PG&E

CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

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Draft Report Sidelighting – Daylighting Requirements for Sidelit Areas near Windows

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Overview

Windows are a desirable feature of buildings and "windows are the leading factor in occupant satisfaction with their environment." (BetterBricks) As a proxy for how desirable windows are, often in organizations one's proximity to a window is an indication of one's rank within the company. Research conducted for the CEC sponsored Public Interest Energy Research (PIER) program found that the presence of view to the outside is correlated to increased student test score performance and increased performance on cognitive performance tests for office workers. (HMG 2003a, 2003b) In spite of the fact that windows by themselves usually increase energy consumption, the allowance for fairly large glazing areas in energy codes is in part due to the widespread recognition of the non-energy benefits of windows.

However, if windows are coupled with photocontrols, controls that reduce of turn off lights in response to the amount of interior daylight availability, significant energy savings are possible. As described in the Results section of this report, the TDV (time dependent valuation) weighted savings of lighting energy consumption are between 20% and 60% depending upon the area and transmittance of windows.

The energy savings from photocontrols are hugely dependent on the design of the space they are in as well as the lighting design, installation and commissioning. A field study of 57 buildings in the Western US found that the success of photocontrols saving their predicted amounts of energy was dependent on the preconditions of correct application and installation (HMG 2005). A common cause of control failure was controlling lights in areas that were not sufficiently daylit. As a result, this proposal seeks to reduce the size of the Title 24 "daylit area by windows" so that savings from photocontrols can be reasonably assured. This proposal also seeks to require the installation of photocontrols when this revised daylit area is sufficiently large to justify the expense of the controls.

Description

As many of the other major building efficiency measures have already been addressed by earlier versions of the energy code, sidelighting is one of the few large nonresidential energy savings measures yet to be adopted into the Title 24 energy code. Sidelighting is the admission of daylight though fenestration (windows and clerestories) in the perimeter walls of the building and reduction in electric lighting consumption with daylight responsive controls (photocontrols). Photocontrols sense the amount of light in the space and either switch of lights or dim lights in response to the amount of daylight available. Approximately 12% of nonresidential floor area is within one window head height (height to the top of the highest window) of windows with a similar amount of additional floor area within two window head heights of perimeter windows.

This proposal for sidelighting can be summarized as having three major features:

1. Redefinition of the daylit area by windows (sidelit area by windows) in terms of a geometric relationship to window head height. Taller windows have proportional and thus deeper daylit areas.

2. Definition of a primary and a secondary daylit (sidelit) area by windows. The primary sidelit area has mandatory requirements for separate circuiting (controls) and when the primary sidelit area is large, photocontrols are required. The secondary sidelit area can be used for optional photocontrols when lighting control credits are desired. For a given window size, the lighting control credits for lighting in the secondary sidelit area are less than for the lights in the primary sidelit area.

3. Revised definition of the effective aperture for the primary and secondary sidelit areas by windows. This definition is the product of the window area and window visible light transmittance divided by the area of the sidelit area.

Redefinition of the daylit area (sidelit area) by windows. The daylit area by windows is redefined in terms of a ratio to the window head height. This is similar to rules of thumb that daylighting practitioners have used for defining the daylit zone. However, the current standards are based on a fixed 15 foot distance from windows.

This new basis is derived from the results of a recent study completed by HMG on sidelighting photocontrol performance and computer simulations of daylight. With taller windows it is possible to extend the daylit area deeper into the building away from the perimeter walls

This geometric ratio of daylight area to window head height should not be surprising to architects who practice daylighting. The scalability of daylighting is the very feature that makes it possible to use scale models to represent daylighting in full-size buildings.

Primary versus secondary sidelit area by windows. From the field survey results, we found that daylighting controls are more reliable the closer the controlled zone is to the windows. However, savings are possible with larger daylit zone depths. If the zones are controlled so that lights near the windows are separately controlled or have separate setpoint, energy savings can be higher and illuminance uniformity is increased.

As a result, it is reasonable to limit mandatory circuiting and controls requirements to the areas closest to the windows, but to allow optional control credits to designers who wish to install automatic daylighting controls somewhat deeper into the space. Thus new definitions are created for these two zones, the "primary sidelit area" which is within one head height distance from the exterior windows and the secondary sidelit area which is within two head height distance from the exterior windows.

Two mandatory requirements are associated with the primary sidelit area.

1. When the primary sidelit area in any "enclosed space" (room) is greater than 250 square feet, 50% or more of the lighting in this area must be on a separate control. This control can be as simple as a manually operated light switch or could be an automated control. For most rooms, this requirement would cover only the first row of lights near the windows. Fewer lights would be controlled on this circuit as compared to the current standard, but this circuit may be turned off more frequently.

2. When the primary sidelit area in an "enclosed space" is greater than 2,500 square feet, an automatic daylighting control (photocontrol) is required. In rooms with window head heights that are 10 feet above the floor, this would require a sidelit area that is 250 feet long. Only a few large spaces would fall under this requirement: airport concourses, convention centers, perimeter hallways, very large open offices etc.

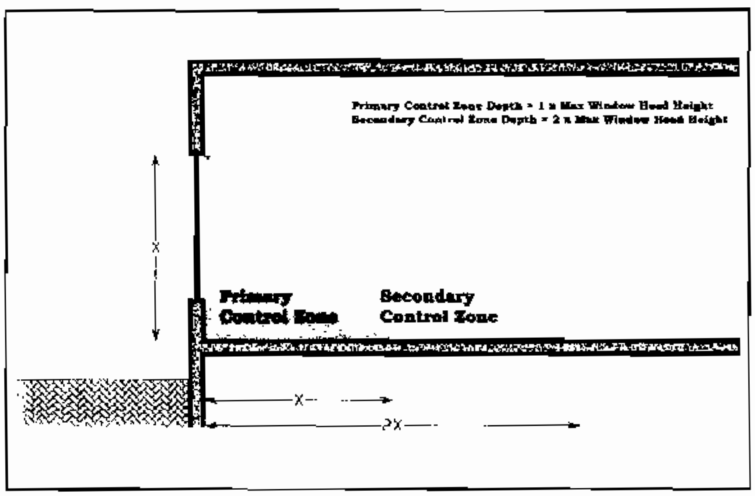


Figure 1: Side view of depth of primary and secondary sidelit area.

We have purposely selected extremely conservative mandatory control requirements. In many cases the shallower control zone depth for the primary sidelit area has no impact on the number of light switches used. The theoretical savings from automated controls would pay for themselves in a couple of years. Actual measured savings have been more modest. This conservative approach then assures that realized savings will be robust while increasing the experience of design practitioners and installers. These larger spaces provide large enough potential financial savings, that many of the owners of such spaces will be motivated to assure savings are maintained.

Revised definition of the effective aperture. Currently the effective aperture for windows is the window to wall ratio (WWR) multiplied by the visible transmittance (VT) of the window. The effective aperture is used to define the exception to the requirement for separate circuiting of lighting in the daylit area by windows. This definition is essentially applied for calculating the Power Adjustment Factor for photocontrols in that a matrix of WWRs and window VTs are used to define bins of power adjustment factors..

This definition would be acceptable if the desired metric was for the average amount of daylight that enters the room. However, the metric of interest is how much daylight enters the daylit area. One can have the same configurations of window properties, areas and spacing in two rooms but if one room is larger than the other, the WWR will be lower and the effective aperture is lower. However, this does not impact the amount of light in the sidelit area. Thus the new definition does not include the variable window wall ratio.

The new definition of primary sidelit area effective aperture is the total window area times the area weighted window visible transmittance divided by the area of the primary sidelit area. The secondary sidelit area effective aperture is the same except it is divided by the total areas of the primary and secondary sidelit areas. In general for a given space, the secondary sidelit area effective aperture will be one half that of the primary sidelit area effective aperture.

We developed a series of DOE-2 daylighting models with various combinations of window area, window transmittance, view windows only and in conjunction with clerestory windows etc. What we found was that the effective aperture metric correlated well with TDV energy cost savings.

Energy Benefits

This proposal mandates and encourages the use of photocontrols in sidelit spaces. It also prohibits some poor design practices. The upper quartile of 129 daylit spaces surveys found that the average energy savings in these well-designed spaces saved approximately 1.1 kWh/sf. DOE-2.2 simulation models conducted for this project estimate an average savings of 0.7 to 1.5 kWh/sf for typical configurations (Effective Apertures between 0.1 and 0.7), corresponding to a present value discounted over 15 years $1.20 to $2.70/sf in TDV savings. This estimate is a statewide average based on energy simulations conducted for the relatively overcast coastal CTZ3 (San Francisco), and the sunny central valley CZ13 (Fresno). Note that these savings are relative to a base case with the same windows but no photocontrols. Thus this proposal is not promoting more window space but rather harvesting the daylight from the typical window configurations that are part of the vocabulary of standard building design.

Non-energy Benefits

Several studies have been conducted on the productivity benefits of daylighting or view. However, we are not aware of any study showing that daylight responsive electric lighting controls (photocontrols) promote improved quality or productivity. However, well designed daylighting controls can result in the illuminance levels in the space to be more uniform with the control enabled than with the electric lighting not responding to daylight. The IESNA (Illuminating Engineering Society of North America) has set a number of consensus design standards based on uniformity as one measure of the goodness of the design. Thus it is likely that these controls do improve the quality of the visual environment.

Statewide Energy Impacts

The statewide energy impacts will be based upon an estimate of how many new spaces per year are constructed with large enough windows that would exceed the 2,500 sf primary sidelit area criteria and thus would be required to install photocontrol systems. The average savings per site would be 1.1 kWh/sf based on both the midpoint of our energy savings simulations as well as the typical savings for well performing photocontrol system in the field survey of sidelit spaces.

[redacted]

Environmental Impact

Photocontrols make use a very small amount of lead in the solder that are contained in printed circuit boards of any electronic circuit. This very small impact is vastly outweighed by the positive environmental impact is the reduction in air emissions from power plants due to reduced electricity consumption when electric lighting is turned off. When lights are turned off, internal gains from lights are reduced; this results in additional energy savings due to reduced air conditioner electricity consumption in the summer and swing months and increased furnace or boiler energy consumption in the winter. The emissions impacts of this sidelighting measure are calculated by multiplying the change in statewide electricity and natural gas consumption by the respective emissions factor values generated by the California Energy Commission for evaluating the environmental impacts of the 2005 standards as shown in Table 1 below.[1]

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

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

Type of Change

The proposal does not increase the scope of the standards. Mandatory requirements for lighting controls already exist in Section 131 and currently photocontrols are required for daylit areas under skylights when the combined daylit areas in a given enclosed area are over 2,500 sf. Similar requirements are proposed for the primary sidelit areas by windows when they also exceed 2,500 sf.

Standards - Section 131 of the standards would be changed to include required photocontrols for sidelighting. The definition of the daylit area in Section 131 would also be changed. The definition of the effective aperture by windows would be moved to Section 146. The power adjustment factors for photocontrol by windows in Table146A would also be revised to be a function of the effective aperture.

ACM – The ACM would include how to implement the daylighting algorithms in DOE-2.1E with especial emphasis on the definition of light levels, and placement of the light-ref-pt (light sensor).

Manual – the manual would have to incorporate the changes described above including new figures which describe the area of the daylit area by windows. There would need to be new Q & A to describe how the PAF's for photocontrols is calculated and when the photocontrols are a mandatory requirement. The acceptance section of the manual would also have to be updated to include any changes to how photocontrols by windows are tested.

Technology Measures

The energy savings from this measure relies on the effective use of photocontrols, controls that reduce electric lighting energy consumption in response the amount of available daylight in the space.

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

Measure Availability and Cost

Photocontrols have been available for several decades. However, the current market share for photocontrols has traditionally been very small. There is approximately a 1% penetration of daylighting controls into the market. This is changing with utility programs providing incentives for photocontrols. In addition, the 2005 Title 24 standards require photocontrols in the daylit area under skylights. This should increase the market and use for photocontrols in advance of the 2008 Standards taking effect.

The market for photocontrols in sidelit spaces is dominated by two manufacturers. However, we found products of six other manufacturers in the sidelit photocontrols field study and additional controls manufacturers are entering the daylight control market. Thus the technology is not proprietary and the market can scale up production if needed. Given the fairly conservative nature of this proposal, we do not anticipate that it will result in a market dislocation.

Multi-level daylighting controls can have an installed cost as low as $1,000 to a high end of $3,800. A prior study (NBI 2005) had given estimates of $0.2/sf for the addition of daylighting controls to existing control systems. They also made note of two estimates of $2,000 to $3,800 for control systems in a 5,000 sf office that also provided automatic shut-off control (time sweep) with override switches in addition to daylighting controls. They also give an estimate of $600 for commissioning from a contractor that rarely installs such systems. Another study estimates equipment cost at $300 to $600 for a single daylit zone. (Walerczyk 2004) Dimming ballasts add another $35 per ballasts or approximately another $0.35/sf. An estimate of $2,000 is likely high but conservative for this analysis.

Useful Life, Persistence and Maintenance

Photocontrols have no moving or parts that wear outside of the relay contacts for switching systems. Many systems have been disabled or otherwise mis-calibrated. We found this to be the case in the field survey of sidelit photocontrol systems. However, once a system was working well it could work for a long time. One system monitored was installed in 1989 and was saving more energy than many of its more recent counterparts! A common finding of this study and similar studies is that it is very important to commission the control correctly the first time to prevent dissatisfaction from space occupants. In interviews with commissioning agents and installers, a common complaint was the problem of self shielding while adjusting the control. If the adjustment to the control is on the light sensor itself, the presence of the installer interferes with the view that the sensor "sees". These complaints lead to the requirement for the sensor to have its control adjustments separate from the light sensor.

Performance Verification

The 2005 standards introduced acceptance tests for a wide range of HVAC and lighting controls. These acceptance tests in principle will help assure that the controls are working the way the standards and the designer intended. These acceptance tests will likely get a fair amount of use by the end of the year. We recommend that feedback be solicited to understand:

- Are the tests being conducted?
- Are there with the tests or the forms?
- Are inspectors asking for the forms? What are inspector and contractor attitudes towards these forms and what is the level of compliance?
- Are the forms being archived or not?

Cost Effectiveness

This proposal errs on the side of conservativism, so that the theoretical cost-effectiveness is extremely high. We think it is a reasonable first step for requiring photocontrols in sidelit spaces as actual savings have been substantially less than theoretical savings. This proposal has taken several steps to assure that good practice is enforced by the standards and should increase the likelihood of savings.

With energy cost savings discounted over 15 years to approximately $1.20 to $2.70/sf, the cost savings for a 2,500 sf space is $3,000 to $6,750 over the life of the controls. If the installed cost of the controls is $2,000, the benefit/cost ratio is 1.5 to 3.4.

Analysis Tools

The tool used for the analysis is eQUEST, a DOE2.2 based hourly simulation tool. The DOE2.2 engine uses the same calculation algorithms for daylighting and photocontrols operation as in the DOE2.1e reference engine used for the Title 24 standards. However, currently these daylighting and lighting controls algorithms are not being used for calculating savings from photocontrols. Instead a flat PAF value is used to modify the installed lighting load for all hours. We proposed to change the methodology such that the savings from photocontrols are calculated hourly using the daylighting and lighting controls algorithms built into the DOE2.1e engine.

Currently, the DOE2.1e engine can be used with our without any geometric definitions of the space – using just the space and envelope areas suffices, and the user is not required to enter dimensions and shape of spaces. As part of the change in the calculation procedures for daylighting and lighting controls, we propose that the simulation tools based on the ACM to use geometric models that specify the dimensions and shape of the room/space when someone is attempting to get a daylighting control credit or they are using the performance method to avoid installing skylighting or daylighting controls.

Relationship to Other Measures

The sidelighting and skylighting measures are inter-related. They use many of the same technologies and calculation processes. Changes resulting from this proposal interact with skylighting.

Methodology

The code changes proposed in this CASE report seek to utilize existing daylighting controls calculation capabilities in the approved ACM tools that use the reference energy simulation tool (DOE2.1e) for spaces that are lit with windows or 'sidelit' spaces.

In the current standards (2005 Title 24), the lighting control credits are not calculated within the DOE-2.1e reference engine algorithms. Instead, the installed lighting wattage is reduced by a set value for all hours of the day. The proposed methodology in this CASE report does away with this static value, and instead proposes to use the daylighting calculation methodology inherent to the DOE-2.1e calculation engine.

Overview of the DOE-2 daylighting calculation methodology

The DOE-2 daylighting calculations are done in three steps:

1. First, daylight factors are calculated for a lighting reference point(s) in the space for a number of sun positions and for CIE clear and overcast sky conditions. One can specify up to two lighting reference points in a given space. The daylight factor is the contribution of both direct light from windows and light reflected from internal building surfaces to the lighting reference point.

2. Second, the stored daylight factors are interpolated for every hour of the annual energy simulation, using the current hour external horizontal illumination, sun position and cloud cover. If glare control algorithms are used, the program automatically closes window blinds or drapes to reduce glare. Thus for each hour of simulation, the program knows the amount of daylight reaching the specified lighting reference points.

3. Third, the software simulates the daylighting control system to determine the electric lighting energy needed to make up the difference between the available daylight level and the design illuminance level. The resultant electric lighting requirements are passed on to the thermal calculations to calculate the energy consumption from lighting along with cooling and heating energy interactions.

Thus, to calculate the lighting energy needed for a given space, the user (or the ACM tool) needs to specify several inputs for the daylighting calculation – hourly local weather data, space and window orientation, window size, window light transmittance, orientation and reflectances of indoor surfaces, lighting reference points within the space, desired illuminance levels at those lighting reference points, and the lighting controls option (switching or dimming).

The inputs above can be categorized into three categories – Existing inputs, inputs that need to be modified, and new inputs.

Existing Inputs

These are inputs that are entered by the user (or the ACM tool) as part of the thermal simulations for the building/space. These inputs can be used as-is in the calculation of the daylighting controls.

Included are the hourly weather data (16 CZ weather files), building orientation, window orientation.

Inputs that need to be modified

These are inputs that are currently used for the thermal simulations, but which need to be modified in order to be useful for the daylighting simulation.

The space/window orientation and window sizes (area) are entered by the user as part of the building description language currently implemented in the approved ACM tools. Ideally, the users (or the tool) would specify the geometry of the space as well as the relative dimensions of the space (10' x 10' instead of specifying 100 sf.). Currently, users are not required to enter the dimensions and shape of the space, and are also not required to describe internal surfaces that do not have heat transfer across them. In order to conduct a proper daylighting calculation, we would require that the ACM tools require the users to enter the space dimensions and shape as well as define the internal surfaces for the daylit space. This would allow proper calculation of the daylight factor in the space.

Window U-factor and SHGC are currently specified by the users through the ACM tools, but the window light transmittance is not specified directly by the user. This will need to be specified for a given window so that appropriate daylight factors can be computed.

New Inputs

These are inputs that are currently not specified by the users or the ACM tools. These include the lighting reference point, lighting control strategy and desired illuminance levels in the space.

The desired illuminance levels are specified by the IESNA lighting handbook for particular tasks and occupancy types. The lighting control strategy is easily chosen by the user based on the actual technology used on site.

However, the most critical part of the calculation is the specification of the lighting reference point. While all the other inputs are fixed either by the building design and material choices or technologies used, there are no set guidelines for locating the lighting reference points.

However, there are some rules of thumb that have been established over the last 50+ years of daylighting analysis. The lighting reference point is usually located at a distance from the window that represents the edge of the daylit zone, or the depth beyond which there is no useful amount of daylight in the space. This distance is usually referenced as ratio of the daylit zone depth to the head-height of the window from which daylight enters the space.

For the sake of simplicity, we will refer to this ratio as the "DZ Depth/HH ratio" this point forward in the document. For a given building, the window head height is constant, and hence the DZ Depth/HH ratio is used to predict the daylit zone depth.

Literature review

The current Title 24 standards use a daylit zone depth of 15 feet regardless of the window head height. As part of the CASE work, our hypothesis is that the daylit zone depth is not a single number (15'), but rather is determined by a DZ Depth/HH ratio where there is an optimum distance from the window inside which savings are guaranteed. We used two separate studies that looked that at the relationship between the DZ Depth/HH ratio and photocontrols performance to guide the DOE2 based analysis we conducted for this CASE report.

Sidelighting Photocontrols Study

This study set out to describe the current status and performance of photocontrols in those daylit buildings utilizing a "sidelighting strategy", i.e. with daylight entering a space from windows along the walls rather than from above. Since the study was funded by two California utilities and the Northwest Energy Efficiency Alliance, it focused on buildings in California, Oregon and Washington State along the west coast of the USA. (HMG 2005)

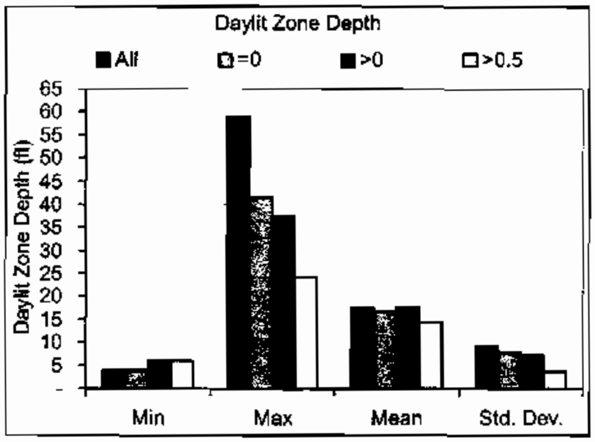
In order to gather candidate buildings for this field study, extensive professional networks were tapped to identify 369 buildings that would potentially fit the study criteria, with daylight provided primarily from the side, and photocontrols installed to reduce electric lighting energy use. A phone survey was conducted with the building managers of 162 of these buildings to verify the status of daylighting, to collect preliminary information and to recruit sites for more detailed on-site surveys. Ultimately, 56 of these buildings were visited, and the monitored performance of lighting energy in 123 spaces in 49 of these buildings was included in the analysis.

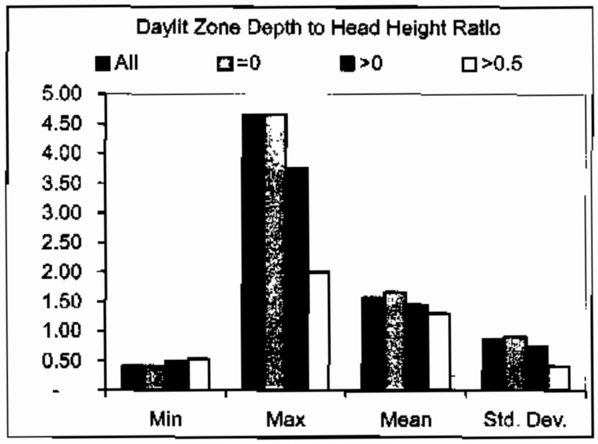
The monitored lighting energy performance of the spaces was then compared to an idealized savings estimate based on a DOE2 simulation of the space. The performance for each space was then rated through a Realized Savings Ratio (RSR). The RSR is the ratio of the monitored lighting energy performance onsite against the idealized lighting energy performance from DOE2. A RSR ratio of less than 1 indicates that photocontrol system saves less than the DOE2 predictions.

Following are the results of the study comparing the RSR with the DZ Depth/HH ratio and depth of daylit zone:

Figure 2: Sidelighting Photocontrols Study Results

A	B	C	D	E	F	G	H	I
	Daylit Zone Depth				Daylit Zone Depth to Head Height Ratio			
RSR	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.
All	4.00	58.75	17.48	9.19	0.40	4.65	1.57	0.86
=0	4.00	41.50	16.57	7.93	0.40	4.65	1.66	0.90
>0	6.00	37.50	17.72	7.43	0.50	3.75	1.46	0.72
>0.5	6.00	24.25	14.51	3.62	0.53	2.00	1.28	0.40





The results are presented in aggregate for various bins of RSR values for the monitored spaces (Column A). The 'All' bin represents all the spaces monitored, "=0' bin represents spaces where the photocontrol system is not operational, ">0" represents spaces where the photocontrol system is working, and ">0.5" represents spaces where the photocontrol system is working very well (at least 50% of the predicted savings). Only those spaces where the RSR>0.5 can be called as spaces where the photocontrols are working properly, and ones where the energy savings are fairly guaranteed.

Figure 1 illustrates the values for daylit zone depth. The best functioning systems (RSR>0.5) had daylit zone depths averaging 14.5 feet with a standard deviation of 3.6 feet. Thus, 11' to 18' was the norm for well functioning systems.

Figure 1 also illustrates the ratio of the daylit zone depth to head height (DZ Depth/HH ratio). The best functioning systems (RSR>0.5) had ratios averaging 1.3 with a standard deviation of 0.4. Thus, 0.9 to 1.7 was the normal ratio for well functioning systems, with a ratio of 2 as the maximum observed, i.e. a control zone depth that was twice the window head height. This suggests that limiting daylit zone depth for effective photocontrols to 1.7 or 2 times the window head height is a reasonable guideline.

Daylighting Autonomy Studies

Studies done at the National Research Council Canada (NRCC) by Christoph Reinhart have also shed more light on the appropriateness of various DZ Depth/HH ratios. In a paper presented at the Building Simulation 2005 conference, Christoph presents the results of a simulation-based analysis of the daylit zone depth and DZ Depth/HH ratio. He does so by establishing a link between the depth of the daylit zone and the simulated daylight autonomy distribution in a space. (Reinhart 2005)

Daylight autonomy is a percentage number that indicates the percent of occupied day-time hours when a task-specific minimum illuminance is maintained by daylight alone. In Christoph's analysis, the depth of the daylit area corresponds to points at which the daylight autonomy falls to half of its maximum value.

Using this basis, daylit zone depths of rectangular sidelit spaces were simulated using Radiance for a variety of climates, facade orientations, façade geometries, and usage patterns as seen in Table 2 below. For all the combination of these variables, a standard window head height was maintained.

Table 2: NRCC Analysis Variables

Variable	Range					#
Climates centers	Daytona Beach, FL	Los Angeles, CA	New York, NY	Vancouver, BC	Winnipeg, MB	5
Facade orientation	North	South	West	East		4
VT of windows [%]	35		75			2
Balustrade	yes		no			2
Sill	yes		no			2
Occupancy	Office		classroom			2
Min illuminance [fc]	30		50			2

Based on a parametric analysis of all these variables (640 design combinations spread over a variety of climate regions), the study presents the distribution of the appropriate daylit zone depth to window head height ratio as seen in Figure 3 below.

Figure 3: NRCC Analysis Results

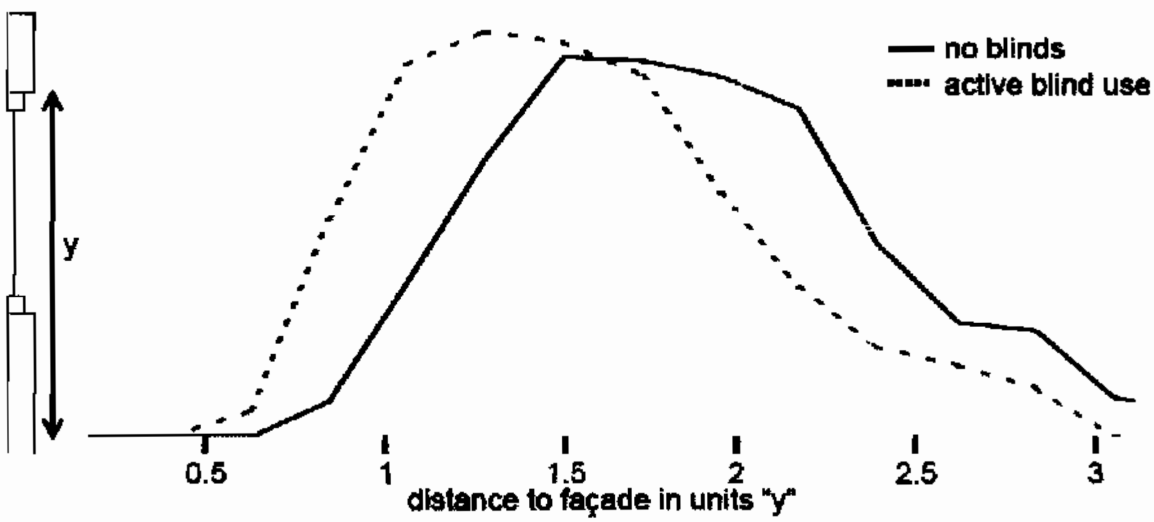


Figure 3: Frequency distribution of predicted daylit zone depths for 640 design combinations without a shading device (solid line) and with manually controlled generic venetian blinds (dotted line).

The results show that in the absence of blinds, predicted daylit zone depths range from as little as 0.5 to over 3.3 times the window-head-height. Over 85% of predicted zone depths fall into the ratio band of 1.0 to about 2.5. In the presence of blinds however, overall daylit zone depths decrease, with 85% of all predictions now lying between 0.8 and 2. Since some type of shading device is necessary in most spaces, an upper boundary of 2 seems to be preferable to the optimistic 2.5 that can be achieved without blinds.

Literature Review Conclusions

Based on the results of the two studies, it is clear that energy savings from daylighting controls with windows are largely dependant on how deep the control zone is in relation to the window head height. The DZ Depth/HH ratio expresses this relationship, and results show that a DZ Depth/HH ratio of 2.0 is the maximum allowable ratio for a successful daylighting control system. Results also show that savings are most optimal around a DZ Depth/HH ratio of 1.0.

In considering how the results of this literature review are applied to the Title 24 standards, it should be recognized that these definitions of the "daylit zone" are different from what is called the "daylit area" in Title 24. The daylit area in Title 24 defines whether a luminaire should be on a separate circuit or be controlled by a daylighting control. As such one can conceive of the "daylit zone" to extending past the controlled luminaire to halfway to the next row of luminaires. Thus the Title 24 "daylit area." can be thought of being one half the luminaire spacing less than the "daylit area." If light fixtures are approximately spaced one head height apart (10 feet apart in a 10 foot ceiling), the Title 24 daylit area is approximately one half head height less than the daylit zone considered in these studies.

DOE-2 Analysis

Currently, the code requirements are based on the assumption of daylit zone of a constant 15 ft from the closest window. In our experience, this static value of daylit zone (15 ft) is not representative of the actual area of the space that can be controlled through daylight controls. Our hypothesis based on the studies and other lighting models is that the actual daylit zone is dependant on the space geometry and the relationship between the window size/height and the depth of the space along with the visible transmittance of the windows.

Initial Parametric Analysis

To illustrate the limitations of using a static 15' control zone depth, and to illustrate the range of savings possible from daylighting controls, we initially conducted a parametric analysis using the DOE-2 engine with a simple box model using the following criteria as a stage 1 analysis.

Table 3: DOE-2 Analysis Stage 1Parameters

Variable	# of Runs per Variable	Parametric Values
Building Type	1	*Open Office (50' x 50')*
Location	1	*CZ 03 (San Francisco)*
Orientation	2	*North Window, South Window*
Window Area	2	*Small (20% Window/Wall ratio)), Medium (40%) window sizes. Window Head Height held constant at 8 feet.*
Distance from Window	8	*Every 5' from Window(5',10',15',20',25',30' etc)*
Lighting Control Strategies	3	*(On/Off, On/50%/Off, Dimming)*
Total # of Runs	**96**	

The model assumed fluorescent luminaires most typical for office spaces. For each of these runs, the key outcome variables were the lighting energy savings (kWh) and demand savings (kW). Dimming controls assumed that the lighting system went to a minimum of 10% light output and consumed 20% of its rated power at that light output. The model also used glare control algorithms embedded in DOE2 to model the operation of blinds in response to excessive sunlight penetration in the space.

We chose to run the models for Climate Zone 3 – a mild climate with a good mix of clear and cloudy days. Figure 4 through Figure 6 illustrate the results for this initial set of runs. Each of the three graphs shows the energy savings (kWh) possible from On/OFF switching, Bi-level switching (ON/50%/OFF), and continuous dimming. The results are segregated by orientation (North vs. South) and window to wall area ratio (20% vs. 40%).

Figure 4: Lighting Energy Savings in CZ3 with ON/OFF Controls

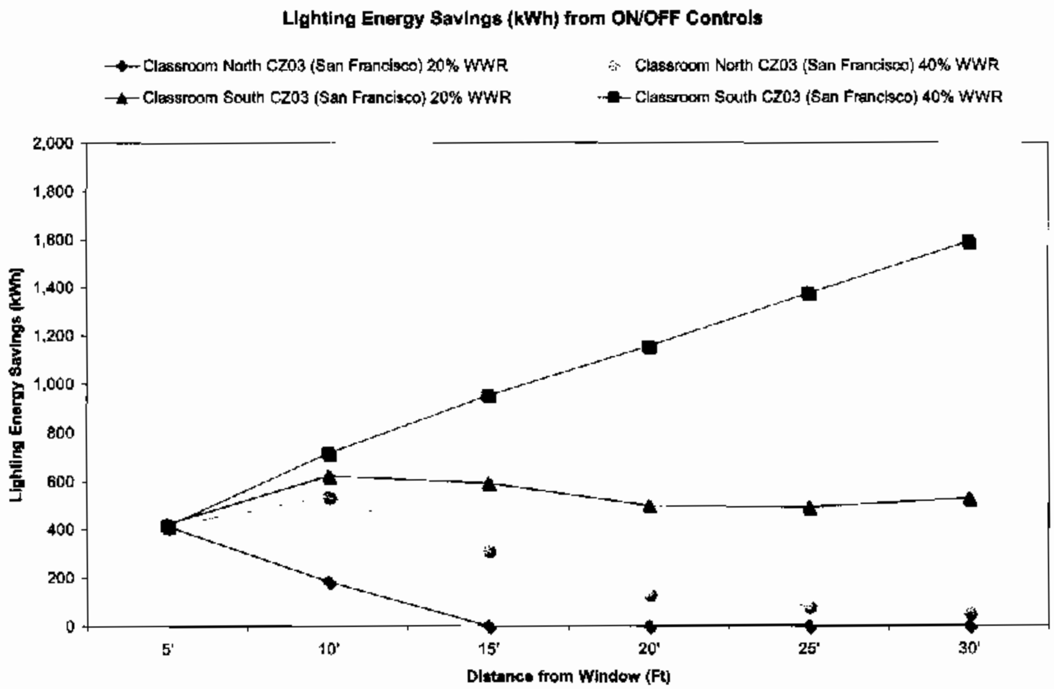


Figure 5: Lighting Energy Savings in CZ3 with Bi-level Switching

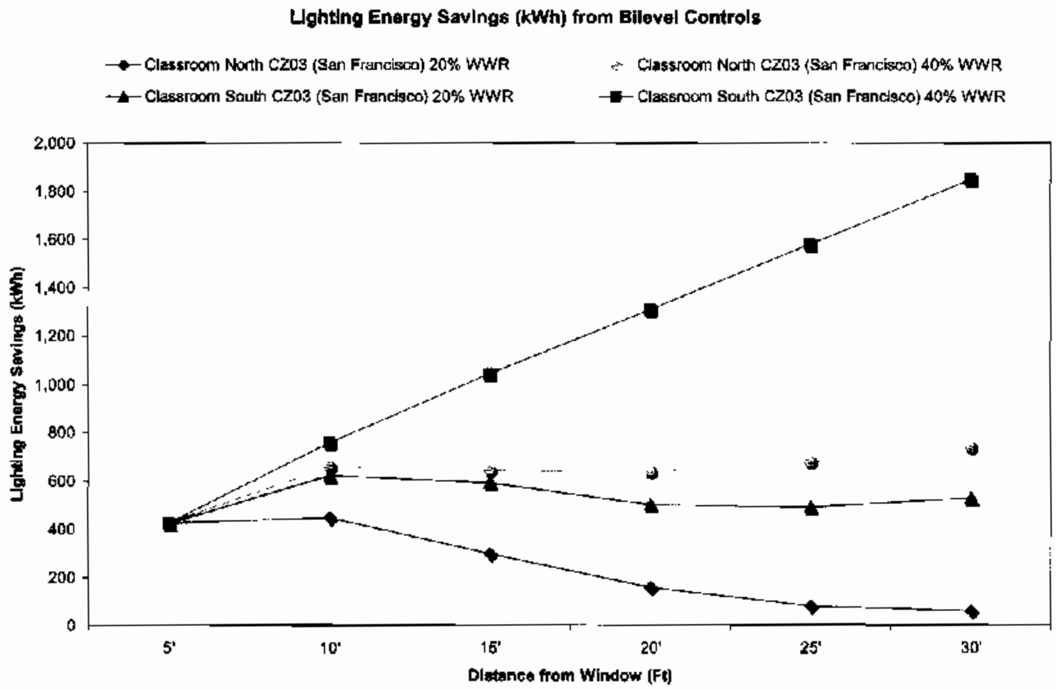
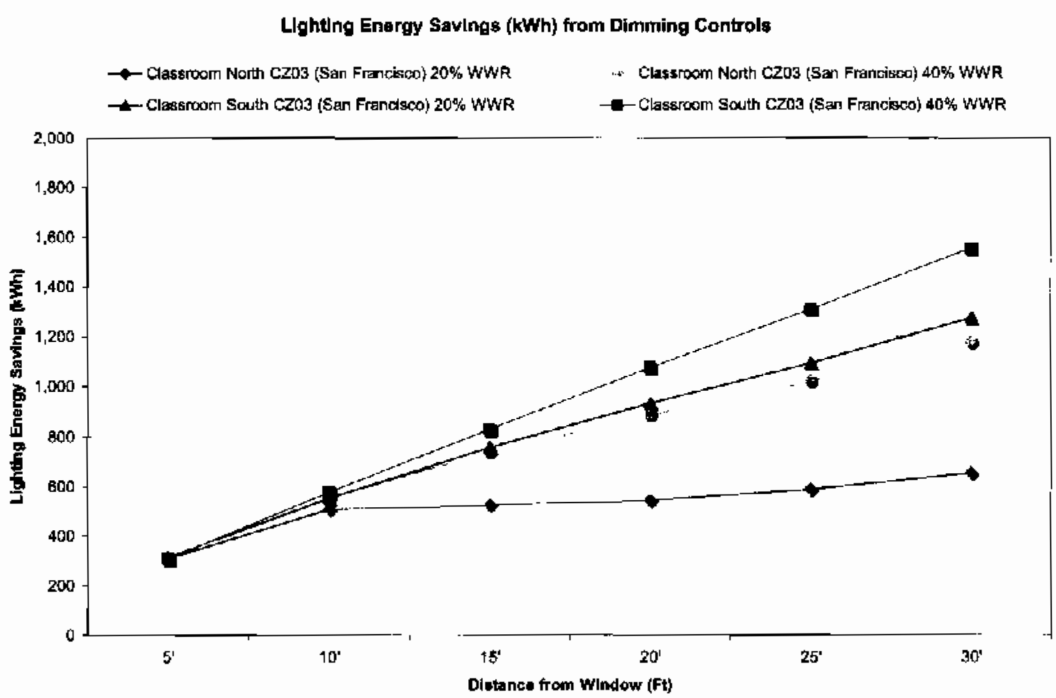


Figure 6: Lighting Energy Savings in CZ3 with Dimming Controls



Results from these three graphs show that while the savings vary significantly not only by control type, window wall area ratio, but also by the depth of the control zone (distance from window). For the ON/OFF controls, least savings are seen on the north orientation with 20% WWR, with maximum savings on the south orientation with 40% WWR. This same dynamic is seen for both bi-level and dimming controls. For each of the three controls, the control depth at which optimal savings are achieved varies between 10' to 30' from window. This indicates that a better metric for depicting the actual daylit zone is needed. To identify this metric, we conducted a second set of parametrics that we will discuss below.

The one cause for concern in the DOE2 models is the probably over-prediction of savings for the southern orientation at 40% WWR. We suspect that DOE2 is erroneously calculating ever-increasing savings as one increases the daylit zone depth for the given space. We account for this potential error in our further analysis by tempering the DOE2 savings prediction by applying the Realized Savings Ratio (RSR) explained earlier in this report.

Effective Aperture Parametric Analysis

As mentioned in the literature review section of this document, we strongly believe (based on field data and lighting simulations) that the proper metric for determining the effectiveness of daylighting controls in sidelit applications is the 'effective aperture' of the space. The effective aperture (EA) is a good proxy for the amount of daylight entering the space and accounts for the control zone depth, window area, window head height, and window visible transmittance.

The effective aperture is the product of the window area and its visible light transmittance divided by the area of the sidelit zone. This definition of effective aperture matches quite closely to the definition of daylight "lunes" for windows that are infinitely wide. That is the effective aperture gives a good representation of the effect of window size and window location on the fraction of daylight entering a space.

To calculate and illustrate the impacts of the effective aperture on lighting energy savings, we conducted a second set of parametrics using the following variables:

Table 4: Variables for the Effective Aperture Parametric Analysis

Variable	# of Runs per Variable	Parametric Values
Building Type	1	*Open Office (50' x 50')*
Location	2	*CZ 03 (San Francisco), CZ 13 (Fresno)*
Orientation	2	*North Window, South Window*
Ceiling Height*	3	*10.0, 12.0, 20.0*
Window Height*	3	*4.0, 7.0, 12.0, 20.0*
Window/Façade Type*	4	*View Window, Clerestory Window, View + Clerestory Window, Window wall*
Distance from Window/ Max. Window Head Height (DZ Depth/HH ratio)	2	*1.0, 2.0*
Window Visible Light Transmittance	4	*10%, 30%, 50%, 70%*
Lighting Control Strategies	3	*(None, On/Off, Multi-level Switching or Stepped Dimming)*
Total # of Runs	**696**	

* We modeled a number of combinations using these three variables, as shown in Table 5 below.

Table 5: Effective Aperture Parametric Window Details

Ceiling Height	Head Height	View window height	Clerestory Height
10	7		7
10	7	4	
12	12		3
12	12	4	3
12	12		12
20	20		4
20	20	4	4
20	20		20

The windows were modeled with Venetian blinds, and glare control algorithms in the DOE2 engine were used to approximate control of blinds to eliminate glare.

Results from this parametric analysis were then used to calculate the PAF's for sidelit photocontrols as a function of effective aperture of the space.

Results

The lighting energy consumption was the output of interest in the parametric analysis. Once the simulations were completed, the raw hourly lighting energy consumption numbers (kWh) for each of the 696 runs were then multiplied with the appropriate Time Dependent Valuation (TDV) multipliers to get the annual TDV weighted lighting energy consumption numbers. Lighting energy savings for the various parameters is the difference in their energy use vs. a case with no lighting controls.

Figure 7 through Figure 10 show the TDV weighted lighting energy consumption plotted against the effective aperture of the space using a scatter plot. The TDV energy consumption is represented as % of controlled load for a case with no controls. Controlled load is the amount of lighting load that is controlled by the photocontrols. Each graph has two series. The blue dots indicate the energy use of the lighting circuits in the primary zone (DZ Depth/HH ratio = 1), and the magenta dots indicate the energy use of lighting circuits in the secondary zone (DZ Depth/HH ratio = 2). A trend line is drawn for each of the two datasets using the logarithmic trending algorithms. The slope and intercept of the trend lines was then used to calculate projected lighting energy savings for the space at various EA values.

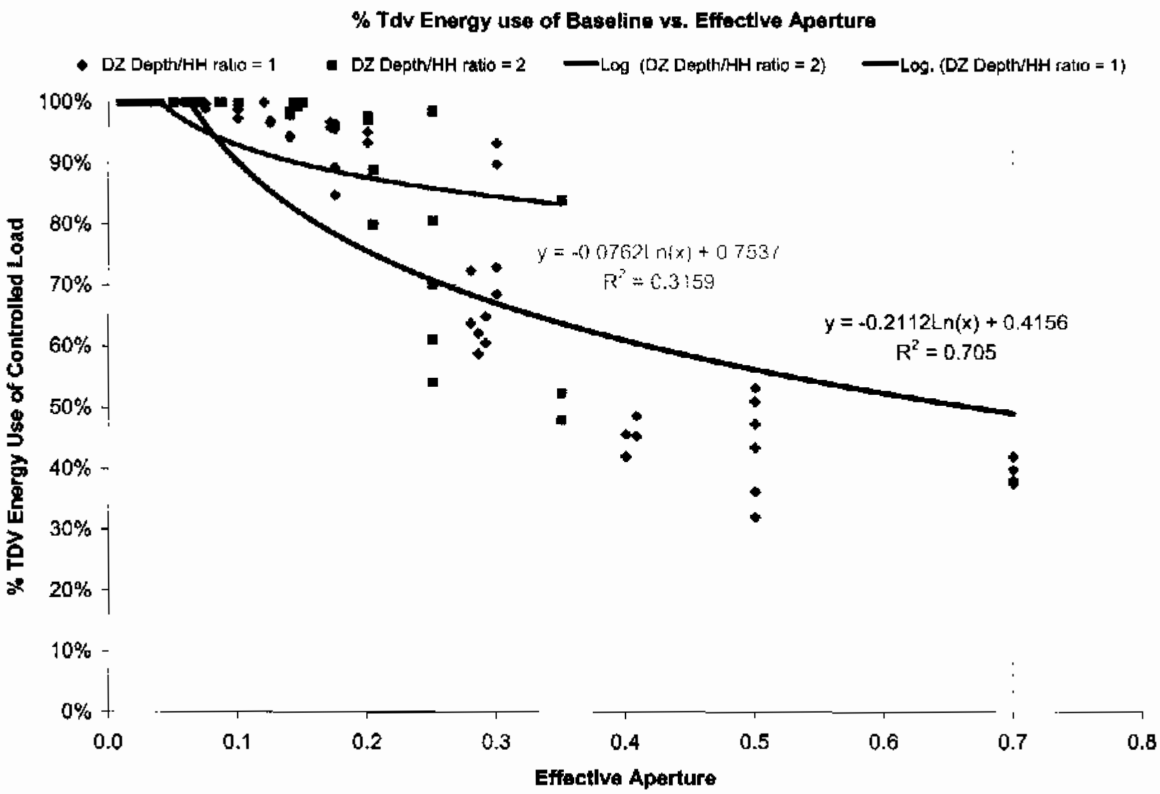


Figure 7: North Facing with ON/Off Controls

As seen in Figure 7, there are minimal lighting energy savings below 0.1 EA for a space facing north and using simple ON/OFF controls. As the EA increases, savings increase (% TDV energy use decreases). At about 0.3 EA, we can see ~35% savings for the control zone with DZ Depth/HH =1 (primary zone). Savings stabilize around 55% once the EA reaches 0.4.

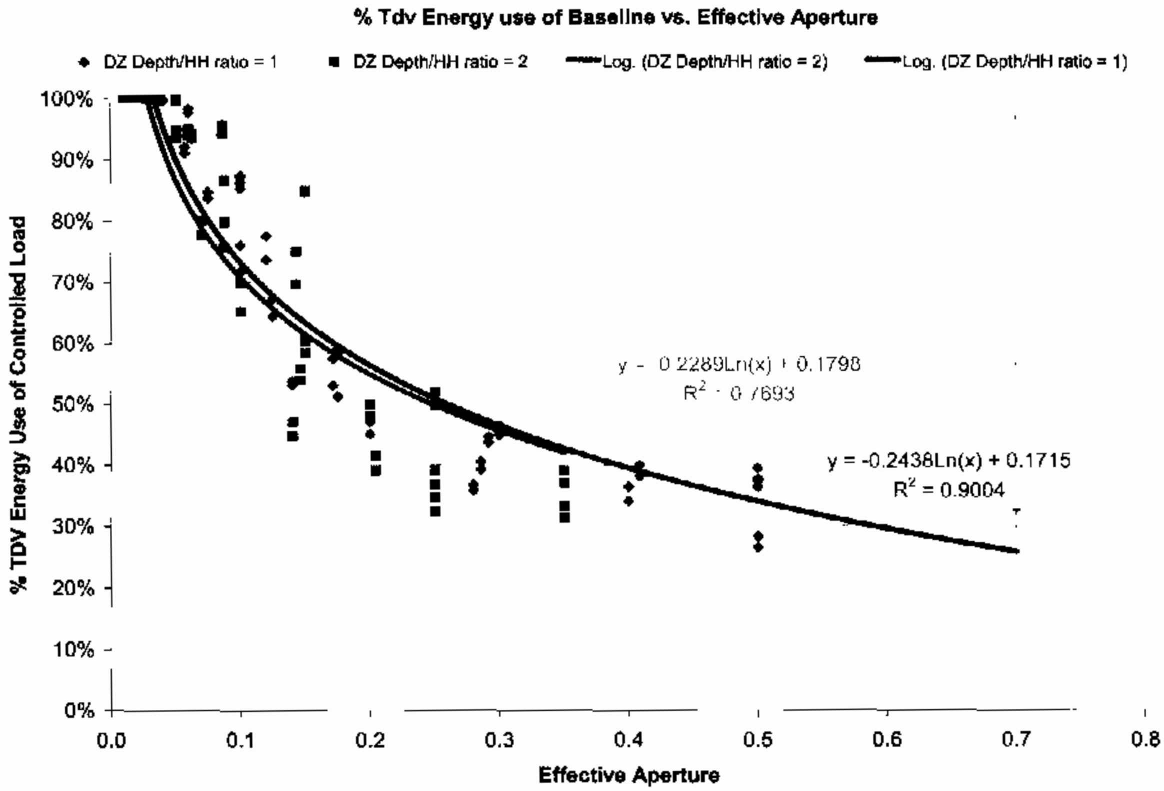


Figure 8: South Facing with ON/OFF Controls

For the south facing spaces, lighting energy savings show a steady increase (steady decrease in % TDV Energy Use) as the EA increases. Savings still stabilize around 60% as the EA reaches 0.4 and beyond.

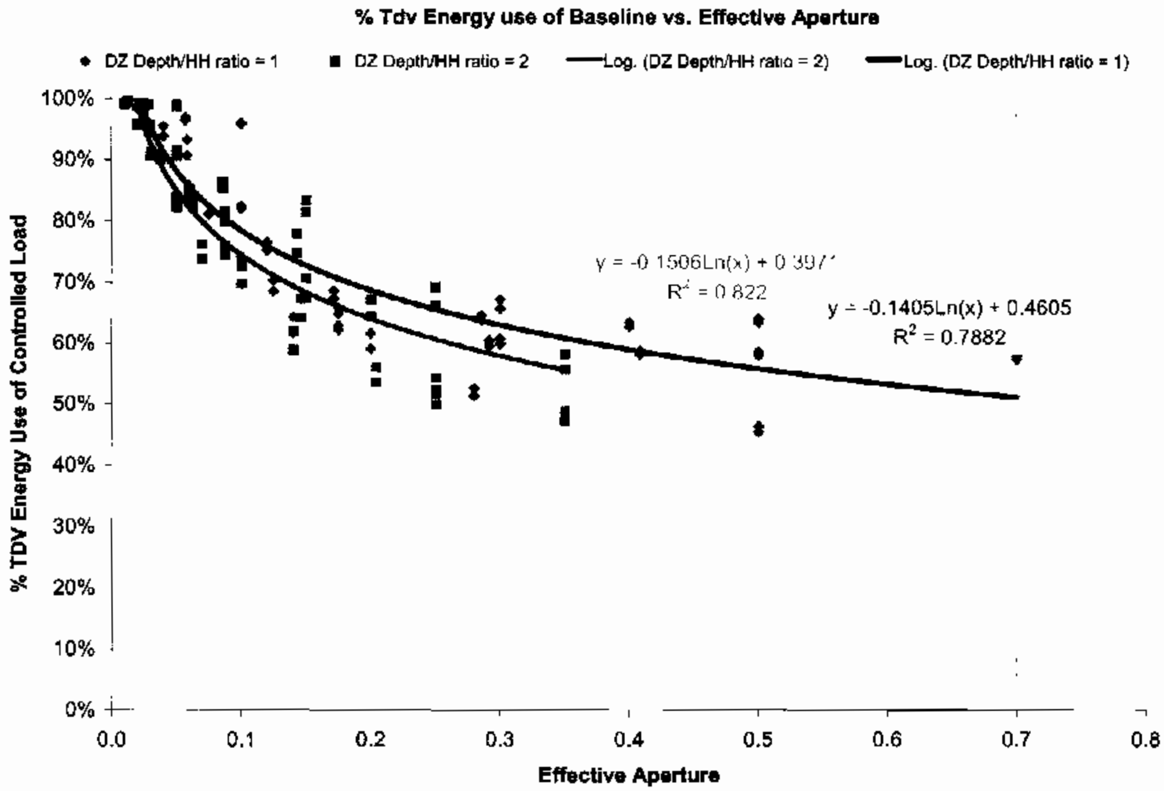


Figure 9: North Facing with Multi-level Controls

Multi-level (including dimming) controls provide greater savings than ON/OFF controls for the north orientation. Savings stabilize at ~40% around 0.3 EA.

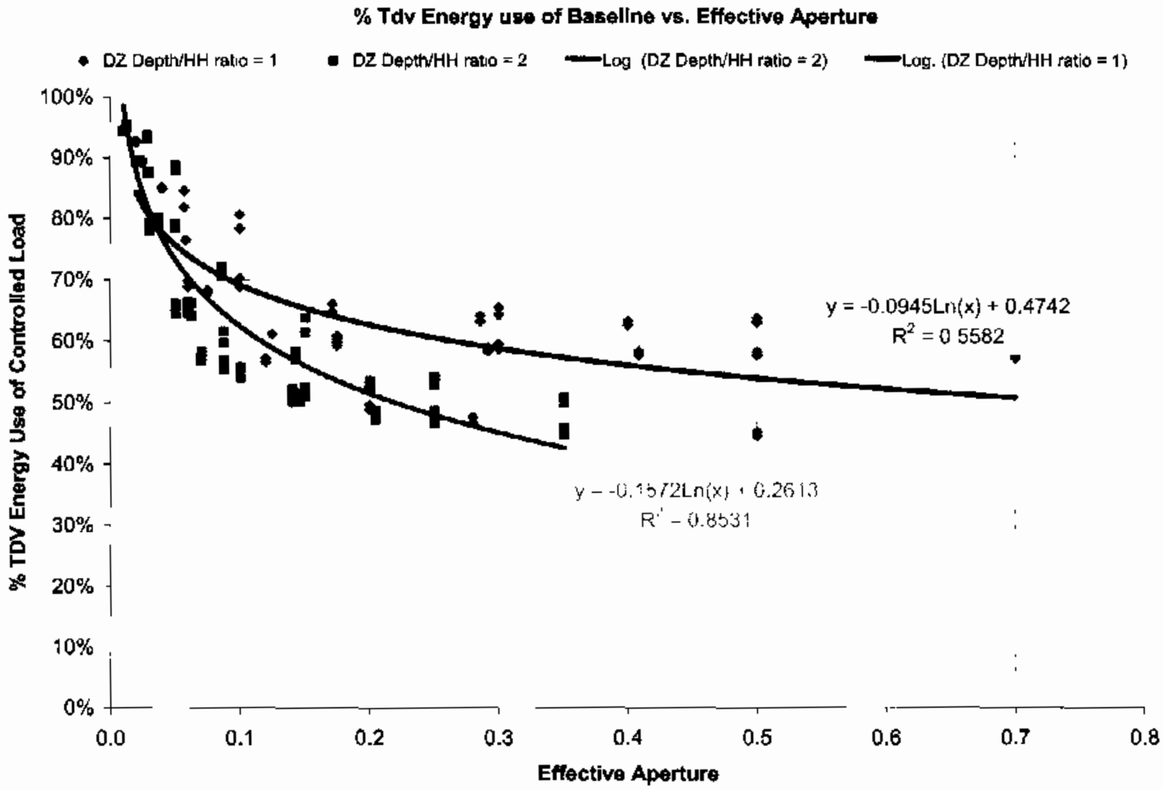


Figure 10: South Facing with Multi-level Controls

Again the savings increase with EA, but stabilize at around 40% beyond 0.3 EA.

The trend lines in the graphs for primary and secondary zones were then used to re-calculate savings for various EA values from 0% to 100%. Results from these calculations were then used for calculating the PAF's. Since multi-level controls are required in most daylit spaces in the current standards (2005 Title 24 code), we based the PAF's on savings from multi-level controls.

Following are the PAF's based on the calculations described above:

Table 6: Raw Power Adjustment Factors

Effective Aperture	Raw PAF
< 10%	-
10%-20%	0.21
20%-35%	0.34
35%-65%	0.43
> 65%	0.52

Our survey results for the sidelighting study (HMG 2005) had found that control systems don't often work as well as intended, and we suspect that the DOE2 software over-predicts savings from dimming controls. We therefore reduced the savings estimates by multiplying the savings numbers with the RSR values from our sidelighting study. These RSR (realized savings numbers) are the most comprehensive numbers to date that compare DOE2 simulated ideal photocontrol system performance to real-world savings and operation. Sorting the sidelighting survey results by DZ Depth/HH ratio, we then calculated the mean RSR for all spaces where the DZ Depth/HH ratio was close to 1 (between 0.8 and 1.2). The mean RSR thus calculated was 0.58 or 58% of the DOE-2 predicted savings. We then applied this RSR value to the raw PAF's to generate the final PAF numbers seen below.

Table 7: Final Power Adjustment Factors

Effective Aperture	Raw PAF	RSR Weighted PAF
< 10%	-	-
10%-20%	0.21	0.12
20%-35%	0.34	0.20
35%-65%	0.43	0.25
> 65%	0.52	0.30

Energy and Cost Savings

As described in the DOE-2 Analysis section of this report, we conducted a detailed parametric analysis of sidelit zones in climate zone 3 (San Francisco) and climate zone 13 (Fresno). The energy savings in South facing exposures are greater but again to be conservative we chose to make use of average energy savings that also account for savings from daylighting in a space with windows facing north. The energy savings and TDV present valued energy costs savings are tabulated in Table 8 below.

Table 8: Statewide Average Energy and TDV energy cost savings

	No Controls		ON/OFF Controls				Multi-level Controls			
Effective Aperture	kWh/sf Daylit Area	TDV/sf Daylilt Area	kWh/sf Daylit Area	TDV/sf Daylilt Area	kWh Savings/sf Daylit Area	TDV Savings/sf Daylilt Area	kWh/sf Daylit Area	TDV/sf Daylilt Area	kWh Savings/sf Daylit Area	TDV Savings/sf Daylilt Area
0.04	8.04	$ 13.46	8.04	$ 13.46	0.00	$ 0.00	7.74	$ 12.94	0.30	$ 0.53
0.10	14.81	$ 24.79	14.62	$ 24.48	0.18	$ 0.31	14.13	$ 23.60	0.68	$ 1.19
0.20	8.04	$ 13.46	7.27	$ 12.08	0.77	$ 1.38	6.66	$ 11.00	1.38	$ 2.46
0.30	18.19	$ 30.45	17.34	$ 28.94	0.85	$ 1.51	16.98	$ 28.33	1.21	$ 2.12
0.40	22.98	$ 38.46	21.52	$ 35.85	1.46	$ 2.61	21.64	$ 36.14	1.33	$ 2.32
0.50	14.81	$ 24.79	13.13	$ 21.74	1.68	$ 3.05	13.25	$ 22.07	1.55	$ 2.72
0.70	18.19	$ 30.45	16.31	$ 27.07	1.88	$ 3.38	16.65	$ 27.77	1.54	$ 2.68

For the effective apertures of interest (10% to 70%), the energy savings for multi-level controls are between 0.68 kWh/yr·sf and 1.54 kWh/yr·sf. This yields a present values savings between PV$1.20 and PV$2.70/sf.

Cost-effectiveness

The discounted energy cost savings over 15 years more than pay for the cost of the daylighting controls. As described above, the energy cost savings discounted over 15 years result in approximately PV$1.20 to PV$2.70/sf. For a 2,500 sf space, the present valued cost savings is between $3,000 and $6,750 over the life of the controls. Taking a relatively high estimate for the installed cost of the controls of $2,000, the benefit/cost ratio is 1.5 to 3.4.

Statewide Energy Savings

Statewide energy savings estimates are based on unit energy savings multiplied by estimates of statewide quantities. Unit energy savings may be in terms of kWh/yr (or therm/sf for gas) savings per sf of building stock or may be in terms of size of equipment controlled (tons or cooling or hp of motors etc.)

[redacted]

Recommendations

Summarize the specific recommendations changing the Standards. This section should have specific recommended language for the Standards and/or the ACM approval manual. This section should contain enough detail to develop the draft standard in the next phase of work.

Proposed Standards Language

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

SECTION 119 – MANDATORY REQUIREMENTS FOR LIGHTING CONTROL DEVICES

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

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

1. Be capable of reducing the ~~light output~~ power consumption of the general lighting of the controlled area by at least ~~one-half~~ two thirds in response to the availability of daylight while maintaining relatively uniform illumination throughout the area; and
2. If the device is a dimmer, provide electrical outputs to lamps for reduced flicker operation through the dimming range and without causing premature lamp failure; and
3. If the devices reduce lighting in control steps, incorporate time-delay circuits to prevent cycling of light level changes of less than three minutes and have a deadband adjustment to provide sufficient separation ~~(deadband)~~ of on and off points for each control step to prevent cycling; and
4. If the devices have a time delay, have the capability for the time delay to be over-ridden or set to less than 5 seconds time delay for the purpose of set up and calibration, and automatically restore its time delay settings to normal operation programmed time delays after no more than 60 minutes; and
5. Have a setpoint control that easily distinguishes settings to within 10% of full scale adjustment; and
6. Have a light sensor that has a linear response with 5% accuracy over the range of illuminances measured by the light sensor; and
7. Have a light sensor that is physically separated from where calibration adjustments are made; and
8. If the device is a stepped switching control device, show the status of lights in the controlled zone by an indicator on the control device; and

9. If the device is a continuous dimming control device, display the light level measured by the light sensor, if the controlled electric lighting cannot be viewed from where setpoint adjustments are made.

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

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

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

1. Contain at least 2 separately programmable steps (relays) per zone that reduces illuminance in a relatively uniform manner as specified in Section 131(b); and
2. Have a separate offset control for each step of 1 to 240 minutes; and
3. Have sunrise and sunset prediction accuracy within +/- 15 minutes and timekeeping accuracy within 5 minutes per year; and
4. Store time zone, longitude and latitude in non-volatile memory; and
5. Display date/time, sunrise and sunset, and switching times for each step; and
6. Have an automatic daylight savings time adjustment; and
7. Have automatic time switch capabilities specified in Section 119 (c).

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

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

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

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

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

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

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

SECTION 131 – INDOOR LIGHTING CONTROLS THAT SHALL BE INSTALLED

(a) **Area Controls.**

1. Each area enclosed by ceiling-height partitions shall have an independent switching or control device. This switching or control device shall be:

    A. Readily accessible; and

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

    C. Manually operated, or automatically controlled by an occupant-sensor that meets the requirements of Section 119 (d).

2. Automatic time switch controls may be installed in conjunction with the switching or control device, provided the area control is an override switching device as described in §131(d)2.

~~2.~~ 3. Other lighting control devices may be installed in conjunction with the area switching or control device provided that they:

    A. Permit the area switching or control device to ~~override the action of all other devices~~ turn the lights off in each area enclosed by ceiling-height partitions; and

    B. When the area switching or control device is not turning off the lights, ~~Reset the mode of~~ any other automatic system ~~to~~ is in normal operation mode without further action.

EXCEPTIONS to Section 131 (a):

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

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

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

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

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

1. Dimming all lamps or luminaires; or
2. Switching alternate lamps in luminaires, alternate luminaires, and alternate rows of luminaires.

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

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

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

The primary sidelit ~~daylit~~ area illuminated by vertical glazing shall be the primary sidelit ~~daylit~~ depth multiplied by the sidelit ~~daylit~~ width.~~, where~~ the The primary sidelit ~~daylit~~ depth is one window head height horizontal distance ~~15~~

feet the height of the , or the distance on the floor, perpendicular to the glazing , to the nearest 60-inch or higher permanent partition, whichever is less; and the daylit sidelit width is the width of the window plus, on each side, either 2 feet, the distance to a permanent partition, or one half the distance to the closest skylight or vertical glazing, whichever is least.

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

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

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

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

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

2. When the daylit skylit area and primary sidelit area in any enclosed space is under skylights and has a total area greater than 2,500 square feet, the general lighting in the daylit area under skylights skylit area or primary sidelit area shall be controlled separately by either an automatic multi-level daylighting control device that meets the requirements of Section 119 (e i) and,

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

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

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

EXCEPTIONS to Section 131 (c)2

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

2. When the skylight effective aperture exceeds 2.0%, a multi-level astronomical time switch that meets the requirements of Section 119(g) and has override switches that meet the requirements of section 131 (d) 2 shall be a deemed to comply. The skylight effective aperture is specified in Section 146(a)4E.

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

EXCEPTIONS to Section 131 (c)

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

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

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

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

   EXCEPTIONS to Section 131 (d) 1:

   1. Where the system is serving an area that must be continuously lit, 24 hour per day/365 days per year.
   2. Lighting in corridors, guestrooms, and lodging quarters of high-rise residential buildings and hotel/motels.
   3. Up to ~~one-half~~ 0.3 watt per square foot of lighting in any area within a building that must be continuously illuminated for reasons of building security or emergency egress.

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

   A. Is readily accessible; and

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

   C. Is manually operated; and

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

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

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

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

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

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

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

[redacted]

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

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

TABLE 143-F MINIMUM SKYLIGHT AREA TO ~~DAYLIT FLOOR~~ SKYLIT AREA OR MINIMUM SKYLIGHT EFFECTIVE APERTURE IN LOW-RISE ENCLOSED SPACES >25,000 FT² DIRECTLY UNDER A ROOF

General Lighting Power Density in ~~Daylit~~ Skylit Areas (W/ft²)	**Minimum Skylight Area to ~~Daylit~~ Skylit Area Ratio**	Minimum Skylight Effective Aperture
1.4 W/ft² ≤ LPD	3.6%	1.2%
1.0 W/ft² ≤ LPD < 1.4 W/ft²	3.3%	1.1%
0.5 W/ft² ≤ LPD < 1.0 W/ft²	3.0%	1.0%

SECTION 146 – PRESCRIPTIVE REQUIREMENTS FOR INDOOR LIGHTING

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

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

   A. The control complies with Section 119; and

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

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

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

      i. Activating the alternate set of lights.

      ii. Activating 100% of the lights.

      iii. Deactivating all lights.

   E. For daylighting control credits, the luminaire is controlled by the daylighting control as described in §131(c)2, and the luminaire is located within the daylit area. Control credits are not available for daylighting controls required by §131(c)2.

      i. Daylighting control credits in sidelit areas. If lighting is being controlled separately in the primary sidelit area, the power adjustment factor is a function of the effective aperture of primary sidelit area. If lights are controlled together in the primary and secondary sidelit areas, the power adjustment factor is a function of the effective aperture of the secondary sidelit area. For lights that are controlled only in the secondary sidelit area only, the power adjustment factor is a function of the effective aperture of the secondary sidelit area.

EQUATION 146-A EFFECTIVE APERTURE OF THE PRIMARY SIDELIT AREA

$$\text{Primary Sidelit Area Effective Aperture} = \frac{\sum \text{Window Area x Window VT}}{\text{Area of Sidelit Area}}$$

EQUATION 146-B – EFFECTIVE APERTURE OF THE SECONDARY SIDELIT AREA

$$\text{Secondary Sidelit Area Effective Aperture} = \frac{\sum \text{Window Area x Window VT}}{\text{Area of Primary Sidelit Area + Area of Secondary Sidelit Area}}$$

ii. Daylighting control credits in skylit areas. The power adjustment factor is a function of the lighting power density of the general lighting in the space and the effective aperture of the skylights determined using Equation 146-A.C

EQUATION 146-AC – EFFECTIVE APERTURE OF SKYLIGHTS

~~$$\text{EffectiveAperture} = \frac{\text{0.85 x TotalSkylightArea x GlazingVisibleLightTransmittance x WellEfficiency}}{\text{DayltArea Under Skylights}}$$~~

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

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

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

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

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

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

EQUATION 146-B WELL CAVITY RATIO FOR RECTANGULAR WELLS

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

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

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

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

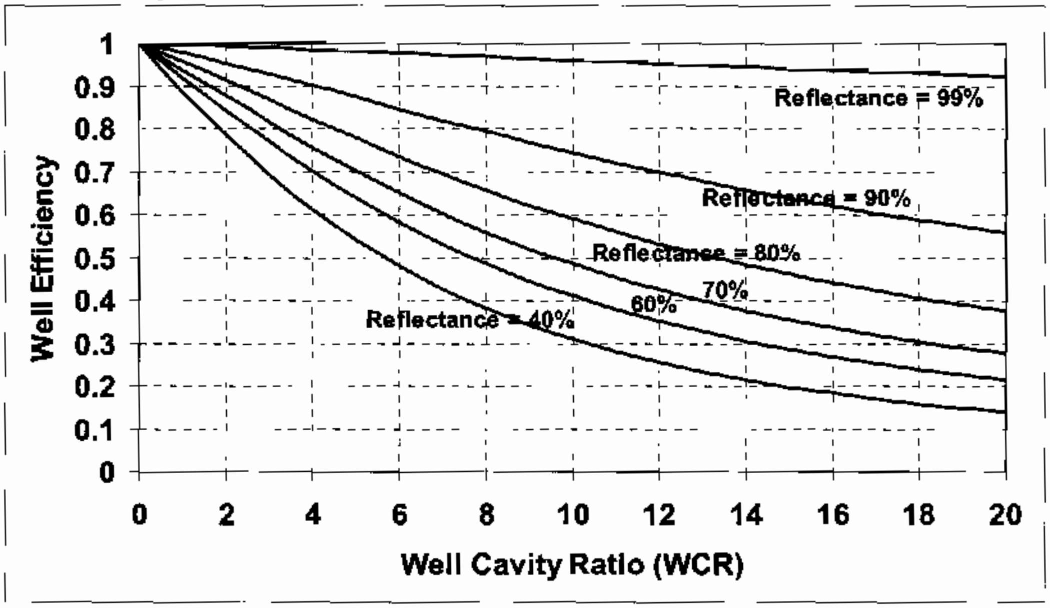


FIGURE 146-A WELL EFFICIENCY NOMOGRAPH

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

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

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

where,

ρ = specular reflectance of interior pipe wall

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

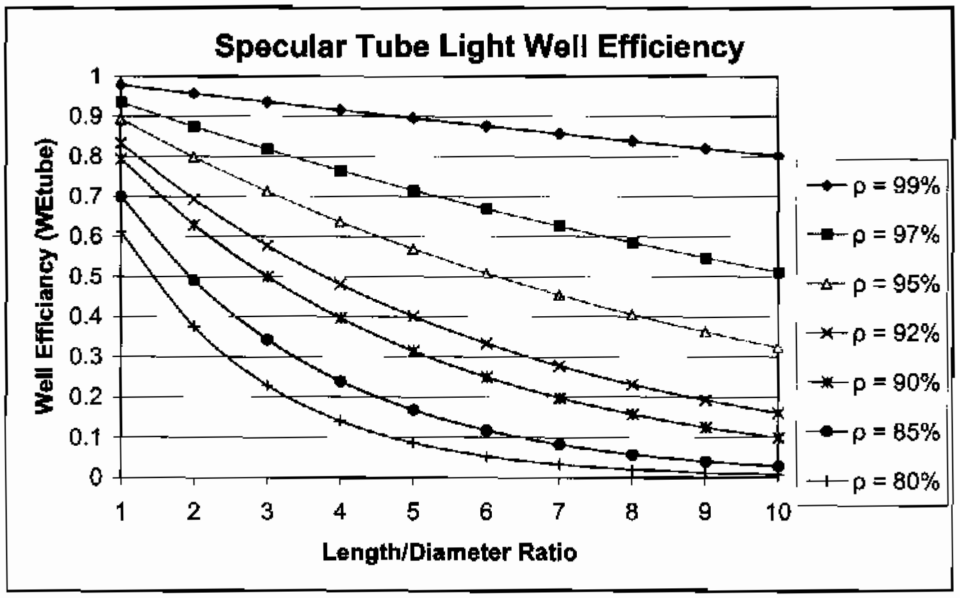


FIGURE 146-B SPECULAR TUBULAR WELL EFFICIENCY NOMOGRAPH

TABLE 146-A LIGHTING POWER ADJUSTMENT FACTORS

TYPE OF CONTROL	TYPE OF SPACE		FACTOR
Occupant sensor with "manual ON" or bi-level automatic ON combined with multi-level circuitry and switching	Any space ≤ 250 square feet enclosed by floor-to-ceiling partitions; any size classroom, corridor, conference or waiting room		0.20
Occupant sensor controlled multi-level switching or dimming system that reduces lighting power at least 50% when no persons are present	Hallways of hotels/motels		.25
	Commercial and Industrial Storage stack areas (max. 2 aisles per sensor)		.15
	Library Stacks (maximum 2 aisles per sensor)		.15
Dimming system			
Manual	Hotels/motels, restaurants, auditoriums, theaters		0.10
Multiscene programmable	Hotels/motels, restaurants, auditoriums, theaters		0.20
Manual dimming with automatic load control of dimmable electronic ballasts.	All building types		.25
Combined controls			
Occupant sensor With "manual ON" or bi-level automatic ON combined with multi-level circuitry and switching in conjunction with daylighting controls	Any space ≤ 250 square feet within a daylit area and enclosed by floor-to-ceiling partitions, any size classroom, corridor, conference or waiting room.		0.10 (may be added to daylighting control credit)
Manual Dimming with Dimmable Electronic Ballasts and Occupant sensor with "manual ON" or automatic ON to less than 50% power and switching	Any space ≤ 250 square feet enclosed by floor-to-ceiling partitions; any size classroom, corridor, conference or waiting room		0.25
Automatic Daylighting Controls with Windows (Stepped Switching or Stepped Dimming/Continuous Dimmed)			
	~~Window Wall Ratio~~		
Glazing Type - Windows	~~< 20%~~	~~20% to 40%~~	~~> 40%~~
~~VLT ≥ 60%~~	~~0.20/0.30~~	~~0.30/0.40~~	~~0.40/0.40~~
~~VLT ≥ 35 and < 60%~~	~~0/0~~	~~0.20/0.30~~	~~0.30/0.40~~
~~VLT < 35%~~	~~0/0~~	~~0/0~~	~~0.20/0.40~~
Glazing Type – Windows	Effective Aperture		PAF
Multi-level photocontrols	< 10%		-
	10%-20%		0.12
	20%-35%		0.20
	35%-65%		0.25
	> 65%		0.30
Automatic Multi-Level Daylighting Controls with Skylights			
Glazing Type - Skylights	Spaces where the daylit area under skylights is less than 2,500 sf		
Glazing material or diffuser with ASTM D1003 haze measurement greater than 90%	~~10 × Effective Aperture − Lighting Power Density / 10 + 0.2~~ ~~WHERE~~ ~~Effective Aperture is as calculated in the Equation 146-A~~ ~~Lighting Power Density is the lighting power density of general lighting~~ Effective Aperture (EA)		

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

Alternate Calculation Manual

In order to make the daylighting calculations compatible with TDV (time dependent valuation) it is recommended that the daylighting calculation algorithms in DOE-2 be used in the current performance software. It is recognized that this algorithm overestimates the energy savings form sidelighting when one is far from the window. This can be accounted for by cutting the savings in half when modeling savings in the secondary sidelit area. The "reference sensor point" should be placed one head height away from the window when modeling lighting in the primary sidelit area and the sensor should be placed two head heights away from the perimeter windows when modeling lighting in the secondary sidelit area.

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