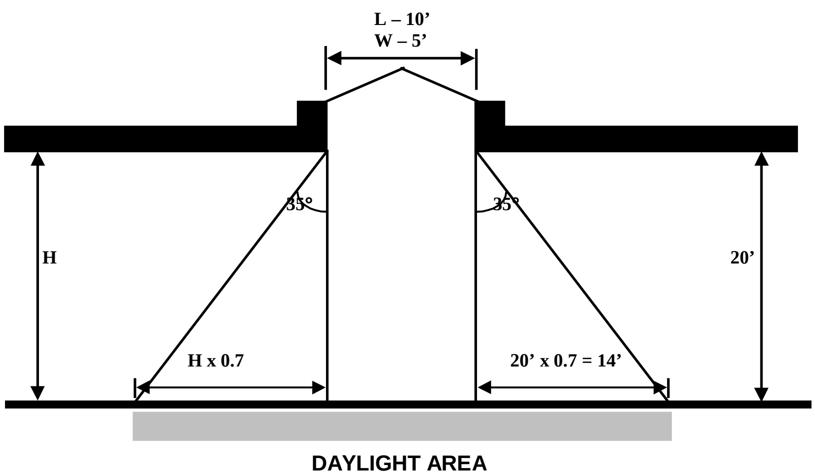

Figure 15: Revised Illustration of the Skylight Daylit Area

Definitions of Effective Aperture and Well Efficiency

The following revisions are proposed to the definitions in Section 101 "DEFINITIONS AND RULES OF CONSTRUCTION" of the Building standards:

EFFECTIVE APERTURE (EA) is (1) for windows, the visible light transmittance (VLT) times the window wall ratio; and (2) for skylights, the *well* ~~*index*~~ *efficiency* times the VLT times the *skylight area* times 0.85 divided by the ~~gross exterior roof area~~ *daylit area* under skylights.

The definition of well index is removed altogether and replaced by the following definitions:

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 is calculated from the nomograph below using the weighted average reflectance of the walls of the well and the *Well Cavity Ratio* (WCR).

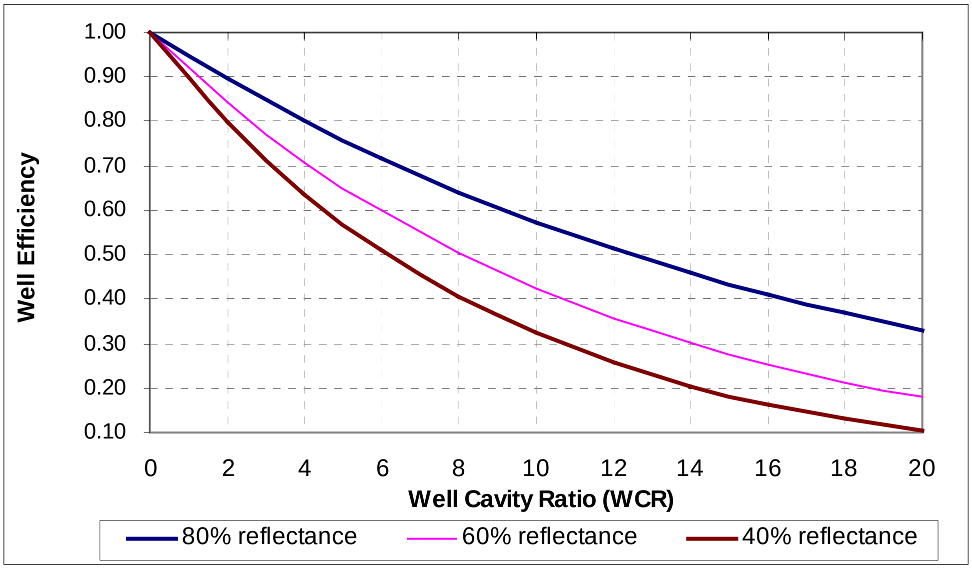

Figure 16: Well Efficiency Nomograph

WELL CAVITY RATIO (WCR) characterizes the geometry of the skylight well and is used for calculating the skylight *well efficiency*. It is calculated as follows:

(a) For rectangular wells:

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

(b) For irregular 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.

SKYLIGHT AREA ~~is the area of the surface of a skylight, plus the area of the frame, sash, and mullions.~~is the area of the rough opening for the skylight.

Requirements for Automatic Multi-Level Daylighting Controls

The following revisions and additions are proposed for Section 119 – Mandatory Requirements For Lighting Control Devices

(e) **Automatic Multi-level Daylighting Control Devices**. Automatic multi-level daylighting control devices shall:

1. Be capable of ~~reducing the light output of the general lighting of the controlled area by at least one half while maintaining a uniform level of illuminance throughout the area~~ automatically reducing the general lighting in the controlled area in multiple steps in response to available daylight while maintaining a reasonably uniform level of illuminance. These controls shall have at least one control step that is between 50% and 70% of design illuminance and the controlled electric lighting shall consume less than 35% of rated power at minimum light output. A reasonably uniform level of illuminance in an area shall be achieved in a manner described in Section 131(b)1 through 3; 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 device is a stepped dimming system, incorporate time-delay circuits to prevent cycling of light level changes of less than three minutes; and

4. If the device uses step switching ~~with separate on and off settings for the steps~~, the device shall have sufficient separation (deadband) of on and off points for each step of control to prevent cycling; and,

5. Have provided by the manufacturer step-by-step instructions for installation and start-up calibration to design footcandle levels; and

6. If the device uses step switching, status of each control step will be *annunciated* by an indicator light on the control device; and

7. If the device has a time delay, the time delay shall be capable of being over ridden or set to less than 5 seconds time delay for the purpose of commissioning; and

8. The light sensor shall have a linear response with 5% accuracy over the range of illuminances measured by the sensor; and

9. The light sensor shall be separate from the control device where calibrations adjustments are made; and

10. Controls for calibration adjustments to the lighting control device shall be *readily accessible* to authorized personnel, and the setpoint control have an indicator so that settings can be easily distinguished to within 10% of full scale adjustment.

This definition of automatic multi-level daylighting control devices references section 131(b) of the standard. Though the Nonresidential Manual is clear about the intent of the standard, the wording in this section was ambiguous. We recommend that the wording of Section 131(b) also be clarified as follows:

(b) Controls to Reduce Lighting. The general lighting of any enclosed space 100 square feet or larger in which the connected lighting load exceeds 0.8 watts per square foot for the space as a whole, and that has more than one light source (luminaire), shall have multi-level lighting controls that reduce lighting power in multiple steps while maintaining a reasonably uniform level of illuminance throughout the area controlled. Multilevel controls shall have at least one control step that is between 70% and 50% of design illuminance and at minimum light output consume less than 35% of rated power. ~~be controlled so that the load for the lights may be reduced by at least one half while maintaining a reasonably uniform level of illuminance throughout the area.~~ A reasonably uniform reduction of illuminance shall be achieved by:

1. Controlling all lamps or luminaires with dimmers; or

2. Dual switching of alternate rows of luminaires, alternate luminaires, or alternate lamps; or

3. Switching the middle lamps of three lamp luminaires independently of the outer lamps; or

4. Switching each luminaire or each lamp.

The parallels between this revised wording of Section 131(b) and Section 119(e) clearly defines lighting levels and power consumption at specified control steps.

Revised Power Adjustment Factors

After evaluating the TDV energy (or cost) savings from various control strategies we have developed revised Power Adjustment Factors. Because we have also proposed that some form of automatic control is required for most spaces, the proposed factors are approximately one half of the TDV savings from photocontrols. The current proposal for mandatory automatic controls under skylights would allow either an astronomical timeclock or a photocontrol. Thus the PAF for automatic multi-level daylighting controls for skylights reflects the additional savings over the mandatory minimum control method of astronomical timeclocks.

We recommend that the Power Adjustment Factors for *Automatic Daylighting Controls - Skylights* be updated in *Table 1-L Lighting Power Adjustment Factors*. These updates include how controls are defined as well as the format of the tables. We propose that the PAF's are based on the Effective Aperture – a term already defined in Section 101 of the Standards.

As was shown under the Revised Power Adjustment Factors part of the Results and Discussion section, there is little difference between a multi-level switched control that turns the lights to a low power level and dimming controls. Thus a single PAF value can be specified for the generic category of multi-level automatic daylighting controls. The revised Requirements for Automatic Multi-Level Daylighting Controls in item 1 of section 119(e) clearly states that the control is to be multi-level and spells out the specifics of illuminance and power consumption at specified control steps.

Thus Table 1-L for Daylighting Controls should be revised as follows:

Type of Control	Type of Space	Factor
Automatic Multi-Level Daylighting Controls (Skylights)		
Glazing Type	Factor	
Glazing material or diffuser with ASTM D1003 haze measurement greater than 90%	$\text{PAF} = 10 \times \text{Effective Aperture} - \frac{\text{Lighting Power Density}}{10} + 0.2$	

Since these PAF's are the savings from photocontrols above which is saved from multi-level astronomical timeclocks, the lighting power reduction in the ACM compliance software should use this PAF calculation for astronomical time clock controls and for automatic daylighting controls use twice the values calculated for the PAF's here.

Mandatory Automatic Lighting Controls in the Daylit Zone under Skylights

We recommend that Section 131c) of the Efficiency Standards be amended as follows.

c) **Daylit Areas**. Lamps providing general lighting that are in or are partially in the daylit area shall be controlled according to the applicable requirements in items 1 and 2 below.

1) Daylit areas greater than 250 square feet in any enclosed space shall have at least one additional multi-level control that:

A. Controls 50% or more of the lamps in the daylit areas separately from other lighting in the enclosed space; and

B. Controls luminaires in vertically daylit areas separately from horizontally daylit areas. and

C. Has at least one control step that is between 70% and 50% of design illuminance; and

D. Shall maintain a reasonably uniform level of illuminance in the daylit area as described in Section 131(b)1 through 3

2) When the daylit 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 shall be controlled separately by either:

A. an automatic multi-level daylighting control; or

B. a multi-level astronomical time-switch control with an override switching device that complies with section 131(d)2.

Exception1 to 131c): Daylit areas where the effective aperture of glazing is less than 0.1 for vertical glazing and less than 0.006 for horizontal glazing.

Exception2 to 131c): Daylit areas where existing adjacent structures or natural objects obstruct daylight to the extent that effective use of daylighting is not feasible.

Prescriptive Requirements for Skylights in Large Low-Rise Nonresidential Buildings

This part of the proposal prescriptively requires that at least half of the area of certain low-rise large enclosed spaces be lit with skylights. Unconditioned areas having LPD's greater than 0.5 W/SF are required to have skylights as a lighting efficiency measure. This is within the CEC's jurisdiction to regulate lighting efficiency in all locations including in unconditioned occupancies and outdoor lighting.[17] However, the skylight U-factor is not regulated for unconditioned spaces as this is regulating the thermal aspects of the envelope for an unconditioned space.

It should be noted that Title 24 sets a maximum limit of 5% skylight to floor area ratio in Section 143(a)6. This proposal does not suggest any changes to this maximum skylight area limitation.

Low rise enclosed spaces having all of the characteristics of A-D below

A. greater than 25,000 square feet; and

B. directly under a roof; and

C. with ceiling heights greater than 15 feet; and

D. having a lighting power density for general lighting equal to or greater than 0.5 W/SF

shall have at least one half of the floor area in the daylit zone under skylights. Electric lighting in the daylit zone shall be controlled by with multi-level automatic daylighting controls as described in Section 131c. Skylights shall comply with items 1-3 below:

[17] This new regulatory power resulted from the passage of SB5X which allowed the CEC to regulate all lighting power for all applications not previously regulated. For more information see http://www.energy.ca.gov/outdoor_lighting/background.html

1) The minimum ratio of skylight area to floor area in the daylit zone from skylights shall be a function of the general lighting LPD in the daylit area under skylights as shown in Table xx.

2) The skylights shall have a glazing material or diffuser that has been tested according to ASTM D1003 and has a measured haze value greater than 90%.

3) If the space is conditioned, the skylights shall have a tested U-factor equal to or less than the values in Section 143, Table 1-H. If the space is unconditioned, the skylights may be single glazed.

Table xx Minimum Skylight to Floor Area in Low-Rise Enclosed Spaces >25,000 SF Directly under a Roof

General Lighting Power Density in the Daylit Zone (Watt/SF)	Minimum Skylight to Floor Area Ratio
1.0 W/SF ≤ LPD	4%
0.5 W/SF ≤ LPD<1.0 W/SF	3%

Exception 1: Buildings in climate zones 1 or 16.

Exception 2: Auditoriums, movie theatres, museums, and refrigerated warehouses.

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The *SkyCalc* tool used for calculating appropriate Power Adjustment Factors (PAF's) was developed by the HESCHONG MAHONE GROUP for Southern California Edison as part of the California third party market transformation initiatives and is part of the Energy Design Resources suite of efficient building design tools. For more information see http://www.energydesignresources.com/.

David Kuo and Henry Lau of the Savings By Design program for Southern California Edison provided DOE-2 simulations of big box retail stores as well as detailed estimates of the costs associated with adding skylights. This was immensely helpful to this project.

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Energy Savings from Daylighting in New Construction Program

Table 12 tabulates the estimated gross savings by measure from the statewide nonresidential new construction program, Savings By Design (SBD)[18]. The Savings By Design program has two major incentive categories: the Systems approach and the Whole Building approach. Under the systems approach specific energy efficiency measures are incentivized whereas under the whole building approach a computer simulation compares the whole package of measures for a building and compares the savings relative to a building that minimally complies with Title 24. The tracking of whole building energy savings are not disaggregated to the measure level in the utility databases, therefore measure specific savings are not readily available for Whole Building projects. Table 12 demonstrates that daylighting controls incentivized under the Systems Approach component of the SBD program have saved 8.7 GWh/yr for 35% of the savings for the Systems Approach component. Also this 8.7 GWh/yr savings from daylighting controls represents 22% of the total Statewide nonresidential new construction program savings.

Table 12: Savings By Design - Annual Gross Energy Savings by Measure 1999-2001

	Measure	Savings MWh/yr	% of systems	% of total
Systems Approach	Shell	0	0%	0%
	LPD	9,037	36%	23%
	Daylighting Controls	8,755	35%	22%
	Other Lighting Controls	83	0%	0%
	Motors	1,965	8%	5%
	HVAC	4,665	18%	12%
	Refrigeration	773	3%	2%
	Systems Total	*25,278*	*100%*	*63%*
	Whole Building	14,871		37%
	Total	**40,149**		**100%**

Revised Power Adjustment Factors

The primary item of note from this analysis is that the savings from photocontrols do not change markedly between climate zones. In the main text of this report, a more detailed study of the effect of effective aperture on savings was performed using the climate data for climate zone 3 (San Francisco) which has lower savings from photocontrols than most other climate zones. This initial multi-climate analysis was performed using the SkyCalc defaults which includes a conservative70% dirt factor. The later analysis on climate zone 3 alone (see Table 4) used a dirt factor of 85% - because a dirt factor of 85% is implicit in the current definition of effective aperture in section 101 of the Standards.

[18] Savings combined from two reports: RLW Analytics for Southern California Edison, "Statewide Market Assessment and Evaluation Non-Residential New Construction Program Area: Building Efficiency Assessment Quarterly Report - 4th Quarter 1999 through 3d Quarter 2000" and "Statewide Market Assessment and Evaluation Non-Residential New Construction Program Area: Building Efficiency Assessment Quarterly Report - 4th Quarter 2000 through 2nd Quarter 2001"

Table 13: Fraction of TDV Energy Savings by Photocontrol Type for Warehouses

SFR Percent	Climate zone	Warehouse LPD = 0.7										
		Fluorescent setpoint = 20 fc					Metal Halide setpoint = 13 fc					
		On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 10% light	On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 25% light	hi/lo ballast
	2	0%	7%	7%	9%	17%	0%	13%	13%	17%	17%	1%
	3	0%	7%	7%	8%	18%	0%	13%	13%	17%	17%	1%
	7	0%	9%	9%	9%	20%	0%	14%	14%	20%	19%	3%
	10	0%	9%	9%	10%	20%	0%	15%	15%	20%	19%	2%
1%	12	0%	8%	8%	9%	18%	0%	14%	14%	18%	18%	2%
	2	34%	44%	27%	35%	45%	46%	52%	29%	39%	29%	26%
	3	33%	44%	28%	35%	45%	46%	53%	30%	40%	29%	26%
	7	38%	49%	30%	39%	49%	51%	58%	33%	43%	31%	29%
	10	40%	50%	30%	38%	49%	52%	57%	31%	42%	30%	29%
3%	12	35%	45%	28%	35%	46%	46%	53%	30%	40%	29%	26%
	2	50%	57%	32%	42%	53%	57%	62%	34%	45%	32%	32%
	3	51%	58%	33%	43%	54%	59%	64%	34%	46%	32%	33%
	7	56%	63%	35%	46%	57%	64%	68%	36%	48%	33%	35%
	10	56%	61%	34%	44%	55%	62%	66%	35%	47%	33%	34%
5%	12	51%	58%	33%	43%	54%	59%	64%	35%	46%	32%	32%

Table 14: Fraction of TDV Energy Savings by Photocontrol Type for Retail Occupancies

SFR Percent	Climate zone	Retail LPD = 1.6										
		Fluorescent setpoint = 65 fc					Metal Halide setpoint = 40 fc					
		On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 10% light	On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 25% light	hi/lo ballast
	2	0%	0%	0%	0%	7%	0%	0%	0%	3%	7%	0%
	3	0%	0%	0%	0%	7%	0%	0%	0%	4%	7%	0%
	7	0%	0%	0%	0%	7%	0%	0%	0%	5%	8%	0%
	10	0%	0%	0%	0%	7%	0%	0%	0%	4%	8%	0%
1%	12	0%	0%	0%	0%	7%	0%	0%	0%	4%	7%	0%
	2	0%	10%	10%	15%	22%	13%	26%	19%	25%	20%	12%
	3	0%	10%	10%	14%	22%	13%	26%	19%	25%	20%	12%
	7	0%	11%	11%	17%	24%	16%	29%	21%	27%	21%	13%
	10	0%	12%	12%	17%	24%	16%	29%	21%	27%	21%	13%
3%	12	0%	11%	11%	15%	23%	15%	27%	19%	25%	20%	12%
	2	14%	26%	19%	25%	34%	33%	41%	24%	33%	24%	21%
	3	14%	26%	19%	26%	34%	32%	41%	25%	33%	24%	20%
	7	16%	29%	21%	29%	36%	37%	45%	27%	35%	25%	22%
	10	16%	29%	21%	29%	36%	37%	45%	26%	34%	24%	20%
5%	12	16%	27%	19%	26%	34%	33%	41%	25%	33%	24%	21%

Mandatory Automatic Lighting Controls in the Daylit Zone under Skylights

These tables show that the electric lighting savings from photocontrols do not vary substantially by climate zone. The savings are much more sensitive to the lighting power density of the space (and by extension its lighting setpoint) and the skylight to floor area ratio (SFR).

Table 15:TDV Cost Savings by Photocontrol Type for Warehouses

SFR Percent	Climate zone	Warehouse LPD = 0.7										
		Fluorescent setpoint = 20 fc					Metal Halide setpoint = 13 fc					
		On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 10% light	On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 25% light	hi/lo ballast
	2	$ -	$ 0.25	$ 0.25	$ 0.32	$ 0.66	$ -	$ 0.49	$ 0.49	$ 0.65	$ 0.65	$ 0.03
	3	$ -	$ 0.26	$ 0.26	$ 0.32	$ 0.67	$ -	$ 0.48	$ 0.48	$ 0.65	$ 0.66	$ 0.04
	7	$ -	$ 0.34	$ 0.34	$ 0.37	$ 0.78	$ -	$ 0.56	$ 0.56	$ 0.79	$ 0.76	$ 0.12
	10	$ -	$ 0.37	$ 0.37	$ 0.42	$ 0.85	$ -	$ 0.63	$ 0.63	$ 0.88	$ 0.82	$ 0.10
1%	12	$ -	$ 0.31	$ 0.31	$ 0.34	$ 0.69	$ -	$ 0.51	$ 0.51	$ 0.69	$ 0.67	$ 0.06
	2	$ 1.30	$ 1.66	$ 1.01	$ 1.32	$ 1.71	$ 1.74	$ 1.99	$ 1.11	$ 1.49	$ 1.09	$ 0.98
	3	$ 1.27	$ 1.69	$ 1.05	$ 1.34	$ 1.73	$ 1.74	$ 2.02	$ 1.15	$ 1.53	$ 1.11	$ 1.01
	7	$ 1.51	$ 1.95	$ 1.20	$ 1.53	$ 1.94	$ 2.02	$ 2.30	$ 1.29	$ 1.72	$ 1.22	$ 1.15
	10	$ 1.71	$ 2.14	$ 1.28	$ 1.65	$ 2.09	$ 2.24	$ 2.48	$ 1.36	$ 1.82	$ 1.30	$ 1.25
3%	12	$ 1.34	$ 1.72	$ 1.05	$ 1.34	$ 1.74	$ 1.76	$ 2.01	$ 1.13	$ 1.53	$ 1.11	$ 1.00
	2	$ 1.89	$ 2.16	$ 1.22	$ 1.58	$ 2.00	$ 2.18	$ 2.37	$ 1.28	$ 1.72	$ 1.20	$ 1.21
	3	$ 1.93	$ 2.21	$ 1.25	$ 1.62	$ 2.04	$ 2.26	$ 2.44	$ 1.31	$ 1.75	$ 1.22	$ 1.24
	7	$ 2.21	$ 2.48	$ 1.38	$ 1.80	$ 2.24	$ 2.55	$ 2.70	$ 1.43	$ 1.91	$ 1.32	$ 1.37
	10	$ 2.41	$ 2.65	$ 1.45	$ 1.91	$ 2.39	$ 2.70	$ 2.86	$ 1.52	$ 2.02	$ 1.41	$ 1.45
5%	12	$ 1.93	$ 2.22	$ 1.26	$ 1.62	$ 2.04	$ 2.22	$ 2.44	$ 1.33	$ 1.76	$ 1.23	$ 1.23

Table 16: TDV Cost Savings by Photocontrol Type for Retail Occupancies

SFR Percent	Climate zone	Retail LPD = 1.6										
		Fluorescent setpoint = 65 fc					Metal Halide setpoint = 40 fc					
		On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 10% light	On/Off	Two level + off switching	1/2 controlled on/off	2/3 controlled on/off	Dimming min 25% light	hi/lo ballast
	2	$ -	$ -	$ -	$ -	$ 0.70	$ -	$ -	$ -	$ 0.36	$ 0.74	$ -
	3	$ -	$ -	$ -	$ -	$ 0.71	$ -	$ -	$ -	$ 0.37	$ 0.75	$ -
	7	$ -	$ -	$ -	$ -	$ 0.81	$ -	$ -	$ -	$ 0.50	$ 0.86	$ -
	10	$ -	$ -	$ -	$ -	$ 0.88	$ -	$ -	$ -	$ 0.53	$ 0.93	$ -
1%	12	$ -	$ -	$ -	$ -	$ 0.73	$ -	$ -	$ -	$ 0.45	$ 0.77	$ -
	2	$ -	$ 1.08	$ 1.08	$ 1.54	$ 2.31	$ 1.41	$ 2.76	$ 2.05	$ 2.60	$ 2.09	$ 1.26
	3	$ -	$ 1.04	$ 1.04	$ 1.52	$ 2.32	$ 1.39	$ 2.72	$ 2.02	$ 2.62	$ 2.10	$ 1.24
	7	$ -	$ 1.23	$ 1.23	$ 1.84	$ 2.63	$ 1.74	$ 3.17	$ 2.30	$ 3.00	$ 2.30	$ 1.42
	10	$ -	$ 1.39	$ 1.39	$ 2.01	$ 2.85	$ 1.98	$ 3.53	$ 2.54	$ 3.29	$ 2.50	$ 1.60
3%	12	$ -	$ 1.14	$ 1.14	$ 1.63	$ 2.39	$ 1.62	$ 2.85	$ 2.04	$ 2.67	$ 2.11	$ 1.32
	2	$ 1.52	$ 2.78	$ 2.02	$ 2.69	$ 3.59	$ 3.48	$ 4.31	$ 2.57	$ 3.45	$ 2.51	$ 2.18
	3	$ 1.44	$ 2.71	$ 2.00	$ 2.74	$ 3.61	$ 3.40	$ 4.36	$ 2.66	$ 3.51	$ 2.56	$ 2.16
	7	$ 1.79	$ 3.17	$ 2.27	$ 3.13	$ 3.97	$ 4.04	$ 4.98	$ 2.95	$ 3.83	$ 2.73	$ 2.43
	10	$ 1.86	$ 3.53	$ 2.51	$ 3.43	$ 4.33	$ 4.50	$ 5.37	$ 3.12	$ 4.08	$ 2.93	$ 2.46
5%	12	$ 1.68	$ 2.86	$ 2.02	$ 2.76	$ 3.65	$ 3.48	$ 4.35	$ 2.61	$ 3.50	$ 2.55	$ 2.19

Prescriptive Requirements for Skylights in Large Low-Rise Nonresidential Buildings

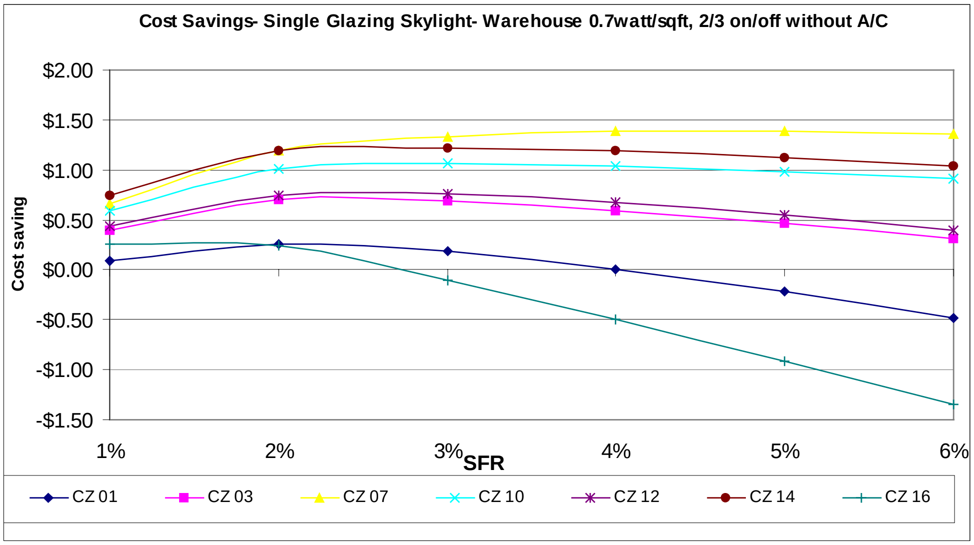

Figure 17: Warehouse(No A/C) 0.7 LPD Energy Cost Savings – Single Glazed Skylights

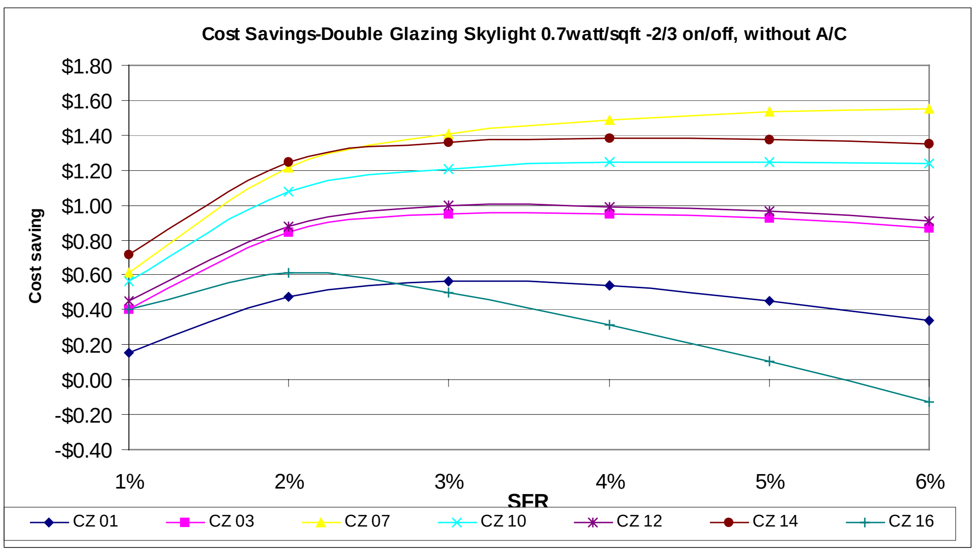

Figure 18: Warehouse(No A/C) 0.7 LPD Energy Cost Savings – Double Glazed Skylights

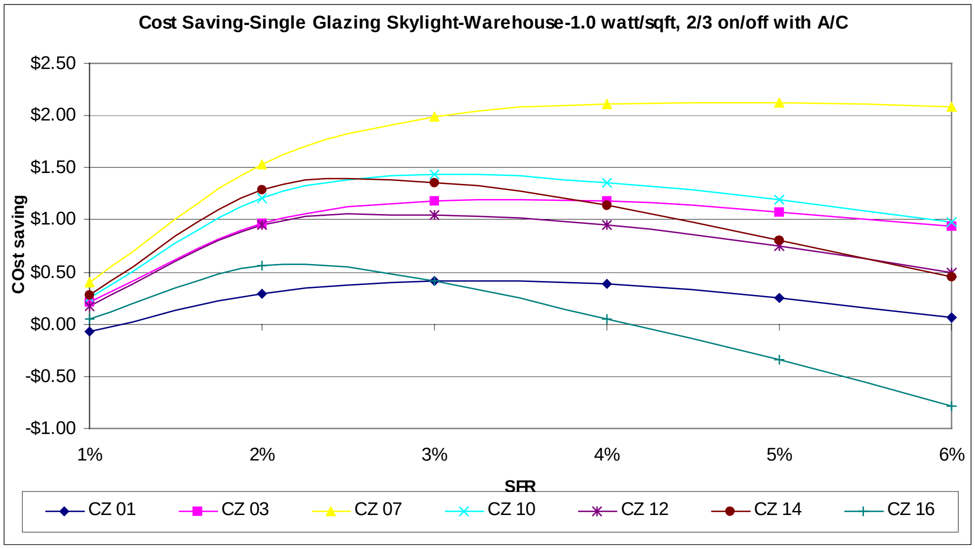

Figure 19: Warehouse 1.0 LPD Energy Cost Savings ($/SF) – Single Glazed Skylights

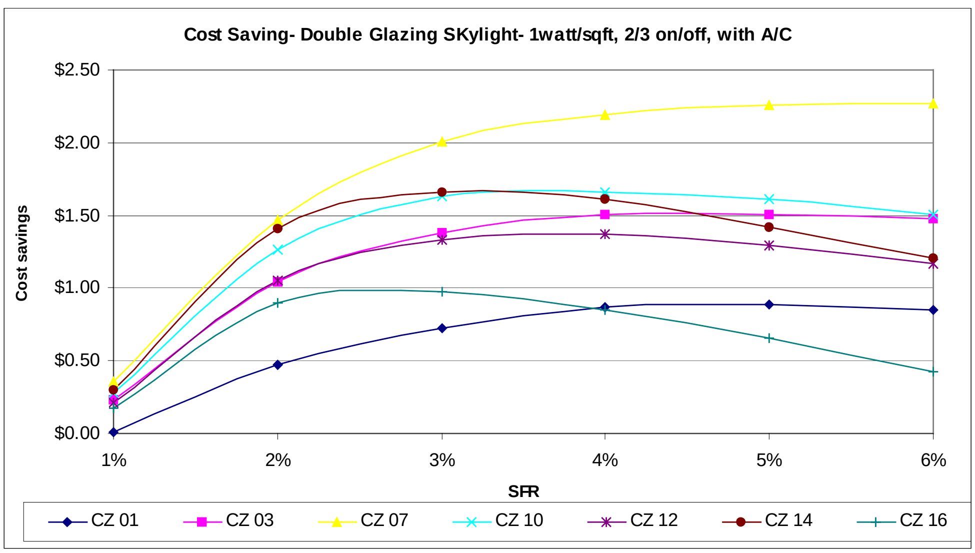

Figure 20: Warehouse 1.0 LPD Energy Cost Savings ($/SF) – Double Glazed Skylights

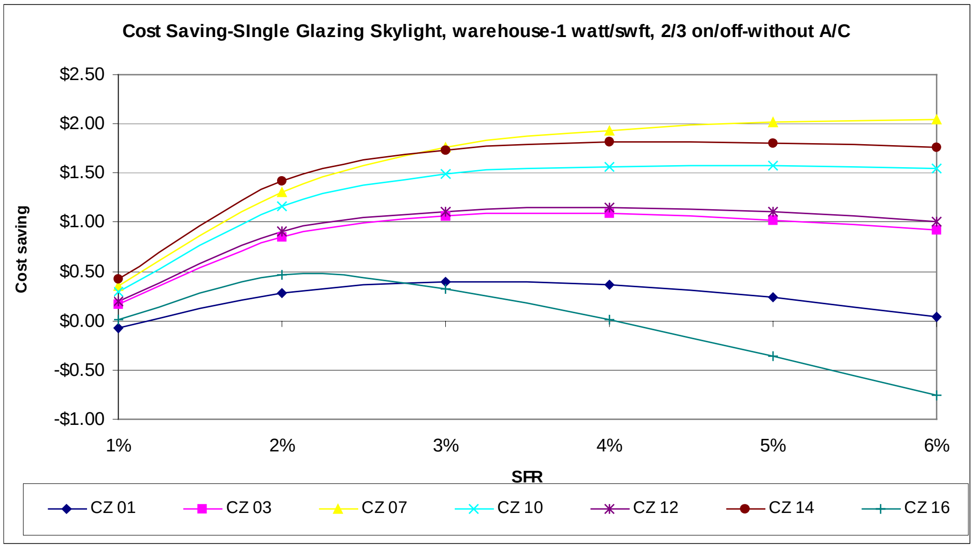

Figure 21: Warehouse(No A/C) 1.0 LPD Energy Cost Savings ($/SF) – Single Glazed Skylights

Figure 22: Warehouse(No A/C) 1.0 LPD Energy Cost Savings ($/SF) – Double Glazed Skylights

SkyCalc B/C Analyses of Warehouses - Varying LPD and Air Conditioning

Warehouses are often not air-conditioned and frequently not even heated. The benefit cost analyses below consider what happens to the benefit cost ratios when air conditioning is removed from the models. Section 146 Prescriptive Requirements for Lighting in the Complete Building Method (Table 1-M) allows different LPD's for warehouse type structures depending upon the occupancy. As a warehouse, the maximum LPD is 0.7 W/SF and as a low bay general commercial and industrial building the limitation is 1.0 W/SF. We considered both allowable LPD's to better characterize the energy savings impacts as LPD varies. What we find is that the addition of air-conditioning has only a little impact on the cost/benefit ratio at their optimal point. However, at larger SFR's the negative impacts of oversizing skylights are more pronounced when air-conditioning costs are considered and thus the drop off in B/C ratio is steeper when air conditioning is modeled.

Considering air conditioning costs even when air-conditioning is not used is a good idea so that the value of discomfort from overheating is monetized. But as is shown below, maximum B/C ratios occur at similar skylight to floor ratios with and without air-conditioning.

Table 17: Warehouse 0.7 Watt/SF LPD without Air Conditioning

CZ	SFR	***Single** Glazed Acrylic*				***Double** Glazed Acrylic*				***B/C Ratio Single to Double Glaz.***			
		2/3 on/off		Dimming 20%		2/3 on/off		Dimming 20%		2/3 on/off		Dimming 20%	
		15 year	30 year	15 year	30 year	15 year	30 year	15 year	30 year	15 year	30 year	15 year	30 year
1	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	(0.31)	(0.56)	0.25	0.15	(0.02)	(0.10)	0.40	0.44	1.83	3.35	1.35	2.63
	2%	0.41	0.29	0.51	0.41	0.66	0.78	0.79	0.95	1.83	3.37	2.10	3.77
	3%	0.44	0.31	0.27	0.07	0.75	0.91	0.66	0.79	2.09	3.77	2.38	4.18
	4%	0.33	0.13	0.01	(0.32)	0.75	0.90	0.52	0.58	2.75	4.87	2.97	5.18
	5%	0.14	(0.14)	(0.21)	(0.63)	0.63	0.74	0.35	0.35	2.91	5.10	3.01	5.24
	6%	(0.03)	(0.39)	(0.39)	(0.89)	0.51	0.57	0.22	0.16	2.98	5.20	3.05	5.31
	8%	(0.31)	(0.80)	(0.64)	(1.28)	0.30	0.27	0.03	(0.12)	3.04	5.29	3.08	5.35
	10%	(0.51)	(1.11)	(0.81)	(1.54)	0.14	0.04	(0.10)	(0.31)	3.07	5.34	3.10	5.37
	12%	(0.67)	(1.35)	(0.93)	(1.72)	0.02	(0.14)	(0.19)	(0.44)	3.09	5.37	3.10	5.37
3	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	0.48	0.51	1.20	1.43	0.49	0.60	1.07	1.35	0.62	1.31	0.25	0.77
	2%	1.58	1.98	1.40	1.73	1.46	1.94	1.39	1.84	0.89	1.74	1.35	2.44
	3%	1.41	1.78	0.98	1.19	1.40	1.90	1.10	1.48	1.37	2.48	1.63	2.86
	4%	1.17	1.45	0.69	0.77	1.29	1.75	0.91	1.21	1.87	3.31	1.99	3.48
	5%	0.89	1.07	0.44	0.42	1.08	1.46	0.72	0.95	1.94	3.42	2.06	3.58
	6%	0.67	0.76	0.25	0.15	0.91	1.23	0.57	0.74	2.01	3.51	2.07	3.60
	8%	0.35	0.29	(0.02)	(0.25)	0.66	0.88	0.36	0.44	2.08	3.63	2.10	3.65
	10%	0.12	(0.04)	(0.20)	(0.51)	0.49	0.62	0.22	0.23	2.10	3.66	2.11	3.66
	12%	(0.04)	(0.28)	(0.32)	(0.70)	0.36	0.43	0.13	0.09	2.11	3.67	2.12	3.68
7	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	1.10	1.38	2.05	2.59	0.87	1.13	1.63	2.13	-0.59	-0.79	-1.01	-1.43
	2%	2.63	3.52	2.40	3.21	2.10	2.89	2.01	2.76	-0.40	-0.48	0.19	0.42
	3%	2.50	3.46	1.91	2.63	2.07	2.93	1.64	2.31	0.18	0.40	0.44	0.80
	4%	2.22	3.10	1.60	2.22	1.91	2.73	1.43	2.04	0.42	0.80	0.60	1.07
	5%	1.88	2.65	1.32	1.84	1.65	2.38	1.20	1.72	0.58	1.04	0.65	1.15
	6%	1.62	2.29	1.09	1.52	1.45	2.10	1.02	1.48	0.64	1.14	0.71	1.24
	8%	1.24	1.76	0.79	1.11	1.14	1.66	0.78	1.13	0.68	1.21	0.70	1.23
	10%	0.98	1.38	0.60	0.82	0.93	1.36	0.62	0.90	0.72	1.26	0.73	1.27
	12%	0.79	1.10	0.46	0.62	0.78	1.13	0.51	0.74	0.73	1.28	0.74	1.29
10	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	0.92	1.12	1.81	2.26	0.80	1.02	1.48	1.91	0.02	0.24	-0.61	-0.72
	2%	2.32	3.06	2.02	2.64	1.94	2.64	1.78	2.41	0.13	0.41	0.64	1.19
	3%	2.11	2.85	1.53	2.03	1.84	2.56	1.41	1.96	0.62	1.18	0.89	1.58
	4%	1.79	2.43	1.21	1.60	1.65	2.32	1.19	1.66	0.97	1.74	1.13	1.99
	5%	1.48	2.01	0.93	1.23	1.41	1.99	0.98	1.36	1.08	1.91	1.17	2.05
	6%	1.22	1.65	0.73	0.94	1.21	1.72	0.82	1.14	1.15	2.02	1.20	2.09
	8%	0.87	1.15	0.45	0.54	0.92	1.31	0.59	0.82	1.17	2.06	1.21	2.11
	10%	0.62	0.79	0.27	0.27	0.73	1.03	0.44	0.61	1.21	2.11	1.24	2.15
	12%	0.44	0.53	0.14	0.08	0.59	0.82	0.34	0.45	1.23	2.14	1.24	2.16
12	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	0.58	0.65	1.34	1.61	0.59	0.72	1.19	1.50	0.61	1.27	0.22	0.67
	2%	1.76	2.24	1.51	1.89	1.57	2.10	1.45	1.93	0.69	1.39	1.19	2.16
	3%	1.53	1.97	1.09	1.36	1.48	2.03	1.16	1.57	1.29	2.32	1.44	2.55
	4%	1.28	1.63	0.78	0.92	1.35	1.85	0.95	1.28	1.68	2.98	1.79	3.13
	5%	1.01	1.25	0.52	0.55	1.14	1.56	0.75	1.00	1.75	3.08	1.87	3.26
	6%	0.78	0.92	0.32	0.27	0.96	1.30	0.60	0.78	1.79	3.14	1.89	3.29
	8%	0.43	0.43	0.04	(0.15)	0.69	0.92	0.38	0.46	1.86	3.25	1.93	3.35
	10%	0.20	0.08	(0.15)	(0.43)	0.51	0.66	0.23	0.24	1.92	3.33	1.94	3.36
	12%	0.02	(0.19)	(0.28)	(0.63)	0.37	0.45	0.13	0.09	1.94	3.37	1.94	3.37
14	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	1.29	1.60	2.30	2.88	1.03	1.33	1.89	2.45	-0.60	-0.73	-0.66	-0.81
	2%	2.85	3.78	2.38	3.14	2.36	3.22	2.06	2.81	0.02	0.24	0.57	1.07
	3%	2.46	3.35	1.76	2.36	2.12	2.97	1.59	2.21	0.62	1.15	0.85	1.51
	4%	2.08	2.85	1.38	1.86	1.89	2.68	1.33	1.86	1.00	1.77	1.07	1.88
	5%	1.69	2.32	1.06	1.42	1.58	2.24	1.08	1.52	1.06	1.88	1.15	2.01
	6%	1.40	1.92	0.83	1.09	1.35	1.92	0.89	1.25	1.10	1.94	1.17	2.03
	8%	0.98	1.31	0.52	0.64	1.01	1.45	0.64	0.89	1.18	2.06	1.19	2.07
	10%	0.70	0.91	0.31	0.34	0.79	1.12	0.47	0.65	1.20	2.08	1.21	2.10
	12%	0.50	0.62	0.17	0.12	0.63	0.89	0.36	0.48	1.21	2.11	1.22	2.12
16	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	0.01	(0.26)	0.81	0.74	0.37	0.34	1.06	1.23	2.63	4.86	2.64	4.90
	2%	0.89	0.80	0.47	0.24	1.29	1.57	1.01	1.19	3.15	5.64	3.54	6.22
	3%	0.45	0.19	(0.14)	(0.63)	1.03	1.23	0.58	0.61	3.55	6.24	3.75	6.53
	4%	(0.01)	(0.49)	(0.57)	(1.28)	0.76	0.84	0.30	0.20	4.43	7.73	4.49	7.81
	5%	(0.34)	(0.99)	(0.87)	(1.72)	0.50	0.48	0.08	(0.12)	4.45	7.76	4.53	7.87
	6%	(0.62)	(1.39)	(1.09)	(2.06)	0.29	0.18	(0.08)	(0.36)	4.50	7.83	4.56	7.90
	8%	(0.99)	(1.96)	(1.39)	(2.53)	0.01	(0.23)	(0.31)	(0.70)	4.54	7.88	4.57	7.92
	10%	(1.25)	(2.35)	(1.58)	(2.83)	(0.18)	(0.52)	(0.46)	(0.92)	4.58	7.94	4.58	7.94
	12%	(1.43)	(2.63)	(1.72)	(3.05)	(0.32)	(0.73)	(0.56)	(1.07)	4.57	7.93	4.58	7.94

Table 18: Warehouse 1.0 Watt/SF LPD with Air Conditioning

CZ	SFR	***Single** Glazed Acrylic*				***Double** Glazed Acrylic*				***B/C Ratio Single to Double Glaz.***			
		2/3 on/off		Dimming 20%		2/3 on/off		Dimming 20%		2/3 on/off		Dimming 20%	
		15 year	30 year	15 year	30 year	15 year	30 year	15 year	30 year	15 year	30 year	15 year	30 year
	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	(0.78)	(1.14)	(0.21)	(0.42)	(0.43)	(0.64)	0.03	(0.03)	1.74	3.16	1.56	2.88
	2%	0.19	0.03	0.59	0.57	0.39	0.43	0.78	0.96	1.32	2.54	1.63	3.03
	3%	0.68	0.68	0.59	0.55	0.91	1.16	0.85	1.08	1.90	3.46	2.00	3.61
1	4%	0.67	0.64	0.44	0.32	0.99	1.27	0.83	1.04	2.50	4.49	2.69	4.76
	5%	0.59	0.52	0.23	0.01	0.95	1.21	0.69	0.85	2.62	4.67	2.86	5.01
	6%	0.45	0.31	0.05	(0.26)	0.86	1.09	0.56	0.66	2.79	4.93	2.93	5.12
	8%	0.15	(0.12)	(0.26)	(0.71)	0.66	0.80	0.33	0.33	2.94	5.14	3.00	5.23
	10%	(0.09)	(0.49)	(0.48)	(1.04)	0.47	0.53	0.16	0.08	3.00	5.23	3.04	5.28
	12%	(0.29)	(0.78)	(0.65)	(1.30)	0.33	0.32	0.04	(0.11)	3.05	5.31	3.06	5.32
	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	(0.41)	(0.61)	0.66	0.76	(0.32)	(0.46)	0.60	0.75	0.22	0.64	0.25	0.70
	2%	1.67	2.14	1.95	2.51	1.29	1.73	1.72	2.32	-0.48	-0.40	0.65	1.34
	3%	2.16	2.86	1.68	2.19	1.91	2.65	1.61	2.21	0.83	1.64	1.28	2.32
3	4%	1.97	2.62	1.36	1.75	1.90	2.65	1.44	1.99	1.54	2.81	1.82	3.21
	5%	1.68	2.22	1.02	1.28	1.69	2.37	1.18	1.63	1.75	3.12	1.91	3.35
	6%	1.39	1.81	0.76	0.90	1.48	2.07	0.98	1.34	1.90	3.35	1.98	3.47
	8%	0.92	1.14	0.38	0.34	1.12	1.56	0.68	0.92	2.02	3.52	2.07	3.60
	10%	0.60	0.67	0.11	(0.05)	0.87	1.20	0.47	0.61	2.07	3.61	2.10	3.65
	12%	0.36	0.31	(0.08)	(0.33)	0.68	0.91	0.33	0.39	2.11	3.67	2.11	3.66
	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	0.24	0.28	1.24	1.56	(0.14)	(0.19)	0.96	1.24	-2.51	-3.75	-0.82	-1.15
	2%	2.91	3.92	3.06	4.12	2.08	2.87	2.42	3.34	-1.81	-2.67	-0.59	-0.81
	3%	3.45	4.80	2.85	3.95	2.69	3.82	2.34	3.32	-0.64	-0.87	0.11	0.28
7	4%	3.36	4.74	2.45	3.44	2.78	3.99	2.10	3.01	-0.02	0.11	0.41	0.78
	5%	2.91	4.15	2.01	2.85	2.47	3.58	1.77	2.55	0.39	0.74	0.61	1.08
	6%	2.54	3.64	1.67	2.38	2.19	3.19	1.50	2.18	0.55	0.99	0.70	1.22
	8%	1.93	2.78	1.18	1.68	1.71	2.51	1.11	1.62	0.68	1.20	0.76	1.31
	10%	1.50	2.16	0.84	1.19	1.37	2.01	0.84	1.22	0.76	1.32	0.81	1.39
	12%	1.18	1.69	0.60	0.84	1.11	1.64	0.65	0.94	0.84	1.44	0.83	1.42
	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	(0.41)	(0.58)	0.79	0.96	(0.52)	(0.71)	0.73	0.93	-1.22	-1.68	0.38	0.78
	2%	2.27	3.01	2.42	3.21	1.73	2.36	2.09	2.86	-0.83	-1.08	0.54	1.03
	3%	2.74	3.75	2.06	2.79	2.34	3.29	1.90	2.66	0.57	1.09	1.20	2.05
10	4%	2.50	3.45	1.57	2.13	2.31	3.29	1.59	2.25	1.44	2.46	1.72	2.89
	5%	2.03	2.81	1.14	1.52	1.97	2.81	1.26	1.78	1.68	2.82	1.85	3.09
	6%	1.63	2.26	0.79	1.03	1.66	2.38	1.00	1.41	1.79	3.00	1.95	3.23
	8%	1.04	1.40	0.31	0.34	1.20	1.71	0.61	0.85	1.92	3.19	1.98	3.29
	10%	0.61	0.78	(0.01)	(0.14)	0.86	1.23	0.36	0.48	1.99	3.31	2.03	3.35
	12%	0.31	0.33	(0.24)	(0.48)	0.62	0.87	0.18	0.21	2.02	3.35	2.05	3.39
	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	(0.64)	(0.91)	0.51	0.57	(0.61)	(0.84)	0.56	0.69	-0.41	-0.34	0.82	1.56
	2%	1.70	2.18	1.90	2.45	1.34	1.80	1.74	2.35	-0.37	-0.26	1.01	1.86
	3%	2.15	2.86	1.50	1.94	1.96	2.73	1.56	2.14	1.15	2.09	1.81	3.10
12	4%	1.88	2.50	1.10	1.39	1.90	2.65	1.32	1.81	1.99	3.44	2.35	3.99
	5%	1.50	1.98	0.71	0.84	1.62	2.26	1.02	1.39	2.15	3.70	2.43	4.12
	6%	1.15	1.48	0.40	0.39	1.37	1.91	0.77	1.04	2.37	4.03	2.49	4.20
	8%	0.60	0.67	(0.06)	(0.28)	0.95	1.31	0.42	0.53	2.55	4.30	2.58	4.35
	10%	0.21	0.10	(0.37)	(0.75)	0.64	0.86	0.18	0.18	2.58	4.35	2.64	4.44
	12%	(0.08)	(0.33)	(0.60)	(1.09)	0.42	0.53	0.01	(0.09)	2.63	4.43	2.67	4.49
	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	(0.30)	(0.43)	0.86	1.05	(0.53)	(0.71)	0.79	1.01	-1.97	-2.84	0.34	0.69
	2%	2.63	3.49	2.59	3.44	2.04	2.80	2.33	3.20	-0.69	-0.88	1.13	1.92
	3%	2.88	3.95	1.94	2.63	2.59	3.65	1.94	2.73	1.31	2.20	1.95	3.18
14	4%	2.44	3.37	1.31	1.77	2.40	3.42	1.55	2.18	2.25	3.68	2.66	4.31
	5%	1.88	2.60	0.76	0.99	1.99	2.85	1.11	1.57	2.53	4.13	2.75	4.45
	6%	1.35	1.85	0.36	0.41	1.60	2.29	0.80	1.12	2.74	4.44	2.81	4.54
	8%	0.62	0.78	(0.22)	(0.45)	1.01	1.44	0.34	0.46	2.79	4.52	2.91	4.70
	10%	0.12	0.05	(0.60)	(1.01)	0.63	0.88	0.05	0.01	2.92	4.72	2.94	4.75
	12%	(0.25)	(0.50)	(0.87)	(1.42)	0.34	0.45	(0.16)	(0.30)	2.94	4.76	2.96	4.78
	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	(0.60)	(1.02)	0.17	(0.05)	(0.44)	(0.69)	0.47	0.48	0.62	1.76	2.38	4.46
	2%	1.23	1.27	1.13	1.14	1.37	1.69	1.48	1.84	2.02	3.91	3.11	5.56
	3%	1.25	1.31	0.58	0.38	1.63	2.09	1.13	1.39	3.25	5.79	3.54	6.21
16	4%	0.87	0.75	0.06	(0.39)	1.44	1.82	0.81	0.93	4.16	7.32	4.43	7.72
	5%	0.43	0.13	(0.33)	(0.95)	1.13	1.39	0.51	0.50	4.39	7.66	4.46	7.76
	6%	0.06	(0.41)	(0.63)	(1.41)	0.84	0.98	0.28	0.17	4.45	7.75	4.51	7.83
	8%	(0.46)	(1.19)	(1.05)	(2.04)	0.44	0.40	(0.04)	(0.30)	4.53	7.87	4.55	7.89
	10%	(0.82)	(1.73)	(1.33)	(2.47)	0.16	(0.01)	(0.25)	(0.62)	4.56	7.92	4.59	7.95
	12%	(1.07)	(2.11)	(1.53)	(2.78)	(0.04)	(0.31)	(0.40)	(0.85)	4.57	7.93	4.59	7.95

Table 19: Warehouse 1.0 Watt/SF LPD without Air Conditioning

CZ	SFR	***Single*** *Glazed Acrylic*				***Double*** *Glazed Acrylic*				***B/C Ratio Single to Double Glaz.***			
		2/3 on/off		Dimming 20%		2/3 on/off		Dimming 20%		2/3 on/off		Dimming 20%	
		15 year	30 year	15 year	30 year	15 year	30 year	15 year	30 year	15 year	30 year	15 year	30 year
1	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	(0.78)	(1.14)	(0.23)	(0.44)	(0.43)	(0.63)	0.02	(0.05)	1.79	3.22	1.60	2.95
	2%	0.16	(0.01)	0.56	0.52	0.37	0.40	0.75	0.93	1.35	2.59	1.66	3.06
	3%	0.64	0.63	0.56	0.51	0.88	1.12	0.83	1.05	1.91	3.47	2.00	3.61
	4%	0.64	0.60	0.42	0.29	0.96	1.23	0.82	1.02	2.50	4.49	2.69	4.77
	5%	0.57	0.49	0.22	(0.01)	0.93	1.19	0.68	0.83	2.63	4.68	2.86	5.01
	6%	0.43	0.28	0.04	(0.28)	0.85	1.07	0.55	0.65	2.79	4.93	2.93	5.12
	8%	0.14	(0.14)	(0.26)	(0.72)	0.65	0.78	0.33	0.32	2.93	5.13	3.00	5.23
	10%	(0.10)	(0.50)	(0.48)	(1.04)	0.47	0.52	0.16	0.08	3.00	5.23	3.04	5.28
	12%	(0.29)	(0.78)	(0.64)	(1.29)	0.33	0.31	0.04	(0.10)	3.05	5.31	3.06	5.31
3	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	(0.36)	(0.55)	0.53	0.59	(0.25)	(0.36)	0.51	0.63	0.49	1.07	0.40	0.93
	2%	1.42	1.79	1.70	2.17	1.14	1.51	1.52	2.05	-0.17	0.07	0.70	1.41
	3%	1.88	2.48	1.52	1.96	1.70	2.35	1.47	2.02	0.89	1.72	1.26	2.28
	4%	1.77	2.33	1.26	1.61	1.73	2.40	1.35	1.86	1.52	2.77	1.78	3.16
	5%	1.53	2.01	0.97	1.20	1.57	2.19	1.13	1.55	1.72	3.07	1.87	3.30
	6%	1.29	1.66	0.74	0.87	1.39	1.94	0.95	1.30	1.86	3.29	1.94	3.41
	8%	0.88	1.08	0.40	0.38	1.08	1.50	0.69	0.93	1.98	3.46	2.03	3.54
	10%	0.60	0.67	0.16	0.03	0.86	1.18	0.51	0.66	2.03	3.55	2.06	3.59
	12%	0.38	0.35	(0.01)	(0.22)	0.69	0.93	0.38	0.46	2.07	3.61	2.07	3.60
7	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	0.32	0.38	1.10	1.38	0.04	0.04	0.86	1.12	-1.74	-2.57	-0.63	-0.87
	2%	2.46	3.31	2.62	3.52	1.79	2.46	2.07	2.86	-1.37	-2.00	-0.48	-0.64
	3%	2.96	4.11	2.52	3.49	2.31	3.28	2.06	2.93	-0.52	-0.69	0.09	0.24
	4%	2.94	4.14	2.24	3.15	2.43	3.48	1.91	2.74	-0.02	0.11	0.34	0.66
	5%	2.61	3.71	1.91	2.70	2.20	3.19	1.66	2.40	0.31	0.62	0.50	0.91
	6%	2.33	3.33	1.64	2.34	1.99	2.91	1.45	2.11	0.45	0.83	0.58	1.03
	8%	1.86	2.67	1.26	1.80	1.62	2.38	1.15	1.68	0.56	1.01	0.63	1.11
	10%	1.52	2.19	0.99	1.41	1.36	2.00	0.93	1.37	0.63	1.12	0.67	1.18
	12%	1.26	1.82	0.80	1.13	1.16	1.71	0.78	1.15	0.69	1.21	0.69	1.21
10	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	0.03	(0.02)	0.92	1.13	(0.13)	(0.20)	0.79	1.01	-1.15	-1.58	-0.06	0.10
	2%	2.18	2.88	2.34	3.09	1.63	2.23	1.93	2.64	-0.94	-1.25	0.06	0.29
	3%	2.62	3.57	2.13	2.89	2.15	3.01	1.84	2.58	0.09	0.34	0.56	1.07
	4%	2.51	3.46	1.82	2.48	2.19	3.11	1.66	2.34	0.68	1.30	0.92	1.65
	5%	2.18	3.03	1.50	2.05	1.95	2.79	1.42	2.01	0.87	1.59	1.04	1.84
	6%	1.89	2.63	1.24	1.69	1.73	2.48	1.22	1.73	0.97	1.75	1.12	1.96
	8%	1.45	2.00	0.88	1.17	1.38	1.99	0.93	1.32	1.09	1.92	1.14	2.00
	10%	1.12	1.53	0.63	0.82	1.12	1.62	0.73	1.04	1.15	2.01	1.18	2.06
	12%	0.89	1.19	0.45	0.55	0.94	1.35	0.59	0.83	1.17	2.05	1.20	2.09
12	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	(0.24)	(0.40)	0.62	0.70	(0.26)	(0.38)	0.60	0.74	-0.35	-0.24	0.46	1.00
	2%	1.60	2.04	1.80	2.32	1.25	1.67	1.59	2.14	-0.36	-0.25	0.58	1.20
	3%	2.02	2.69	1.57	2.05	1.78	2.46	1.51	2.07	0.70	1.39	1.21	2.18
	4%	1.89	2.52	1.33	1.72	1.79	2.50	1.38	1.90	1.31	2.40	1.61	2.86
	5%	1.64	2.18	1.05	1.33	1.60	2.25	1.16	1.60	1.44	2.60	1.69	2.98
	6%	1.39	1.83	0.81	0.99	1.43	2.01	0.98	1.34	1.63	2.90	1.74	3.06
	8%	0.97	1.23	0.46	0.48	1.12	1.56	0.71	0.95	1.79	3.14	1.83	3.19
	10%	0.68	0.80	0.22	0.12	0.89	1.22	0.52	0.68	1.82	3.19	1.89	3.28
	12%	0.45	0.46	0.04	(0.15)	0.71	0.97	0.38	0.47	1.88	3.27	1.92	3.33
14	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	0.43	0.50	1.29	1.60	0.06	0.06	1.03	1.32	-2.26	-3.30	-0.66	-0.83
	2%	2.85	3.80	2.86	3.81	2.10	2.87	2.35	3.21	-1.43	-2.02	-0.06	0.09
	3%	3.15	4.33	2.48	3.39	2.57	3.63	2.12	2.98	0.06	0.28	0.55	1.03
	4%	2.93	4.07	2.10	2.89	2.53	3.60	1.90	2.69	0.61	1.17	0.93	1.66
	5%	2.55	3.57	1.70	2.35	2.25	3.23	1.58	2.26	0.84	1.53	1.01	1.79
	6%	2.17	3.04	1.42	1.95	1.96	2.83	1.35	1.94	0.99	1.77	1.06	1.86
	8%	1.63	2.28	0.99	1.34	1.53	2.21	1.02	1.46	1.04	1.84	1.15	2.00
	10%	1.27	1.75	0.71	0.94	1.24	1.80	0.80	1.13	1.15	2.01	1.17	2.03
	12%	0.99	1.35	0.51	0.64	1.02	1.48	0.64	0.90	1.17	2.04	1.18	2.06
16	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1%	(0.66)	(1.09)	0.04	(0.21)	(0.40)	(0.65)	0.38	0.36	1.23	2.69	2.54	4.70
	2%	0.96	0.92	0.92	0.86	1.18	1.43	1.31	1.60	2.18	4.16	3.11	5.56
	3%	1.03	1.00	0.47	0.22	1.45	1.83	1.04	1.25	3.24	5.78	3.51	6.17
	4%	0.72	0.54	0.00	(0.46)	1.31	1.63	0.76	0.85	4.14	7.28	4.40	7.67
	5%	0.34	(0.01)	(0.34)	(0.97)	1.05	1.26	0.50	0.48	4.36	7.61	4.42	7.70
	6%	0.01	(0.49)	(0.61)	(1.38)	0.79	0.91	0.29	0.18	4.41	7.69	4.47	7.77
	8%	(0.46)	(1.19)	(0.99)	(1.95)	0.44	0.39	0.00	(0.24)	4.49	7.81	4.51	7.82
	10%	(0.78)	(1.68)	(1.25)	(2.35)	0.19	0.02	(0.19)	(0.53)	4.52	7.85	4.55	7.89
	12%	(1.01)	(2.02)	(1.43)	(2.63)	0.01	(0.24)	(0.33)	(0.74)	4.53	7.87	4.55	7.89

SCE Retail Analysis

The big box retail models come from an analysis that Southern California Edison performed for a big box retailer with stores across the state. Thus we can be reasonably assured that the lighting power densities, lighting setpoints and building configuration are representative of a chain of big box retail stores. In addition, SCE was able to obtain from the client how much construction cost was added from the use of skylights in the building design.

This describes the methodology used to calculate the total dollar savings of a retail store warehouse with skylights, for a period of 15 years and 30 years. The building is rectangular in shape with a total area of in excess of 50,000 square feet and a ceiling height of 20 feet. Four different types of conditions are compared here:

1. Base Case (no skylights) Over the entire conditioned square footage, the proposed lighting power density is an average of 1.64 W/sf.

2. Energy Saver Prototype This prototype assumes 108 skylights over the non-racking areas (approx. 59,400 sq ft of area). The skylights are double glazed, 5'x6' in size with a U-factor of 1.1 and an effective aperture of 3.8% in the non-racking areas (light transmission 70 %, skylight to roof ratio 5%, solar heat gain coefficient 0.65) and zero in the racking areas.

3. Energy Saver Plus 109 Skylights This case assumes 217 skylights spread over the non-racking and racking areas. The skylights are double glazed, 5'x6' in size with a U-factor of 1.1 and an effective aperture of 3.3 % (light transmission 70 %, skylight to roof ratio 4.8%, solar heat gain coefficient 0.65).

4. Energy Saver Plus 91 Skylights This case assumes 199 skylights spread over the non-racking and racking areas. The skylights are double glazed, 5'x6' in size with a U-factor of 1.1 and an effective aperture of 3% (light transmission 70 %, skylight to roof ratio 4.4%, solar heat gain coefficient 0.65).

All cases allow the lighting to be controlled using a photoelectric sensor to maintain 50 footcandles by a two step control strategy which turns 50 percent or 100 per cent of the lights off.

The annual consumption of energy, both in electric and gas consumption, are simulated using the DOE-2 simulation tool. The dollar amount and total savings from the base case are calculated for 15 year and 30 year discounted present values. The cost of electric and gas for both 15 and 30 years is as follows:

- Nonres Elec (15 yr) $1.37/kWh
- Nonres Elec (30 yr - envelope measures only) $2.10/kWh
- Nonres Gas (15 yr) $7.30/therm
- Nonres Gas (30 yr) - envelope measures only) $12.64/therm

Based on the number and cost of the double glazed skylight ($770 each) for each of the four cases, and the cost of two photosensor systems ($5,000), the total incremental cost ratio is calculated for both 15 years and 30 years. When the benefit cost ratio is calculated out at 30 years, a discounted value (15 years, 3% real discount rate) of replacing the entire photocontrol system is added to the first costs. The benefit/cost ratios for these prototypical stores are given in Table 20.

The benefit/cost ratio's from the DOE-2 simulations of a prototype of a retailer's store are similar to the benefit/cost ratios that we found using SkyCalc for our less detailed model.

Table 20: Benefit Cost Ratio of SCE Big Box Measures

CZ04	Sunnyvale		
Run	Description	Incremental benefit/cost ratio	
		15 yr	30 yr
1	As-Designed	N/A	N/A
2	EnergySaver Prototype	2.68	3.95
3	EnergySaver + Additional Skylights	2.97	4.45
4	EnergySaver + Reduced Addnl Skylights	2.82	4.22

CZ07	San Diego, CA		
Run	Description	Incremental benefit/cost ratio	
		15 yr	30 yr
2	As-Designed	N/A	N/A
3	EnergySaver Prototype	2.95	4.36
4	EnergySaver + Additional Skylights	3.02	4.53
5	EnergySaver + Reduced Addnl Skylights	2.97	4.46

CZ10	Riverside, CA		
Run	Description	Incremental benefit/cost ratio	
		15 yr	30 yr
2	As-Designed	N/A	N/A
3	EnergySaver Prototype	2.66	3.91
4	EnergySaver + Additional Skylights	2.94	4.42
5	EnergySaver + Reduced Addnl Skylights	2.92	4.37

CZ12	Sacramento, CA		
Run	Description	Incremental benefit/cost ratio	
		15 yr	30 yr
2	As-Designed	N/A	N/A
3	EnergySaver Prototype	2.36	3.47
4	EnergySaver + Additional Skylights	2.67	4.00