CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Final Report – Minimum Skylight Area

Measure Number: 2016-NR-ENV2-F

Nonresidential Envelope

2016 CALIFORNIA BUILDING ENERGY EFFICIENCY STANDARDS

California Utilities Statewide Codes and Standards Team December 2014

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EXECUTIVE SUMMARY

Introduction

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

The overall goal of this CASE Report is to propose a code change proposal for measure name. The report contains pertinent information that justifies the code change including:

- Description of the code change proposal, the measure history, and existing standards (Section 2);
- Market analysis, including a description of the market structure for specific technologies, market availability, and how the proposed standard will impact building owners and occupants, builders, and equipment manufacturers, distributers, and sellers (Section 3);
- Methodology and assumption used in the analyses energy and electricity demand impacts, cost-effectiveness, and environmental impacts (Section 4);
- Results of energy and electricity demand impacts analysis, Cost-effectiveness Analysis, and environmental impacts analysis (Section 5); and
- Proposed code change language (Section 6).

Scope of Code Change Proposal

Measure Name will affect the following code documents listed in Table 1.

Table 1: Scope of Code Change Proposal

Standards Requirements (see note below)	Compliance Option	Appendix	Modeling Algorithms	Simulation Engine	Forms
M, Ps	Y	N/A	Y	Y	Y

Note: An (M) indicates mandatory requirements, (Ps) Prescriptive, (Pm) Performance.

Measure Description

The primary focus of this report is to reinstate the minimum skylight area requirement to section 140.3(c) while maintaining the overall simplicity of showing compliance.

During the 2013 standards development there was an agreement that the calculation of effective aperture as an alternative method of showing compliance with this section was overly complex. Calculating effective aperture was complex for two reasons:

- It required calculating the area of the skylit zone – which can be a convoluted geometry when one includes the presence of racks and other obstructions which truncate the skylight zone.
- It required the calculation of well efficiency which requires the calculation of room cavity ratio and looking up this value on a nomograph for various light well surface reflectances.

When the effective aperture requirement in the 2013 standards was deleted, the minimum total skylight area was also deleted. Though these changes still left a requirement for a minimum fraction of the floor area being in the daylit zone this did not place any threshold of how much daylight or skylight area had to serve this zone. As will be shown later on in this report, the revised structure of the skylighting requirement does not assure that enough skylight area is required to save as much energy as was the case in the 2008 Title 24 standards. An unintended consequence was that the performance approach as documented in the Alternative Compliance Method (ACM) Reference Manual, no longer had a stable baseline of how much skylight area was required for the baseline building.

For the large open enclosed spaces subject to Section 140.3(c), this proposal provides a method of assuring there is enough skylight area in to provide sufficient daylighting while maintaining the overall simplicity of the 2013 daylighting requirements. This will also result in a well-defined baseline daylighting system for the performance approach.

Reinstating the minimum skylight area requirements from the 2008 Title 24 also more closely aligns the Title 24 minimum skylight area requirements with those in the 2010 and 2013 versions of ASHRAE 90.1 Energy Standard for Buildings Except Low-Rise Residential Buildings. This is desirable as designers that are used to complying with the ASHRAE 90.1 daylighting requirements will have less of a learning curve to comply with the proposed 2016 California Title 24 daylighting requirements. In addition, the minimum skylight area requirements in ASHRAE 90.1 are identical to those found in the 2012 version of the International Energy Conservation Code (IECC 2012). The 2016 IECC is used in 16 states.[1]

Section 2 of this report provides detailed information about the code change proposal including: ***Section 2.2 Summary of Changes to Code Documents (page 28)*** provides a section-by-section description of the proposed changes to the standards, appendices, alternative

[1] International Codes-Adoption by State (September 2014) http://www.iccsafe.org/gr/Documents/stateadoptions.pdf

compliance manual and other documents that will be modified by the proposed code change. See the following tables for an inventory of sections of each document that will be modified:

- Table 7: Scope of Code Change Proposal (page 28)
- Table 8: Sections of Standards Impacted by Proposed Code Change (page 28)
- Table 9: Sections of ACM Impacted by Proposed Code Change (page 28)

Detailed proposed changes to the text of the building efficiency standards, the reference appendices, and are given in ***Section 6 Proposed Language*** of this report. This section proposes modifications to language with additions identified with underlined text and deletions identified with ~~struck out~~ text.

The following documents will be modified by the proposed change:

- The text of the Title 24 Standards
- The Nonresidential Alternative Compliance Method (ACM) Reference Manual
- Compliance Form 2013-NRCC-ENV-04-E *Minimum Skylight Area Worksheet*
- The Nonresidential Title 24 Compliance Manual

Market Analysis and Regulatory Impact Assessment

This proposal is cost effective over the period of analysis. Overall this proposal increases the wealth of the State of California. California consumers and businesses save more money on energy than they do for financing the efficiency measure. As a result this leaves more money available for discretionary and investment purposes.

The expected impacts of the proposed code change on various stakeholders are summarized below:

- **Impact on builders:** for those designs that would have used 3% skylight area to daylit area, this proposal will have no impact, for those designs where the designer was planning on using the minimum possible amount of skylight area, this proposal will increase the number of skylights used and slightly increase the cost of the building. This will have most impact taller spaces as will be described later on in this report.
- **Impact on building designers:** this proposal will simplify the process of showing that the design complies. This proposal has a stable skylight area requirement that is unaffected by the presence of racks or partitions. The 2013 requirement could vary by the presence of partitions and could comply at one part of the construction process and not comply later on when partitions were added. Thus designers should like the more simple and stable design requirements. Since this proposal is closely aligned to the ASHRAE 90.1 and 2012 IECC national energy codes, this proposal is likely easier to comply with for design firms that have a multi-state presence.
- **Impact on occupational safety and health:** The proposed code change is not expected to have an impact on occupational safety and health.
- **Impact on building owners and occupants:** Since this measure is cost-effective, building owners who pay the energy bills for the building are reducing their energy costs more than the increased mortgage costs to pay for the cost of the measure (i.e. they are

experiencing net cost savings). For building occupants that are renting the building and paying the energy bills, since the measure saves more energy cost on a monthly basis than the measure costs on the mortgage as experienced by the building owner, the pass-through of added mortgage costs into rents is less than the energy cost savings experienced by occupants.

- **Impact on equipment retailers (including manufacturers and distributors):** This proposal will reverse the decline in fraction of skylight area to floor area allowed by the 2013 standard and revert this fraction back up that required by the 2008 standards. The overall impact is around a 50%-100% increase in skylight area for those designers who minimally comply with the standards. However, many designers who make use of design tools and are trying to optimize skylight area will see no impact from this proposal.
- **Impact on energy consultants:** For consultants showing compliance using the performance approach, the changes occur "under the hood" of the compliance software and would be unaffected. For energy consultants that show compliance using the prescriptive approach, there should be a slight reduction in complexity.
- **Impact on building inspectors:** This proposal should streamline slightly enforcement. As compared to the overall code enforcement effort, this measure has negligible impact on the effort required to enforce the building codes.
- **Statewide Employment Impacts:** skylights are large and therefore cost a lot to ship. This favors skylights being made close by and many being manufactured in state. Skylights take more labor to install than the roofing they replace. Thus skylights increase construction employment. Skylights are relatively cheap (around $20/sf installed cost) and have minimal impact on the construction cost of a building.
- **Impacts on the creation or elimination of businesses in California:** This proposal slightly assists business creation in California as skylights are large and therefore cost a lot to ship. This favors skylights being made close by and many of these being manufactured in state.
- **Impacts on the potential advantages or disadvantages to California businesses:** This proposal slightly assists business creation in California as skylights are large and therefore cost a lot to ship. This favors skylights being made close by and many of these being manufactured in state.
- **Impacts on the potential increase or decrease of investments in California:** This proposal slightly assists business creation in California as skylights are large and therefore cost a lot to ship. This favors skylights being made close by and many of these being manufactured in state.
- **Impacts on incentives for innovations in products, materials or processes:** Skylights have been required in the California Title 24 energy code since the 2005, thus this modification to the skylighting requirement will have little to no impact on incentives.
- **Impacts on the State General Fund, Special Funds and local government:** This proposal slightly increases the cost of construction, to the extent it increases the assessed value of the property this increases property taxes. Since this proposal is cost-effective, it

increases the wealth of businesses which have invested in mortgage payments (or pass throughs of higher rents) that are more than offset by energy cost savings.

- **Cost of enforcement to State Government and local governments:** This proposal should streamline slightly enforcement. As compared to the overall code enforcement effort, this measure has negligible impact on the effort required to enforce the building codes.
- **Impacts on migrant workers; persons by age group, race, or religion:** This proposal and all measures adopted by CEC into Title 24, part 6 do not advantage or discriminate in regards to race, religion or age group.
- **Impact on Tenants:** This proposal is advantageous to renters as it reduces the cost of utilities which are typically paid by renters. Since the measure saves more energy cost on a monthly basis than the measure costs on the mortgage as experiences by the commercial building owner, the pass-through of added mortgage costs into rents is less than the energy cost savings experienced by tenants.
- **Impact on Commuters:** This proposal and all measures adopted by CEC into Title 24, part 6 are not expected to have an impact on commuters

Statewide Energy Impacts

Table 2 shows the estimated energy savings over the first twelve months of implementation of the improved minimum skylight area requirements. The savings estimate is based on an assumption that the improved minimum skylight area requirement results in 10% energy savings from skylights of all the energy savings from skylights over the last three code cycles.

The minimum skylight area requirement in the 2005 and 2008 Title 24 code cycles specifically called out 3% or more skylight area to skylit daylit area ratio (SDR) and the energy savings estimates for the 2013 Title 24 code cycle also assumed at least a 3% SDR as the energy savings calculations were based upon research for ASHRAE 90.1 which used a 3% SDR. The energy savings for each code cycle are incremental savings relative to the prior code cycle. The savings each code cycle are increased by increasing the number building that the requirement applies to by reducing the threshold area. Savings is also increased by increasing the fraction of these spaces that must be in the skylit daylit zone.

Table 2: Estimated First Year Energy Savings

			First Year Energy Savings		Present Value
Title 24 Code Cycle	Threshold Area (sf)	Fraction of Zone	Elec Savings GWh/yr	Gas Savings Million therms/yr	TDV PV Savings1 ($ Millions)
2005	25,000	50%	25.46		$46.6
2008	8,000	50%	4.48	-0.10	$6.9
2013	5,000	75%	46.74	-0.09	$84.4
		Totals	76.68	-0.19	$137.9
2016 Estimate @ 10% of total			7.67	-0.02	$13.8

1. Energy savings multiplied by 2016 average TDV

Section *4.6.1 Statewide Energy Impacts Methodology* discusses the methodology of this energy savings estimate. And Section *5.1.1 Statewide Energy Impacts Results* describes in detail the statewide energy savings estimate including the calculations behind the 10% estimated savings associated with specifying a minimum skylight area to skylit daylit area ratio.

Cost-effectiveness

Results per unit Cost-effectiveness Analyses are presented in Section *4.7.3 Cost-effectiveness Methodology*. The TDV Energy Costs Savings are the present valued energy cost savings over the 15 year period of analysis using CEC's TDV methodology. The Total Incremental Cost represents the incremental initial construction and maintenance costs of the proposed measure relative to existing conditions (current minimally compliant construction practice when there are existing Title 24 Standards). Costs incurred in the future (such as periodic maintenance costs or replacement costs) are discounted by a 3 percent real discount rate, per CEC's LCC Methodology.

The Benefit-to- Cost (B/C) Ratio is the incremental TDV Energy Costs Savings divided by the Total Incremental Costs. When the B/C ratio is greater than 1.0, the added cost of the measure is more than offset by the discounted energy cost savings and the measure is deemed to be cost effective. For a detailed description of the Cost-effectiveness Methodology see Section 4.7 of this report.

Building Type: RETAIL **46,656 sf Area** **24 ft Ceiling**

	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7	8
	Miami, FL	Houston, TX	Phoenix, AZ	Memphis, TN	El Paso, TX	San Francisco, CA	Baltimore, MD	Albqurque, NM	Salem, OR	Indianapolis, IN	Boise, ID	Burlington, VT	Helena, MT	Duluth, MN	Fairbanks, AK
	Double - Clear - Med.Wht											Triple - Clear - Med.Wht			
Lighting Savings (kWh)	129,413	120,731	135,815	116,597	131,715	117,750	106,180	127,648	96,584	113,913	113,589	92,155	95,657	92,375	62,246
Cooling Savings (kWh)	10,661	10,737	6,108	5,182	385	2,194	5,038	686	3,467	4,354	2,295	3,072	3,315	4,688	1,865
Total kWh Savings (kWh)	145,221	138,197	156,010	123,065	131,467	123,364	111,646	127,776	122,567	119,911	116,805	107,494	122,568	114,490	57,580
Heating Savings (Therms)	-227	-1,037	-1,021	-1,671	-1,315	-2,118	-2,291	-2,061	-2,656	-2,635	-2,688	-2,301	-2,718	-3,133	-1,590
Lifecycle Energy Cost Savings in $ (Scalar 11.9)	$264,882	$240,136	$273,264	$202,976	$223,667	$197,031	$172,876	$206,007	$187,739	$183,139	$176,633	$165,064	$186,839	$165,889	$83,222
Cost of Controls ($)	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161
Cost of Skylights ($)	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$35,639	$35,639	$35,639	$35,639
Cost of Bi-Level Wiring ($)	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412
Cost of Extra Cooling Capasity ($)	$785	-$997	-$578	$153	$412	$253	-$859	$2,128	-$3,537	-$1,159	-$1,771	-$3,836	-$3,037	-$5,651	$2,195
Cost of Extra Heating Capasity ($)	$146	$247	$242	$251	$242	$200	$288	$266	$334	$353	$294	$329	$476	$439	-$115
Total Cost ($)	$44,147	$42,465	$42,879	$43,619	$43,869	$43,668	$42,644	$45,609	$40,012	$42,409	$41,738	$43,704	$44,652	$42,000	$49,291
Benefit to Cost Ratio	**6.00**	**5.65**	**6.37**	**4.65**	**5.10**	**4.51**	**4.05**	**4.52**	**4.69**	**4.32**	**4.23**	**3.78**	**4.18**	**3.95**	**1.69**
Breakpoint Area (sf)	1,267	1,410	1,215	1,737	1,546	1,802	2,107	1,726	1,868	1,957	2,038	2,254	1,938	2,210	7,170
Percent of Total Cost Reduction	12%	11%	13%	9%	12%	12%	8%	11%	10%	8%	9%	7%	9%	6%	3%

Figure 1: Breakpoint Area Analysis - Retail Building

Building Type: WAREHOUSE HIGH CEILING **82,944 sf Area** **32 ft Ceiling**

	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7	8
	Miami, FL	Houston, TX	Phoenix, AZ	Memphis, TN	El Paso, TX	San Francisco, CA	Baltimore, MD	Albqurque, NM	Salem, OR	Indianapolis, IN	Boise, ID	Burlington, VT	Helena, MT	Duluth, MN	Fairbanks, AK
	Double - Clear - Med.Wht											Triple - Clear - Med.Wht			
Lighting Savings (kWh)	247,726	245,071	247,571	247,782	251,020	243,743	243,864	249,485	237,902	236,952	238,023	240,926	236,415	237,940	187,108
Cooling Savings (kWh)	11,574	14,184	-5,069	13,758	-1,114	2,755	14,538	-41	3,159	4,840	1,096	5,480	3,139	12,465	14,848
Total kWh Savings (kWh)	254,917	253,529	234,401	253,983	242,840	243,272	252,412	243,551	238,326	237,629	234,588	245,105	239,673	249,422	194,842
Heating Savings (Therms)	-228	-1,758	-1,258	-2,645	-1,746	-2,502	-4,501	-3,088	-4,879	-4,731	-4,936	-4,989	-4,946	-5,971	-6,340
Lifecycle Energy Cost Savings in $ (Scalar 11.9)	$467,444	$442,641	$414,585	$430,586	$423,076	$412,885	$400,707	$404,882	$369,199	$370,063	$361,468	$380,119	$370,713	$373,817	$267,660
Cost of Controls ($)	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161
Cost of Skylights ($)	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$35,639	$35,639	$35,639	$35,639
Cost of Bi-Level Wiring ($)	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967
Cost of Extra Cooling Capasity ($)	$2,320	$2,201	$3,501	$4,722	$2,648	$1,203	$2,196	$2,102	$919	$2,180	$1,656	$3,982	-$67	-$56	-$2,857
Cost of Extra Heating Capasity ($)	$275	$425	$346	$498	$434	$324	$565	$475	$490	$371	$513	$86	$118	-$3	$516
Total Cost ($)	$47,365	$47,396	$48,618	$49,991	$47,852	$46,298	$47,531	$47,348	$46,180	$47,322	$46,939	$52,835	$48,818	$48,708	$46,426
Benefit to Cost Ratio	**9.87**	**9.34**	**8.53**	**8.61**	**8.84**	**8.92**	**8.43**	**8.55**	**7.99**	**7.82**	**7.70**	**7.19**	**7.59**	**7.67**	**5.77**
Breakpoint Area (sf)	1,199	1,273	1,373	1,321	1,340	1,371	1,422	1,405	1,552	1,554	1,593	1,533	1,558	1,543	2,247
Percent of Total Cost Reduction	33%	32%	27%	32%	33%	37%	30%	32%	30%	29%	28%	29%	28%	26%	18%

Figure 2: Breakpoint Area Analysis - Warehouse High Ceiling Building

Building Type: WAREHOUSE LOW CEILING **46,656 sf Area** **24 ft Ceiling**

	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7	8
	Miami, FL	Houston, TX	Phoenix, AZ	Memphis, TN	El Paso, TX	San Francisco, CA	Baltimore, MD	Albqurque, NM	Salem, OR	Indianapolis, IN	Boise, ID	Burlington, VT	Helena, MT	Duluth, MN	Fairbanks, AK
	Double - Clear - Med.Wht											Triple - Clear - Med.Wht			
Lighting Savings (kWh)	139,204	137,594	139,118	139,220	141,005	136,856	136,967	140,153	133,456	132,992	133,687	135,244	132,585	133,670	104,937
Cooling Savings (kWh)	6,259	7,987	-3,071	7,453	-895	1,503	7,869	-212	1,683	2,449	514	2,956	1,685	6,730	8,167
Total kWh Savings (kWh)	142,844	142,337	131,219	142,286	135,880	136,313	141,233	136,458	133,411	132,761	131,474	137,247	134,142	139,703	108,949
Heating Savings (Therms)	-128	-995	-716	-1,515	-1,001	-1,454	-2,575	-1,772	-2,796	-2,705	-2,829	-2,864	-2,838	-3,434	-3,644
Lifecycle Energy Cost Savings in $ (Scalar 11.9)	$261,931	$248,392	$231,916	$240,740	$236,381	$230,596	$223,387	$226,241	$205,730	$205,852	$201,673	$211,825	$206,469	$208,075	$148,229
Cost of Controls ($)	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161
Cost of Skylights ($)	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$35,639	$35,639	$35,639	$35,639
Cost of Bi-Level Wiring ($)	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967
Cost of Extra Cooling Capasity ($)	$6,711	$1,319	$1,719	$2,051	$2,753	$685	$716	$1,204	$538	$1,384	$745	$647	$19	$800	-$1,575
Cost of Extra Heating Capasity ($)	-$2,361	$245	$199	$286	$249	$186	$323	$273	$280	$220	$295	$75	$73	$12	$291
Total Cost ($)	$49,121	$46,334	$46,689	$47,107	$47,773	$45,641	$45,809	$46,247	$45,589	$46,374	$45,810	$49,489	$48,859	$49,580	$47,484
Benefit to Cost Ratio	**5.33**	**5.36**	**4.97**	**5.11**	**4.95**	**5.05**	**4.88**	**4.89**	**4.51**	**4.44**	**4.40**	**4.28**	**4.23**	**4.20**	**3.12**
Breakpoint Area (sf)	1,313	1,380	1,502	1,439	1,476	1,504	1,564	1,544	1,728	1,735	1,774	1,706	1,755	1,746	2,689
Percent of Total Cost Reduction	32%	31%	27%	32%	32%	37%	30%	32%	30%	28%	28%	28%	28%	26%	17%

Figure 3: Breakpoint Area Analysis - Warehouse Low Ceiling Building

This measure was found to be cost-effective in every climate one for the three space types we expected this measure to apply (large warehouse, small warehouse and big box retail).

This analysis was conducted for the 2013 Daylighting CASE report and is repeated here as this proposal assures that the 3% skylight area to skylit daylit area ratio assumption used for the 2013CASE study is reflected in the 2016 Title 24 code language.

It should be noted that 3% skylight area to daylit area ratio was found to be cost effective in retail buildings and heated warehouses in the representative climate zones of 1, 3, 7, 10, 12, 14, 16, in the Skylighting CASE report for the 2005 standards (CASE 2002) and in the representative climate zones of 3, 7, 10 12 and 14 in the Skylighting CASE report for the 2008 standards (CASE 2006).

Greenhouse Gas and Water Related Impacts

For more a detailed and extensive analysis of the possible environmental impacts from the implementation of the proposed measure, please refer to Section 5.3 of this report.

Greenhouse Gas Impacts

Table 3 presents the estimated avoided greenhouse gas (GHG) emissions of the proposed code change for the first year the standards are in effect. Assumptions used in developing the GHG savings are provided in Section 4.8.1 on page 59 of this report.

The monetary value of avoided GHG emissions is included in TDV cost factors (TDV $) and is thus included in the Cost-effectiveness Analysis prepared for this report.

Table 3: Estimated Statewide Greenhouse Gas Emissions Impacts

	First Year Statewide Avoided GHG Emissions ($MTCO_2e/yr$)
TOTAL	2,606

Section *4.8.1Greenhouse Gas Emissions Impacts Methodology* discusses the methodology and Section *5.3.1 Greenhouse Gas Emissions Results* shows the results of the greenhouse gas emission impacts analysis.

Water Use and Water Quality Impacts

The proposed measure is not expected to have any impacts on water use or water quality, excluding impacts that occur at power plants.

1. INTRODUCTION

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

The overall goal of this CASE Report is to propose a code change proposal to reinstate the requirement for minimum skylight area for large open spaces with high ceilings directly under a roof. The report contains pertinent information that justifies the code change.

Section 2 of this CASE Report provides a description of the measure, how the measure came about, and how the measure helps achieve the state's zero net energy (ZNE) goals. This section presents how the Statewide CASE Team envisions the proposed code change would be enforced and the expected compliance rates. This section also summarized key issues that the Statewide CASE Team addressed during the CASE development process, including issues discussed during IOU-sponsored public stakeholder meetings.

Section 3 presents the market analysis, including a review of the current market structure, a discussion of product availability, and the useful life and persistence of the proposed measure. This section offers an overview of how the proposed standard will impact various stakeholders including builders, building designers, building occupants, equipment retailers (including manufacturers and distributors), energy consultants, and building inspectors. Finally, this section presents estimates of how the proposed change will impact statewide employment.

Section 4 describes the methodology and approach the Statewide CASE Team used to estimate energy, demand, costs, and environmental impacts. Key assumptions used in the analyses can be also found in Section 4.

Results from the energy, demand, costs, and environmental impacts analysis are presented in Section 5. The Statewide CASE Team calculated energy, demand, and environmental impacts using two metrics: (1) per unit, and (2) statewide impacts during the first year buildings complying with the 2016 Title 24 Standards are in operation. Time Dependent Valuation (TDV) energy impacts, which accounts for the higher value of peak savings, are presented for the first year both per unit and statewide. The incremental costs, relative to existing conditions are presented as are present value of year TDV energy cost savings and the overall cost impacts over the year period of analysis.

The report concludes with specific recommendations for language for the Standards, Appendices, Alternate Calculation Manual (ACM) Reference Manual and Compliance Forms.

2. MEASURE DESCRIPTION

2.1 Measure Overview

2.1.1 Measure Description

The primary focus of this report is to reinstate the prescriptive minimum skylight area requirement to section 140.3(c) while maintaining the overall simplicity of showing compliance. This section applies to large open spaces with high ceiling heights in particular: *"enclosed spaces, that are greater than 5,000 ft² and that are directly under a roof with ceiling heights greater than 15 feet."*

For the large open enclosed spaces subject to Section 140.3(c), this proposal provides a method of assuring there is enough skylight area in to provide sufficient daylighting while maintaining the overall simplicity of the 2013 daylighting requirements. This will also result in a well-defined baseline daylighting system for the performance approach.

This proposal is designed to closely match the ASHRAE 90.1 and IECC minimum skylight area requirements. For these energy efficiency standards, the daylight area under skylights must be at least 50% of the floor area of the space and the skylight area must be at least 3% of the daylight area under skylights and the skylight visible light transmittance must be at least 0.40. Alternatively the effective aperture of the daylighting system must be at least 1%.

This proposal for the 2016 Title 24 standards continues to require that the daylight area under skylights is at least 75% of the floor area of the large open space. However the "skylit daylit zone" can be very irregularly shaped and hard to calculate its area when accounting for the presence of a *"permanent obstruction that is taller than one half the distance from the floor to the bottom of the skylight."* Shelving and racks are essentially permanent and are frequently taller than one half the ceiling height. A more stable metric of the daylighting geometry of the space that is easier to calculate is *"75 percent of the floor area … within 0.7 times the average ceiling height from the edge of rough opening of skylights."* This requirement is simpler to calculate while assuring that skylights are evenly spaced and are serving most of the floor area in the large tall enclosed space. This metric is more stable as it is not impacted by the presence or absence of tall obstructions in the space that may be added later on in the design process.

This proposal also restores the requirement for a fixed minimum ratio of skylight area to area served by skylights. This proposal uses the same 3% minimum skylight area to skylit area ratio as the ASHRAE 90.1 and IECC proposals. However, in keeping with the simplicity of the approach used above this proposal for the 2016 Title 24 standards assures there is enough skylight are by requiring that "The total skylight area is at least 3% of the total floor area within 0.7 times average ceiling height from the edge of rough opening of skylights." The amount of skylight area required is not reduced by the presence of racks or other permanent obstructions and is simpler to calculate.

The ASHRAE 90.1 and IECC minimum skylight area requirements allow less skylight area if the transmittance of the skylight is higher or the light well is shallow and allows a less transmitting skylight if the skylight area is higher or the light well under the skylight is shallow. These trade-offs are accomplished by achieving a given minimum skylight effective aperture. Both ASHRAE 90.1 and IECC require a minimum effective aperture of 1%. The effective aperture, EA is:

$$EA = \frac{0.85 \times Skylight\ Area \times VT \times WF}{Daylight\ zone\ under\ skylights} \geq 1.0\%$$

Where the well factor (WF) is 0.9 if light well depth is less than 2 feet or 0.7 if light well depth is 2 feet or greater. The 0.85 factor accounts for dirt depreciation as the presence of dirt on the skylights reduces the transmittance of the skylight over time.

This proposal simplifies the effective aperture calculation by assuming a fixed medium light well depth with a well factor of 0.8 and combining the fixed well factor and dirt depreciation factor into the target fraction of the skylit area. For ASHRAE

$$EA = \frac{0.85 \times Skylight\ Area \times VT \times 0.8}{Daylight\ zone\ under\ skylights} \geq 1.0\%$$

Rearranging this equation, we obtain:

$$Skylight\ Area \times VT \geq \frac{1.0\% \times Daylit\ Zone}{0.85 \times 0.8} = 1.5\% \times Daylit\ zone\ under\ skylights$$

Thus we have the simplified proposed exception to the minimum skylight area being: *the product of the total skylight area and the average skylight visible transmittance is no less than 1.5% of the total floor area within 0.7 times the average ceiling height from the edge of rough opening of skylights.*

Skylight Area x VT ≥ 1.5% x Daylit zone under skylights (not counting obstructions).

This proposal also includes some minor clarifications.

- §130.1(d)1. Whenever there is an overlap between the skylit zone and other daylit zones the skylit zone takes precedence. Any areas that overlap between the secondary sidelit zone and the primary sidelit zone, the primary sidelit zone takes precedence.
- §130.1(d)2D. Restores the requirement that calibration adjustments to daylighting controls are readily accessible. This aligns with ASHRAE 90.1 and IECC and is described in more detail in another CASE report. [CASE 2014]. It is included here only for completeness of related daylighting language in Title 24.
- §130.1(d)3 Parking garage requirements. This adds clarifying language that the primary and secondary sidelit daylit zones in parking garages are intended to be controlled together (due to very low LPD and low design illuminance) and the illuminance levels that are the basis of control should be on the far edge of the secondary zone away from the window or exterior opening.
- §140.6(d) Clarifies that skylit daylit zones take precedence over secondary sidelit zones when the two overlap.

The outcome of this proposal is a more stable baseline system for the performance method as reflected in the Alternative Compliance Method (ACM) Reference Manual. Skylighting would be directly modelled using the split-flux algorithms that are embedded in EnergyPlus (the simulation engine for the reference performance method program CBECC-Com). The reference case is a skylighting system with 3% skylight area and the prescriptive visible light transmittance and with continuous dimming daylighting controls controlling 70% of the general lighting power in 75% of the space.

2.1.2 Measure History

2005 Title 24 Standards

Though the Title 24 standards had a power adjustment factors (PAF) for daylighting controls (as a function of skylight VT and skylight to floor area ratio) since the 1992 version of Title 24, the 2005 Title 24 code was the first energy code that prescriptively required a minimum skylight area in buildings. This proposal modified the skylit zone based upon research on skylight photometric distribution. This proposal outlined a detailed requirement for photocontrol systems based upon studies of causes of photocontrol system failure.

The code language that influences the minimum skylight requirements is included at the end of this report in *Appendix A: 2005 Title 24 Minimum Daylight Area Code Language*. This requirement was triggered by large enclosed spaces with ceiling heights greater than 15 feet and an overall floor area of at least 25,000 sf. At least 50% of the floor area had to be in the skylit zone. The minimum skylight area ranged from 3.0% to 3.6% depending upon the LPD in the space; alternatively an effective aperture could be used which varied between 1.0% to 1.2%.

Multi-level photocontrols or multi-level astronomical time switches were required for skylit areas greater than 2,500 sf. Thus the spaces with minimum skylit area would be required to have daylighting controls.

No minimum skylight VT was required so the baseline for the performance approach was based on the effective aperture which in turn relied on the LPD for the space. For the 2005 code, the ACM specified a regression equation for the PAF that was a function of effective aperture and LPD. At that time one could also use an astronomical timeclock to control lighting and as the minimally compliant control this was deemed to save half as much energy as a daylight responsive photocontrol system. Thus one would receive compliance credits for using a photocontrol system.

In the years building up to this code skylighting was the second largest prescriptive energy efficiency measure in the nonresidential new construction energy efficiency program, Savings By Design.

2008 Title 24 Standards

The changes in this code were more evolutionary and expanded the requirement to all spaces larger than 8,000 sf and with ceiling heights greater than 15 feet. The 15 foot high ceiling heights allow for skylights to be spaced relatively further apart which is cheaper and usually do not have suspended ceilings (light wells through ceiling plenums significantly adds to cost). At last 50% of the floor area in the space had to be in the skylit zone or in the primary sidelit zone. In this code cycle the primary sidelit zone (near windows) was required to have photocontrols when the sidelit zone was greater than the 2,500 sf. The same area threshold was the case for automatic daylighting controls in skylit spaces. A key update was to decouple minimum skylight area from lighting power density (LPD) as it can be hard to determine what the LPD will be for core and shell buildings and to simplify enforcement and compliance. The minimum skylight area was reduced to 3.3% skylight to daylit area ratio. The detailed daylighting requirements can be viewed in *Appendix B: 2008 Title 24 Minimum Daylight Area Code Language* of this report.

The Performance Approach ACM (Alternative Compliance Method) manual was modified to directly model skylighting using the split-flux algorithms that are embedded in DOE-2.1E (the simulation engine for the reference performance method program). The reference case is a skylighting system with an effective aperture of 1.1% and with multi-level daylighting controls controlling 70% of the lighting power in 50% of the space.

ASHRAE/IECC Standards

Prior to the 2010 ASHRAE 90.1 standards there had been no daylighting requirements in this standard for 20 years. In the ASHRAE Standard 90.1-2010, requirements for daylighting controls were added built on the California standards and exceeded them. Photocontrols were required for all primary sidelit zones greater than 250 sf and all toplit zones greater than 900 sf.

Minimum skylight area requirements are triggered by enclosed spaces larger than 5,000 sf and having a ceiling height greater than 15 feet. The minimum skylight fenestration area requirements in ASHRAE 90.1-2010 call for at least half of the floor area being in the daylit area under skylights, the skylight area being 3% of the skylit area and the skylight VT being at least 0.40. As an alternative to minimum skylight area and minimum VT, one can comply using an effective aperture calculation. The effective aperture is:

$$\text{Skylight Effective Aperature} = \frac{0.85 \times \text{Skylight Area} \times \text{Skylight VT} \times \text{WF}}{\text{Daylight zone under skylight}}$$

Where the well factor is 0.9 if light well depth is less than 2 feet (610 mm), or 0.7 if light well depth is 2 feet (610 mm) or greater.

The ASHRAE 90.1-2013 standard dropped the room floor area threshold from 5,000 sf to 2,500 sf that triggers minimum skylight area requirement. Also in 90.1-2013, the threshold for automatic daylighting controls was dropped to 150 Watts. Also the automatic daylighting controls are required to have 3 levels of control plus OFF (such as 100%, 67%, 33%, OFF).

The 2012 IECC minimum skylight area requirements are identical to the ASHRAE 90.1 requirements except the room area threshold is 10,000 sf. For more details see *Appendix D: 2012 IECC Minimum Daylight Area Code Language* in the end of this report.

The 2012 version of the IECC requires separate control of lighting in daylit area but allows either manual control or automatic control. The automatic control is required to be at least three levels of control and consume no more than 35% of rated power under full daylight conditions.

2.1.3 Existing 2013 Title 24 Standards

During the 2013 standards development there was an agreement that the calculation of effective aperture as an alternative method of showing compliance with this section was overly complex. Calculating effective aperture was complex for two reasons:

- It required calculating the area of the skylit zone – which can be a convoluted geometry when one includes the presence of racks and other obstructions which truncate the skylight zone.
- It required the calculation of well efficiency which requires the calculation of well cavity ratio and looking up this value on a nomograph (or later on a look up table) for various light well surface reflectances.

When the effective aperture requirement in the 2013 standards was deleted, the minimum total skylight area was also deleted. This loss of the minimum skylight area requirement was missed by some key stakeholders until after the 2013 standard was adopted. Though these changes still left a requirement for a minimum fraction (75%) of the floor area being in the daylit zone, this minimum daylit zone fraction did not place any direct threshold of how much daylight or skylight area had to serve this zone.

The revised structure of the skylighting requirement does not assure minimum skylight areas as in 2008 Title 24 standards. An unintended consequence was that the performance approach as documented in the Alternative Compliance Method (ACM) Reference Manual, no longer has a stable baseline of how much skylight area was required for the baseline building. The code language for the 2013 daylighting standards is provided at the end of this report in *Appendix C: 2013 Title 24 Minimum Daylight Area Code Language.*

The primary requirement for skylight area is indirectly required by the following requirement in Section 140.3(c)1:

1. A combined total of at least 75percent of the floor area, as determined in building floor plan (drawings) view, shall be within one or more of the following:

   A. Primary Sidelight Daylight Zone in accordance with Section 130.1(d)1B, or

   B. Skylit Daylit Zone in accordance with Section 130.1(d)1A.

Table 4: 2013 Title 24 rule set of 75% of floor area is in skylit area for 4’ by 8’ skylights: impact on SDR, SFR, and ASHRAE/IECC calculated skylight effective aperture

	Skylight to Daylit Area	Skylight to Floor area	2013 T-24 ASHRAE/IECC Eff Aperture			
			Plastic VT		Glass VT	
Ceiling Ht	SDR	SFR	EA Deep	EA Shallow	EA Deep	EA Shallow
15	4.4%	3.3%	1.7%	2.2%	1.3%	1.7%
20	2.8%	2.1%	1.1%	1.4%	0.8%	1.0%
22	2.4%	1.8%	0.9%	1.2%	0.7%	0.9%
24	2.0%	1.5%	0.8%	1.0%	0.6%	0.8%
26	1.8%	1.3%	0.7%	0.9%	0.5%	0.7%
28	1.6%	1.2%	0.6%	0.8%	0.5%	0.6%
30	1.4%	1.0%	0.5%	0.7%	0.4%	0.5%
32	1.2%	0.9%	0.5%	0.6%	0.4%	0.5%
34	1.1%	0.8%	0.4%	0.5%	0.3%	0.4%
36	1.0%	0.8%	0.4%	0.5%	0.3%	0.4%

A significant amount of effort over the last decade went into identifying the “sweet spot” for skylighting. Repeatedly, the result from massive simulations runs was that energy cost savings was optimized when the skylight to daylit area ratio (SDR) was around 3% and the effective aperture is around 1% and this is reflecting in the minimum skylight area requirements in ASHRAE 90.1 standard, the IECC and prior versions of Title 24.

The argument has been made that the 2013 Title 24 requirement for 75% of the floor area being in the skylit daylight area will assure there is either sufficient skylight area or sufficient effective aperture of the skylighting system. Table 4 and Table 5, broadly illustrate whether this is the case over a range of skylight sizes, ceiling heights and for shallow and deep light well depths. What is readily apparent from both tables is that the minimum required skylight area decreases as ceiling height increases. As ceiling heights increase, the daylight beneath the skylight spreads (0.7 feet horizontally for each foot of ceiling height) from each skylight source and covers a skylit daylit area, thus reducing the ratio of skylight area to daylit area.

Table 4 illustrates the high end estimate of the minimum skylight area needed as all the calculations are based on the industry standard 4’ by 8’ skylight with a nominal area of 32 sf. This is usually the largest standard unit skylight that one can purchase. Table 5 conducts the same calculations for a commercial sized tubular daylighting device (TDD) with a diameter of 22 inches or a nominal area of 2.65 sf. The requirements for minimum skylight area apply to spaces with ceiling heights greater than 15 feet but the targeted big box retail and warehouse spaces for this measure typically have ceiling heights between 20 and 30 feet. Buildings that minimally comply with the 2013 standards with 26 foot ceilings have SDR’s that are less than 2% when large skylights are used and less than 0.3% when TDDs are used. For the tallest ceilings heights where presumably more skylight area is needed, the skylight areas drop off.

Table 5: 2013 Title 24 rule set of 75% of floor area is in skylit area for TDDs: impact on SDR, SFR, and ASHRAE/IECC calculated skylight effective aperture

			ASHRAE/IECC Eff Aperture			
			Plastic VT		Glass VT	
Ceiling Ht	SDR	SFR	EA Deep	EA Shallow	EA Deep	EA Shallow
15	0.6%	0.5%	0.2%	0.3%	0.2%	0.2%
20	0.4%	0.3%	0.1%	0.2%	0.1%	0.1%
22	0.3%	0.2%	0.1%	0.2%	0.1%	0.1%
24	0.3%	0.2%	0.1%	0.1%	0.1%	0.1%
26	0.2%	0.2%	0.1%	0.1%	0.1%	0.1%
28	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%
30	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%
32	0.2%	0.1%	0.1%	0.1%	0.0%	0.1%
34	0.1%	0.1%	0.1%	0.1%	0.0%	0.1%
36	0.1%	0.1%	0.0%	0.1%	0.0%	0.0%

ASHRAE 90.1 and 2012 IECC allow a system to have a minimum effective aperture of 1% in lieu of 3% SDR. The effective aperture is 0.85 (dirt factor), times SDR, times skylight visible transmittance, times the well factor which is 0.7 for deep light wells over 2 feet deep and 0.9 for all other shallow wells. The 2013 Title 24 standards require a minimum skylight VT of 0.64 for plastic skylights and 0.49 for glass skylights. When taken in conjunction with the SHGC requirements for skylights it is hard to achieve higher visible transmittances except perhaps with tubular skylights. As shown in Table 4, with large 4 by 8 foot plastic skylights, a system that is minimally complying with 2013 Title 24 is below the ASHRAE/IECC 1% effective aperture limit in ceiling heights greater than 25 feet and for large glass skylights at ceiling heights greater than 22 feet. As shown in Table 5, with commercial sized TDDs, a system that is minimally complying with 2013 Title 24 is well below the ASHRAE/IECC 1% effective aperture limit for all covered ceiling heights.

What conclusions can be drawn for this analysis? The minimum ratio of daylit area to total floor area is useful for assuring that skylights are evenly distributed and serving most of the room, but it does not assure that there is sufficient skylight area to provide enough daylight illuminance so lights are turned off or significantly dimmed most hours of the day. As ceiling heights get higher, skylit areas need to overlap or skylight must increase in size so that there is enough daylight available to provide significant energy savings.

This minimum skylight area proposal for the 2016 version of Title 24 would directly regulate minimum skylight area for these large open spaces instead of the current method of indirectly affecting skylight area. The proposed code language for this proposal is in *Section 6 Proposed Language* and contains the following proposed language for the revised Section 140.3(c) items 1 and 4:

1. At least 75 percent of the floor area, as determined in building floor plan (drawings) view, shall be within a horizontal distance of one head height from windows or within 0.7 times average ceiling height from the edge of rough opening of skylights

…

4. The total skylight area is at least 3% of the total floor area within 0.7 times the average ceiling height from the edge of rough opening of skylights.

Exception to Section 140.3(c)4. Skylight area is allowed to be less than 3% where the product of the total skylight area and the average skylight visible transmittance is no less than 1.5% of the total floor area within 0.7 times average ceiling height from the edge of rough opening of skylights.

Table 6: 2016 Proposal for SDR and VT x SDR exception: comparison to ASHRAE 90.1 and IECC

	Proposed min SDR and existing min VT requirement			Proposed Exception	ASHRAE/IECC Effective Aperture	
	min SDR	min SFR	min VT	min (SDR x VT)	EA Deep	EA Shallow
Plastic Skylight	3%	2.3%	64%	1.5%	0.9%	1.1%
Glass Skylight	3%	2.3%	49%	1.5%	0.9%	1.1%

Since this proposal would directly regulate the minimum skylight to daylight ratio to a minimum of 3% as does ASHRAE 90.1 and IECC, this proposal matches that part of the ASHRAE/IECC codes exactly. As we are regulating SDR directly, the results do not vary by ceiling height.

As described above the ASHRAE/IECC codes allow an alternative approach that requires a minimum effective aperture of 1%. To do this the ASHRAE/IECC codes define a well factor of 0.7 for light wells with height greater than 2 feet and a well factor of 0.9 for light wells that are two feet tall or less. The proposed exception to Section 140.3(c)4 is simplified and does not calculate effective aperture as it does not require reporting of light well height and determining which well factor to use. As shown in Table 6, requiring that the product of the skylight area and skylight VT being at least 1.5% of the skylit area, this is equivalent to a minimum ASHRAE/IECC effective aperture of 0.9% when assuming one has deep light wells and a minimum ASHRAE/IECC effective aperture of 1.1% for systems with shallow light wells. The end result is that this proposal matches very closely the 1% ASHRAE/IECC effective aperture requirements while using an easier calculation method.

When the 2013 CASE report for daylighting was written, the authors proposed simplifying the calculation of the daylit area. Rather than calling it the daylit area, the authors had proposed that *"75 percent of the floor area, as determined in building floor plan (drawings) view, shall be within a horizontal distance of one head height from windows or within 0.7 times average ceiling height from the edge of rough opening of skylights."*

This is different than the skylit daylight area in that the skylit daylight area is intended to describe the luminaires that must be controlled by automatic daylighting controls. The skylit daylight area does not include areas that are behind racks and other partial height obstructions where turning off lights would result in occupant complaints and the daylighting control systems being disabled or adjusted so that savings would be substantially reduced for all the other lights that are receiving unobstructed daylight.

Unfortunately this advice did not migrate into the 2013 standards. The problem with using the skylit daylight zone instead of the above language is:

- Partitions and racks may be added after the envelope is designed and thus the daylit areas change, potentially causing confusion and conflict as a space complying originally but not later on when the racks are added.
- Calculating the daylit areas including the cut-outs for partitions and racks is significantly more difficult to calculate than calculating the total areas around skylights without the consideration of these obstructions.

Thus the changes proposed for the 2016 standards would more closely align with the ASHRAE/IECC standards, would save more energy and would be easier to show compliance than the current 2013 Title 24 standard.

2.1.4 Alignment with Zero Net Energy Goals

This proposal increases the energy savings in the applicable spaces. Some observers have commented that skylighting takes away valuable roof space that might otherwise be occupied by renewable energy systems. However it should be noted that the minimum skylight area discussed here is 3% of the skylit area. Title 24 places a prescriptive maximum skylight area of 5% of the gross roof area. Thus it is likely that both technologies can be accommodated on the same roof.

At this point in time skylighting is a significantly lower cost method of reducing the consumption of non-renewable energy sources. Thus it makes sense to give skylighting priority on roof space. If photovoltaics continue dropping in price, this might have to be reviewed along with the California state policy of the “energy loading order” which places a higher priority on saving energy before demand response and renewable energy.

2.1.5 Relationship to Other Title 24 Measures and Other Codes

Reinstating the minimum skylight area requirements from the 2008 Title 24 also more closely aligns the Title 24 minimum skylight area requirements with those in the 2010 and 2013 versions of ASHRAE 90.1 Energy Standard for Buildings Except Low-Rise Residential Buildings. This is desirable as designers that are used to complying with the ASHRAE 90.1 daylighting requirements will have less of a learning curve to comply with the proposed 2016 California Title 24 daylighting requirements. In addition, the minimum skylight area requirements in ASHRAE 90.1 are identical to those found in the 2012 version of the International Energy Conservation Code (IECC 2012). The 2016 IECC is used in 16 states.[2]

The outcome of this proposal impacts the benefits from the proposal to provide Power Adjustment Factors (PAF) lighting control credits for daylight dimming plus OFF controls. [CASE 2014] More daylight area increases the value of these controls, and these controls increases the values of more skylights.

[2] International Codes-Adoption by State (September 2014) http://www.iccsafe.org/gr/Documents/stateadoptions.pdf

2.2 Summary of Changes to Code Documents

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

2.2.1 Catalogue of Proposed Changes

Scope

Table 7 identifies the scope of the code change proposal. This measure will impact the following areas (marked by a "Yes").

Table 7: Scope of Code Change Proposal

Mandatory	Prescriptive	Performance	Compliance Option	Trade-Off	Modeling Algorithms	Forms
Y	Y	Y	Y	Y	Y	Y

Standards

The proposed code change will modify the sections of the California Building Energy Efficiency Standards (Title 24, Part 6) identified in Table 8.

Table 8: Sections of Standards Impacted by Proposed Code Change

Title 24, Part 6 Section Number	Section Title	Mandatory (M) Prescriptive (Ps) Performance (Pm)	Modify Existing (E) New Section (N)
130.1(d)	Automatic Daylighting Controls	M	E
140.3(c)	Minimum Daylighting Requirement for Large Enclosed Spaces	Ps	E
140.6(d)	Automatic Daylighting Controls in Secondary Daylit Zones	Ps	E

Nonresidential Alternative Calculation Method (ACM) Reference Manual

The proposed code change will modify the sections of the Residential or Nonresidential Alternative Calculation Method References identified in Table 9.

Table 9: Sections of ACM Impacted by Proposed Code Change

Nonresidential Alternative Calculation Method Reference		
Section Number	**Section Title**	**Modify Existing) New Section**
3.2.2.4	Design Illumination Setpoint	Modify Existing
5.4.4	Interior Lighting	Modify Existing
5.4.5	Daylighting Control	Modify Existing

Simulation Engine Adaptations

The proposed code change can be modeled using the current simulation engine. Changes to the simulation engine are not necessary.

2.2.2 Standards Change Summary

This proposal would modify the following sections of the Building Energy Efficiency standards as shown below. See ***Section 6.1 Standards*** of this report for the detailed proposed revisions to the standards language.

Changes in Scope

- Nothing in this proposal changes the scope of the standards.

Changes in Mandatory Requirements

- **Section 130.1(d)1 Automatic Daylighting Controls: Daylight Zones.** Whenever there is an overlap between the skylit zone and other daylit zones the skylit zone takes precedence. Any areas that overlap between the secondary sidelit zone and the primary sidelit zone, the primary sidelit zone takes precedence.
- **Section 130.1(d)2D Automatic Daylighting Control Installation and Operation.** More clearly state the requirements for the accessibility of calibration adjustment control for photocontrol (daylighting control) systems. The primary purpose of this requirement is to prevent tampering with the photosensor and to have the calibration controls readily accessible so that adjustments to daylighting controls can be easily performed by authorized personnel in response to changes in geometry or reflectance of the interior, changes in occupancy or tasks and in response to requests for more or less light from occupants. This is only included here for completeness see the Nonresidential Lighting Controls: Clarification and Control Credits CASE report for more details [CASE 2014]
- **Section 130.1(d)3 Parking garage requirements.** This adds clarifying language that the primary and secondary sidelit daylit zones in parking garages are intended to be controlled together (due to very low LPD and low design illuminance) and the illuminance levels that are the basis of control should be on the far edge of the secondary zone away from the window or exterior opening.

Changes in Prescriptive Requirements

- **Section 140.3(c) Minimum Daylighting Requirement for Large Enclosed Spaces**. Simplified the calculation of areas near skylights, and windows. Reinstated the minimum skylight area requirement and reinstated a trade-off between skylight VT and minimum skylight area.
- **Section 140.6(d) Automatic Daylighting Controls in Secondary Daylit Zones**. Clarifies that skylit daylit zones take precedence over secondary sidelit zones when the two overlap.

2.2.3 /Nonresidential Alternative Calculation Method (ACM) Reference Manual Change Summary

This proposal would modify the following sections of the Alternative Calculation Method (ACM) Reference Manual as shown below. Skylighting would be directly modelled using the split-flux algorithms that are embedded in EnergyPlus (the simulation engine for the reference performance method program CBECC-Com). The reference case is a skylighting system with 3% skylight area and the prescriptive visible light transmittance and with continuous dimming daylighting controls controlling 70% of the general lighting power in 75% of the space. See ***Section 6.2 ACM Reference Manual*** of this report for the detailed proposed revisions to the text of the Alternative Calculation Method (ACM) Reference Manual.

2.2.4 Compliance Forms Change Summary

The proposed code change will modify the following compliance forms listed below. Examples of the revised forms are presented in ***Section 6.5 Compliance Manual*** and Compliance Forms.

- **Compliance Form 2013-NRCC-ENV-04-E** *Minimum Skylight Area Worksheet.* This form will be updated to include skylight area for calculating whether the skylight area is greater than 3% of the area near skylights. This form will be expanded to include skylight VT and a calculation method to evaluate if the products of skylight VT and skylight area are greater than 1.5% of the area near skylights.

2.2.5 Simulation Engine Adaptations

No changes are required to the EnergyPlus simulation engine.

2.2.6 Other Areas Affected

No other areas affected.

2.3 Code Implementation

2.3.1 Verifying Code Compliance

Verification will be very similar to how compliance was verified for the 2008 standards except the calculation procedure is streamlined. The calculation of area near skylights is simpler than the calculation of area in the skylit daylit area which had to account for racks and other obstructions.

2.3.2 Code Implementation

As mentioned above code implementation is similar to the 2008 Title 24 code except that the area near skylights is much simplified. In addition the requirements more closely match the ASHRAE 90.1 and 2012 IECC requirements. Thus the learning curve will be less steep for designers and contractors that also work in states covered by those codes.

2.4 Issues Addressed During IOU CASE Development Process

The Statewide CASE Team solicited feedback from a variety of stakeholders when developing the code change proposal presented in this report. In addition to personal outreach to key stakeholders, the Statewide CASE Team brought up this issue during public stakeholder workshops to discuss that this clean-up effort should occur. The issues that were addressed during development of the code change proposal are summarized below.

- Lighting systems are becoming more efficient and lighting controls are turning lights off more frequently. Is skylighting still needed?
  - Many "big box" occupancies such as retail spaces do not turn lighting off based on occupancy and LPDs are still fairly high.
  - Warehouse spaces are frequently heating only or unconditioned so that the skylight area assures lighting is saved without incurring an HVAC penalty.
- Doesn't the fact that the skylit daylit area is at least 75% of the floor area assure that there is sufficient skylight area?
  - The sensitivity analysis in *Section 2.1.3 Existing 2013 Title 24 Standards* for wide range of skylight sizes and ceiling heights show that in many cases, especially with high ceiling heights or moderate skylight sizes, insufficient skylight area is provided.
- Should we consider different minimum skylight areas based on trends in lighting power density and controls?
  - There has been a significant amount of effort to identify the current skylight minimum areas. It would take a significant amount of effort to re-evaluate this for what is essentially a clean-up effort.
  - Aligning with ASHRAE 90.1 and IECC increases the likelihood of compliance.

3. Market Analysis

This market analysis was conducted for skylighting CASE proposals developed for the 2005, 2008 and 2013 standards. A detailed quantitative market analysis was not repeated for this clean-up effort based on the 2008 standards and the ASHRAE 90.1 standards.

3.1 Market Impacts and Economic Assessments

3.1.1 Impact on Builders

For those designs that would have used 3% skylight area to daylit area, this proposal will have no impact, for those designs where the designer was planning on using the minimum possible amount of skylight area, this proposal will increase the number of skylights used and slightly increase the cost of the building. This will have most impact taller spaces as will be described later on in this report.

3.1.2 Impact on Building Designers

This proposal will simplify the process of showing that the design complies. This proposal has a stable skylight area requirement that is unaffected by the presence of racks or partitions. The 2013 requirement could vary by the presence of partitions and could comply at one part of the construction process and not comply later on when partitions were added. Thus designers should like the more simple and stable design requirements. Since this proposal is closely aligned to the ASHRAE 90.1 and 2012 IECC national energy codes, this proposal is likely easier to comply with for design firms that have a multi-state presence.

3.1.3 Impact on Occupational Safety and Health

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

3.1.4 Impact on Building Owners and Occupants

Since this measure is cost-effective, the building owner who pays their energy bills are reducing their energy costs more than their mortgage costs are for the cost of the measure (i.e. there are experiencing net cost savings). For building occupants that are paying for their energy bills, since the measure saves more energy cost on a monthly basis than the measure costs on the mortgage as experiences by the building owner, the pass-through of added mortgage costs into rents is less than the energy cost savings experienced by occupants.

3.1.5 Impact on Retailers (including manufacturers and distributors)

This proposal will reverse the decline in fraction of skylight area to floor area allowed by the 2013 standard and revert this fraction back up that required by the 2008 standards. The overall impact is around a 50%-100% increase in skylight area for those designers who minimally comply with the standards. However, many designers who make use of design tools and are trying to optimize skylight area will see no impact from this proposal.

3.1.6 Impact on Energy Consultants

For consultants showing compliance using the performance approach, the changes occur “under the hood” of the compliance software and would be unaffected. For energy consultants that show compliance using the prescriptive approach, there should be a slight reduction in complexity.

3.1.7 Impact on Building Inspectors

This proposal should streamline slightly enforcement. As compared to the overall code enforcement effort, this measure has negligible impact on the effort required to enforce the building codes.

3.1.8 Impact on Statewide Employment

Skylights are large and therefore cost a lot to ship. This favors skylights being made close by and many being manufactured in state. Skylights take more labor to install than the roofing they replace. Thus skylights increase construction employment. Skylights are relatively cheap (around $20/sf installed cost) and have minimal impact on the construction cost of a building.

3.2 Economic Impacts

The estimated impacts that the proposed code change will have on California's economy are discussed below.

3.2.1 Creation or Elimination of Jobs

Skylights take more labor to install than the roofing they replace. Thus skylights increase construction employment. Skylights are relatively cheap (around $20/sf installed cost) and have minimal impact on the construction cost of a building. Skylights require labor to construct (arc welding frames, thermoforming plastic, assembly etc.). As mentioned above since they are large and expensive to ship long distances they are likely manufactured in California or in the region.

3.2.2 Creation or Elimination of Businesses within California

This proposal slightly assists business creation in California as skylights are large and therefore cost a lot to ship. This favors skylights being made close by and many of these being manufactured in state.

3.2.3 Competitive Advantages or Disadvantages for Businesses within California

This proposal slightly assists business creation in California as skylights are large and therefore cost a lot to ship. This favors skylights being made close by and many of these being manufactured in state. In addition, California businesses operating in buildings with skylighting are saving more on their energy bills than the increase in building costs. Thus skylighting is a wealth generator for California businesses.

3.2.4 Increase or Decrease of Investments in the State of California

This proposal slightly assists business creation in California as skylights are large and therefore cost a lot to ship. This favors skylights being made close by and many of these being manufactured in state.

3.2.5 Incentives for Innovation in Products, Materials, or Processes

Skylights have been required in the California Title 24 energy code since the 2005, thus this modification to the skylighting requirement will have little to no impact on incentives.

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

This proposal should streamline slightly enforcement. As compared to the overall code enforcement effort, this measure has negligible impact on the effort required to enforce the building codes.

3.5.6.1 Cost of Enforcement

Cost to the State

The impact of this proposal as compared to the entire Title 24, part 6 update is negligible.

Cost to Local Governments

This proposal should streamline slightly enforcement. As compared to the overall code enforcement effort, this measure has negligible impact on the effort required to enforce the building codes.

3.5.6.2 Impacts on Specific Persons

- Migrant Workers: This proposal and all measures adopted by CEC into Title 24, part 6 do not advantage or discriminate in regards to national origin.
- Persons by Age: This proposal and all measures adopted by CEC into Title 24, part 6 do not advantage or discriminate in regards to age group.
- Persons by Race: This proposal and all measures adopted by CEC into Title 24, part 6 do not advantage or discriminate in regards to race.
- Persons by Religion: This proposal and all measures adopted by CEC into Title 24, part 6 do not advantage or discriminate in regards to religion.
- Building Owners: Buildings that have sufficient daylight from skylights are perceived to be brighter, cleaner and more enjoyable to work in. Stores with daylighting have been correlated with higher retail sales.[3]
- Renters: This proposal is advantageous to renters as it reduces the cost of utilities which are typically paid by renters. Since the measure saves more energy cost on a monthly basis than the measure costs on the mortgage as experiences by the commercial building owner, the pass-through of added mortgage costs into rents is less than the energy cost savings experienced by tenants.
- Commuters: This proposal and all measures adopted by CEC into Title 24, part 6 are not expected to have an impact on commuters

[3] Heschong Mahone Group. Daylighting and Productivity – CEC PIER. http://h-m-g.com/projects/daylighting/summaries%20on%20daylighting.htm

4. METHODOLOGY

This section describes the methodology and approach the Statewide CASE Team used to estimate energy, demand, costs, and environmental impacts. The Statewide CASE Team calculated the impacts of the proposed code change by comparing existing conditions to the conditions if the proposed code change is adopted. This section of the CASE Report goes into more detail on the assumptions about the existing and proposed conditions, prototype buildings, and the methodology used to estimate energy, demand, cost, and environmental impacts.

4.1 Existing Conditions

To assess the energy, demand, costs, and environmental impacts, the Statewide CASE Team compared current design practices to design practices that would comply with the proposed requirements. This analysis of existing conditions is contained in Section *2.1.3 Existing 2013 Title 24 Standards.* What this discussion of the existing standards shows it that the current rule set allows significantly less skylight area than the 3% skylight area to skylit daylit ratio required by the 2008 version of Title 24 and also required by ASHRAE 90.1 and the 2012 IECC.

4.2 Proposed Conditions

The proposed conditions are defined as the design conditions that will comply with the proposed code change. The proposed conditions are that the minimum skylight area is at least 3% of the area that is within 70% of the ceiling height in plan view (horizontally) from skylights. Alternatively the product of skylight VT and skylight area is at least 1.5% of the area that is within 70% of the ceiling height in plan view (horizontally) from skylights; this reflects the main 3% requirement as applied to glass skylights (with a minimum VT of 0.49).

4.3 Prototype Building(s)

This analysis is based upon the analysis that was conducted for the development of the minimum skylight area proposal for the ASHRAE 90.1-2010 Standard. The following is copied verbatim from the technical report provided to the Lighting and Envelope Subcommittees. [PNNL 2008] The sections of the ASHRAE 90.1 report have the discussion of office spaces with deep light wells were deleted as this was found not to be cost-effective for either the ASHRAE 90.1 standard or Title 24. It is this reason that the minimum skylight area requirements are limited to spaces that have ceiling heights greater than 15 feet. As ceiling heights greater than 15 feet, suspended ceilings and skylight light wells are rarely used.

A total of approximately 40,000 energy simulation runs were conducted by Paul Reeves of The Partnership for Resource Conservation using the DOE2.2 energy simulation engine. The DOE2.2 simulation engine is same engine as used in the popular eQUEST energy simulation tool.

A summary of the simulation parameters is included in Table 10 below. Detailed descriptions of each of the parameters are included in the following sub-sections.

Measure	# Parameters	List of Parameters
Climate Zone	15	Reference: **Table 14**
Building Type	3	Warehouse, Retail, Open-Plan Office
Skylight Type	34	Reference: Table 11, Table 12
SFR	9	0%, 1%, 2%, 2.5%, 3%, 3.5%, 4%, 5%, 6%
Lighting Controls	3	Warehouse: None; On/Off; ON/50%/OFF Retail: None; ON/67%/33%; Dimming Office: None; ON/50%/OFF; Dimming

Table 10: Parametric Analysis Variables

a. Baseline Assumptions

For each of the three buildings, the baseline building was modeled with no skylights and therefore no daylighting controls. Energy cost and life cycle cost savings for each climate zone, building type and skylight configuration was then based on the corresponding baseline building with no skylights and no daylighting controls.

b. Skylight Specifications

Skylight properties were varied to account for high, medium, low and very low transmissivity. This will impact SHGC and visible light transmittance (VLT).

Single, double and triple glazing layers will be modeled. Various skylight frames will also be modeled as a function of the number of glazing layers. Combinations are: Single glazed skylights with metal frames. Double glazed skylights with metal and thermally broken frames. Triple glazed skylights with both thermally broken frames and vinyl frames. The number of glazing layers affects SHGC, VLT and U-factor. The frame configuration affects U-factor only.

Most of the glazing configurations are from a database developed by Joe Deringer for an analysis of ASHRAE 90.1 fenestration requirements. The few modifications come from manufacturer supplied skylight property data.

Skylight areas are incremented as follows: 1%, 2%, 2.5%, 3%, 3.5%, 4%, 5%, and 6% of roof area

U-factor is changed by altering the frame type, the number of glazing layers and for glass skylights by low-e films. Single glazed skylights have metal frames. Double glazed skylights can be either metal or thermally broken metal frames. Triple glazed skylights can be either thermal broken metal frames or vinyl frames.

SHGC and VLT are changed together by investigating common diffusing glazings. For plastic skylights the choices are high white, medium white and low white. Clear layers are added when additional U-factor is desired.

Since we are only interested in diffusing skylights for providing relative uniform daylight into the space glass skylights have either a sheet of laminated glass with a white interlayer or a sheet of prismatic plastic installed in the skylight frame or at the bottom of the light well. If the prismatic plastic diffuser is installed at the bottom of the light well, it is assumed that all of the solar heat gain enters the space directly or by passing through the sides of the light well into the plenum and is not partially filtered out by the diffuser as is the case when the diffuser is installed in the skylight.

A skylight is considered diffusing if the glazing layers have a haze rating greater than 90%. All the skylights modeled have haze ratings greater than 90%.

Glazing Description	SHGC	Tvis	Baseline Size	Total Horizontal U-factor	U-factor Center Glass	U-factor Edge Glass
Metal, Single glass, Med. wht. interlayer	0.666	0.608	4 x 4	1.285	1.149	1.148
Metal, Single glass, 8% SS	0.219	0.081	2 x 4	1.980	1.190	1.190
Metal, Single glass, Bronze	0.593	0.417	2 x 4	1.980	1.190	1.190
Metal, Single glass, Clear + prism. diff.	0.709	0.785	4 x 4	0.803	0.539	0.632
Metal, Single glass, Evergreen + prism. diff.	0.410	0.591	4 x 4	0.803	0.539	0.632
Metal, Dbl glass, 20% TI over clear + prism. diff	0.237	0.189	2 x 4	1.300	0.570	0.650
Metal, Dbl glass, 8% SS over clear + med. wht. diff.	0.138	0.054	2 x 4	1.300	0.570	0.650
Th.Brk., Dbl Low-e glass, Evergreen over med. wht.	0.265	0.369	4 x 4	0.519	0.412	0.475
Th.Brk., Dbl Low-e glass, Clear over med. wht.	0.353	0.474	4 x 4	0.519	0.413	0.476
Th.Brk., Dbl Low-e glass, Argon, Evergreen over med. wht.	0.255	0.369	4 x 4	0.471	0.339	0.415
Th.Brk., Dbl Low-e glass, Argon, Clear over med. wht.	0.351	0.474	4 x 4	0.471	0.340	0.416
Th.Brk., Dbl Low-e glass, Clear over clear + prism. diff.	0.349	0.613	4 x 4	0.430	0.284	0.374
Th.Brk., Dbl Low-e glass, Argon, Clear over clear + prism. diff.	0.347	0.613	4 x 4	0.402	0.247	0.349
Th.Brk., Dbl glass, 20% TI over clear + prism. diff.	0.237	0.189	2 x 4	1.100	0.570	0.650
Th.Brk., Dbl glass, 8% SS over clear + med. wht. diff.	0.138	0.054	2 x 4	1.100	0.570	0.650

Table 11: Glass Skylight Properties

Glazing Description	SHGC	Tvis	Baseline Size	Total Horizontal U-factor	U-factor Center Glass	U-factor Edge Glass
Metal, Single plastic, Prism.	0.802	0.826	4 x 4	1.330	1.056	1.055
Metal, Single plastic, Med. wht.	0.589	0.615	4 x 4	1.330	1.113	1.112
Metal, Single plastic, Low wht.	0.387	0.320	2 x 4	1.920	1.110	1.110
Metal, Single plastic, Ultra low wht.	0.181	0.150	2 x 4	1.920	1.110	1.110
Metal, Dbl plastic, Clear over med. wht.	0.542	0.490	2 x 4	1.290	0.570	0.650
Metal, Dbl plastic, Clear over high wht.	0.619	0.750	2 x 4	1.290	0.570	0.650
Metal, Dbl plastic, Low wht. over clear	0.344	0.290	2 x 4	1.290	0.570	0.650
Metal, Dbl plastic, Ultra low wht. over clear	0.161	0.136	2 x 4	1.290	0.570	0.650
Th.Brk., Dbl plastic, Clear over med. wht.	0.542	0.490	2 x 4	1.120	0.570	0.650
Th.Brk., Dbl plastic, Clear over high wht.	0.619	0.750	2 x 4	1.120	0.570	0.650
Th.Brk., Dbl plastic, Low wht. over clear	0.344	0.290	2 x 4	1.120	0.570	0.650
Vinyl, Triple plastic, Clear over clear over prism	0.765	0.890	2 x 4	0.650	0.360	0.510
Th.Brk., Dbl plastic, Ultra low wht. over clear	0.161	0.136	2 x 4	1.120	0.570	0.650
Vinyl, Dbl plastic, Clear over med. wht.	0.542	0.490	2 x 4	0.840	0.570	0.650
Th.Brk., Dbl plastic, Prism. over prism.	0.690	0.719	4 x 4	0.710	0.516	0.573
Th.Brk., Triple plastic, Prism. over prism. over prism.	0.614	0.631	4 x 4	0.666	0.333	0.411
Th.Brk., Triple plastic, Clear over clear over med. wht. (U 0.91)	0.499	0.450	2 x 4	0.910	0.360	0.510
Th.Brk., Triple plastic, Clear over clear over med. wht. (U 0.66)	0.560	0.414	4 x 4	0.666	0.339	0.415
Th.Brk., Triple plastic, Clear over clear over high wht.	0.585	0.690	2 x 4	0.910	0.360	0.510

Table 12: Plastic Skylight Properties

Actual U-factors versus rated or default U-factors

The tables in the ASHRAE Handbook of Fundamentals and the default skylight properties and the U-factor requirements for skylights are all based on the old NFRC residential rating criteria for skylights. This old criterion assumed skylights were over a 2' by 4' opening. The recent NFRC criteria require that skylights be rated for a 1.200 x 1,200 mm size (48" x 48"). More heat loss occurs through skylight frame and edge of glass per unit area than through the center of glass.

As skylights get larger there is a greater ratio of center of glass area to edge of glass and frame. **As a result, the tables in the Fenestration Chapter of the ASHRAE Handbook of Fundamentals, the default tables and the required skylight U-factors are all higher than current NFRC ratings for the same product configurations.** This analysis adjusts U-factors with respect to the actual size of skylights modeled. As the skylight increases in size, the U-factor drops relative to the ratios of: frame, edge of glass and center of glass areas. We assume that when the skylight size is greater than 32 sf, that additional skylights would be used rather than making a larger skylight. Thus skylight U-factors do not drop any lower than what would be the case for a 32 sf skylight.

The edge of glass area is assumed to be 0.7 inches wide and the frame area is assumed to be 2.5 inches wide. See Figure 4 for an illustration of the frame, edge of glass and center of glass areas.

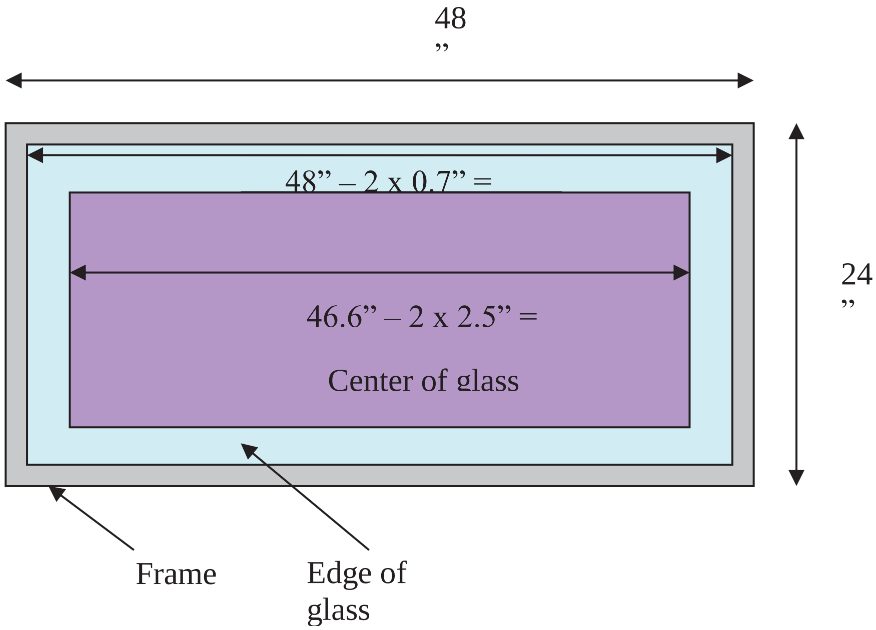

Figure 4: ASHRAE Skylight Size, Frame, Edge and Center of Glass Dimensions

c. Building Types and Specifications

Warehouse Model

The warehouse modeled is 82,944 sf with 32 ft ceiling height. The stacks in this space are 15 feet tall and have an effective reflectance of 40%. The walls, floor and ceiling of the space have reflectances of 50%, 20% and 60% respectively.

The warehouse is modeled with sidelit windows with a 3% Window/Wall ratio. *[Ed note: this is the base case building to which 3% SFR of skylights are added]*

We are interested in looking at the impact of skylights on a heated only warehouse with gas unit heaters.

General lighting systems have a maximum lighting power density of 0.9 W/sf. based on Table 9.6.1 of the ASHRAE 90.1-2004 Standards.

Lighting systems and controls:

High or medium bay HID lighting

d. Single level on/off control

e. Two level on/off control (On/50%/OFF)

Retail Model

The big box retail store is modeled is 46,656 sf with 24 ft ceiling height. The stacks in this space are 15 feet tall and have an effective reflectance of 40%. The walls, floor and ceiling of the space have reflectances of 50%, 20% and 60% respectively.

The building we are considering is heated and cooled with roof top air cooled roof top units. Outside air rates are determined as according to ASHRAE 62.

The retail space is modeled with sidelit windows with a 1.5% Window/Wall ratio. [*Ed note: this is in the base case building to which 3% SFR of skylights are added*]

Lighting power density of general lighting set to 1.7 W/sf based on Table 9.6.1 of the ASHRAE 90.1-2004 Standards.

Lighting systems and controls: There are two likely types of lighting systems with their associated controls:

High or medium bay HID lighting

a. ON/67%/33%

T-8 fluorescent industrial strips

b. Fluorescent dimming 20% power at 10% light level

4.4 Climate Dependent

The energy savings and thus the cost-effectiveness results are climate dependent. This analysis, originally conducted for the ASHRAE 90.1 commercial building energy standard considered a much broader range of climates. This analysis found that a 3% minimum skylight area was cost-effective across all climate zones.

A brief description of the range of climate zones evaluated for the ASHRAE 90.1-2010 proposal is copied below.

We will use the representative US locations that were used to define the weather zones for ASHRAE. Below is an extract from the “Climate Classification for Building Energy Codes and Standard” document generated by PNNL.

B. Thermal Zone Definitions

Zone No.	Climate Zone Name and Type	Thermal Criteria(1,8)	Representative U.S. City*	Köppen Class.	Köppen Classification Description
1A	Very Hot – Humid	5000 < CDD10ºC	Miami, FL	Aw	Tropical Wet-and-Dry
1B(7)	Very Hot – Dry	5000 < CDD10ºC	---	BWh	Tropical Desert
2A	Hot – Humid	3500 < CDD10ºC ? 5000	Houston, TX	Caf	Humid Subtropical (Warm Summer)
2B	Hot – Dry	3500 < CDD10ºC ? 5000	Phoenix, AZ	BWh	Arid Subtropical
3A	Warm – Humid	2500 < CDD10ºC ? 3500	Memphis, TN	Caf	Humid Subtropical (Warm Summer)
3B	Warm – Dry	2500 < CDD10ºC ? 3500	El Paso, TX	BSk/BWh/H	Semiarid Middle Latitude/Arid Subtropical/Highlands
3C	Warm – Marine	HDD18ºC ? 2000	San Francisco, CA	Cs	Dry Summer Subtropical (Mediterranean)
4A	Mixed – Humid	2500 ? CDD10ºC AND HDD18ºC ? 3000	Baltimore, MD	Caf/Daf	Humid Subtropical/Humid Continental (Warm Summer)
4B	Mixed – Dry	2500 ? CDD10ºC AND HDD18ºC ? 3000	Albuquerque, NM	BSk/BWh/H	Semiarid Middle Latitude/Arid Subtropical/Highlands
4C	Mixed – Marine	2000 < HDD18ºC ? 3000	Salem, OR	Cb	Marine (Cool Summer)
5A	Cool – Humid	3000 < HDD18ºC ? 4000	Chicago, IL	Daf	Humid Continental (Warm Summer)
5B	Cool – Dry	3000 < HDD18ºC ? 4000	Boise, ID	BSk/H	Semiarid Middle Latitude/Highlands
5C(7)	Cool – Marine	3000 < HDD18ºC ? 4000	---	Cfb	Marine (Cool Summer)
6A	Cold – Humid	4000 < HDD18ºC ? 5000	Burlington, VT	Daf/Dbf	Humid Continental (Warm Summer/Cool Summer)
6B	Cold – Dry	4000 < HDD18ºC ? 5000	Helena, MT	BSk/H	Semiarid Middle Latitude/Highlands
7	Very Cold	5000 < HDD18ºC ? 7000	Duluth, MN	Dbf	Humid Continental (Cool Summer)
8	Subarctic	7000 < HDD18ºC	Fairbanks, AK	Dcf	Subarctic

Table 13: Thermal Zone Definitions for ASHRAE 90.1 Standards

The ASHRAE requirements are specific to 8 climate zones where 1 is the warmest and mildest climate and climate zone 8 is the coldest. In addition, these climate zones are further subdivided by A, B and C based on humidity. We are only modeling those zones which have a representative city in the US. Thus climates 1B and 5C are not modeled.

In reviewing simulation results we found that models using the Chicago weather files did not match the general trends of energy consumption with respect to climate. Perhaps the Chicago weather file has anomalies. Thus we decided to use another city in climate zone 5A. The city we selected is a TMY2 "primary" weather station, Indianapolis, IN. TMY2 primary weather stations make use of measured solar radiation data, most of the other files make use of modeled solar radiation.

Zone#	City, State
1A	Miami, FL
2A	Houston, TX
2B	Phoenix, AZ
3A	Memphis, TN
3B	El Paso, TX
3C	San Francisco, CA
4A	Baltimore, MD
4B	Albuquerque, NM
4C	Salem, OR
5A	~~Chicago, IL~~ Indianapolis, IN
5B	Boise, ID
6A	Burlington, VT
6B	Helena, MT
7	Duluth, MN
8	Fairbanks, AK

Table 14: Climate zones summary

4.5 Time Dependent Valuation

The TDV (Time Dependent Valuation) of savings is a normalized format for comparing electricity and natural gas savings that takes into account the cost of electricity and natural gas consumed during different times of the day and year. The TDV values are based on long term discounted costs (30 years for all residential measures and nonresidential envelope measures and 15 years for all other nonresidential measures). In this case, the period of analysis used is 15 years. The TDV cost impacts are presented in 2016 present value dollars. The TDV energy estimates are based on present-valued cost savings but are normalized in terms of "TDV kBTUs" so that the savings are evaluated in terms of energy units and measures with different periods of analysis can be combined into a single value.

This analysis however uses the 2013 TDV values as contained in the 2013 Daylighting CASE report. As the authors wrote;

This ASHRAE analysis was based on electricity cost of $0.0942/kWh a natural gas cost of $1.25/therm and a scalar (present worth factor) of 8.8. This analysis was re-evaluated using same energy results but using the economic values that underlie the time dependent valuation of energy efficiency measures for Title 24: average electricity costs of $0.1547/kWh, average natural gas costs of $1.22/therm and a 3% (real) societal discount rate resulting in a scalar of 11.9 for a 15 year period of analysis.

4.6 Energy Impacts Methodology

The Statewide CASE Team calculated per unit impacts and statewide impacts associated with all new construction, alterations, and additions during the first year buildings complying with the 2016 Title 24 Standards are in operation. The simulation models and equipment costs models were developed for the ASHRAE90.1 evaluation of skylighting.[PNNL2008] During the 2013 Title 24 standards these same models were adapted for use with Title 24 by using the TDV (time dependent valuation) estimates of long term energy costs and using the 3% real discount rate embedded in TDV.[CASE 2008] The energy model that is the basis of both evaluations was DOE-2.2 and this energy model used the split flux daylighting simulation model embedded in DOE-2.2. Since that time the California performance method whole building energy software, CBECC-com is now based on the simulation software, EnergyPlus. The daylighting model for EnergyPlus uses the same split-flux model that was used in DOE-22. Thus we are expecting that the energy result whether using CBECC-com or DOE-2.2 would provide the same outcomes.

4.6.1 Statewide Energy Impacts Methodology

The Statewide first year cost savings impacts are calculated by taking one year's savings from the skylighting code changes from the 2005, 2008, and 2013 Title 24 code cycles and multiplying this by 10%. This 10% figure is the estimate of lost skylighting savings when the 2013 standards eliminated the minimum skylight area requirements. For a description of how the 2013 reduced the requirements for minimum skylight area, see Section *2.1.3 Existing 2013 Title 24 Standards*. For an explanation of the 10% estimate of energy savings see Section *5.1.1 Statewide Energy Impacts Results* The energy results are multiplied by the 2016 TDV's average present values for nonresidential gas and electric unit costs for a 15 year period of analysis.

4.7 Cost-effectiveness Methodology

This measure proposes a prescriptive minimum skylight area requirement with an alternate approach that considers the product of skylight area and skylight visible light transmittance. As such, a lifecycle cost analysis is required to demonstrate that the measure is cost-effective over the 15 year period of analysis.

CEC's procedures for calculating lifecycle cost-effectiveness are documented in LCC Methodology (CEC 2014). The Statewide CASE Team followed these guidelines when developing the Cost-effectiveness Analysis for this measure. CEC's guidance dictated which costs were included in the analysis. Incremental equipment and maintenance costs over the 15 year period of analysis were included. The TDV energy cost savings from electricity savings and natural gas increased consumption were considered. Each of these components is discussed in more detail below.

Design costs were not included nor will incremental cost of verification.

4.7.1 Incremental Cost Methodology

The incremental costs are based on the cost of adding skylights and photocontrols. The detailed analysis for the ASHRAE 901-2010 energy code is copied below verbatim. [PNNL 2008] These costs were used to evaluate the 90.1 standard and were the basis of the 2013 Daylighting CASE study recommendations to reduce the threshold space area from 8,000 sf to 5,000 sf for the minimum skylight area requirement. [CASE 2013]

First Cost of Skylights

Skylight costs were derived from and manufacturers' cost for installed skylights as well as the costs developed by the envelope committee[4] for ASHRAE standard 90.1. The ASHRAE figures all were in terms of incremental costs above a single glazed skylight with a metal frame. We then fit a regression line through the data to average the costs. In general the ASHRAE costs were quite close to the average of the manufacturers we interviewed. An example of this is shown in Figure 5 and Figure 6, where the squares represent the ASHRAE cost values and the diamonds represent the manufacturer estimates of installed costs.

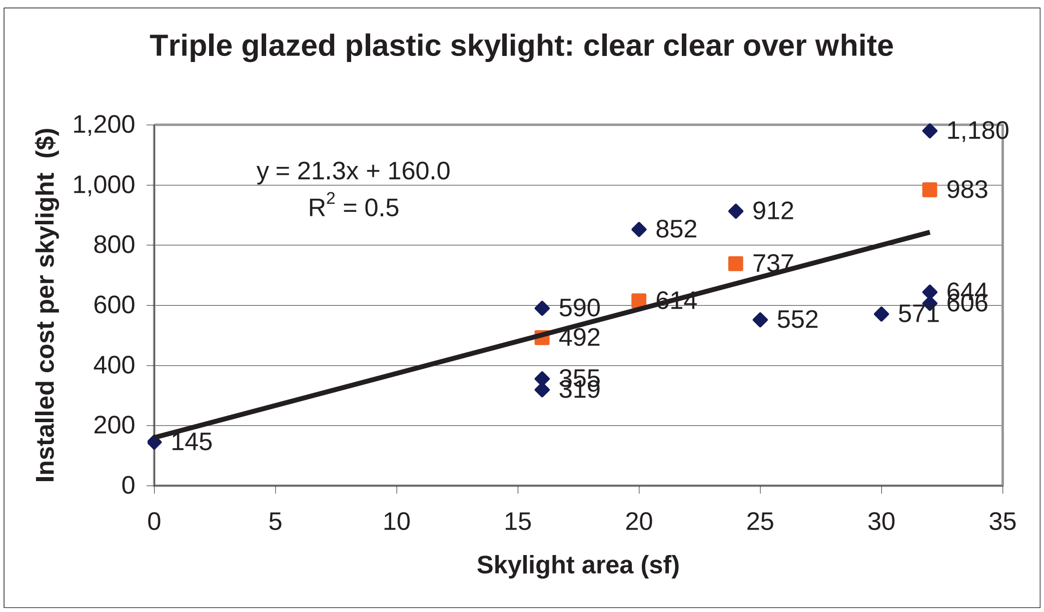

Figure 5: Regression Plot of Cost of Triple Glazed Plastic Dome Skylight vs. Size

[4] We thank Joe Deringer for his assistance in obtaining this data.

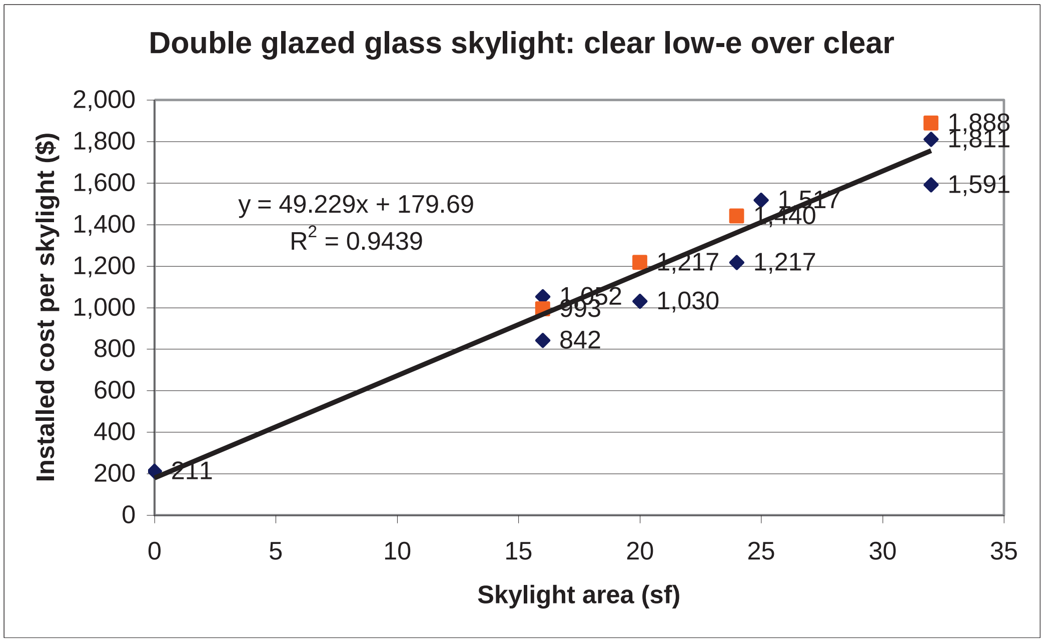

Figure 6: Regression Plot of Cost of Double Glazed Glass Skylight vs. Size

Based upon these regression equations, we then were able to estimate the costs of the skylighting system for each prototype building for each of the skylight to floor ratios from 1% to 6%. These results are given in the tables below.

	Building Area>>	82,944 sq.ft							
		Warehouse							
	Skylight Fraction Index >>	1%	2%	2.5%	3%	3.5%	4%	5%	6%
HMG_ID	Area per skylight >>	**23.04**	**46.08**	**57.6**	**69.12**	**80.64**	**92.16**	**115.2**	**138.24**
501	Med.Wht Interlayer	$945	$1,786	$2,233	$2,679	$3,126	$3,572	$4,465	$5,359
502	1/4" SS on Clear 8%	$1,187	$2,375	$2,969	$3,562	$4,156	$4,750	$5,937	$7,125
503	1/4" Bronze single	$1,133	$2,266	$2,833	$3,400	$3,966	$4,533	$5,666	$6,799
504	Clear - Prismatic	$1,148	$2,200	$2,750	$3,300	$3,850	$4,400	$5,500	$6,601
505	Evergreen - Prismatic	$1,295	$2,492	$3,115	$3,739	$4,362	$4,985	$6,231	$7,477
506	1/4" TI on CLR 20%, PRM	$1,230	$2,460	$3,075	$3,690	$4,304	$4,919	$6,149	$7,379
507	1/4" SS on CLR 8%, MWHT	$1,249	$2,499	$3,123	$3,748	$4,372	$4,997	$6,246	$7,496
508	EvergreenL - Air - Med.Wht	$1,622	$3,141	$3,927	$4,712	$5,497	$6,283	$7,853	$9,424
509	ClearL - Air - Med.Wht	$1,378	$2,667	$3,334	$4,001	$4,668	$5,335	$6,668	$8,002
510	EvergreenL - Arg - Med.Wht	$1,640	$3,179	$3,974	$4,769	$5,563	$6,358	$7,948	$9,537
511	ClearL - Arg - Med.Wht	$1,309	$2,587	$3,234	$3,880	$4,527	$5,174	$6,467	$7,761
512	ClearL - Air - Clear - Prismatic	$1,370	$2,626	$3,283	$3,939	$4,596	$5,252	$6,565	$7,878
513	ClearL - Arg - Clear - Prismatic	$1,368	$2,610	$3,262	$3,915	$4,567	$5,220	$6,525	$7,830
514	1/4" TI on CLR 20%, PRM	$1,304	$2,608	$3,261	$3,913	$4,565	$5,217	$6,521	$7,825
515	1/4" SS on CLR 8%, MWHT	$1,324	$2,647	$3,309	$3,971	$4,633	$5,295	$6,618	$7,942

Table 15: Installed Glass Skylight Costs for Warehouse Prototype

	Building Area>>	82,944 sq.ft							
		Warehouse							
	Skylight Fraction Index >>	1%	2%	2.5%	3%	3.5%	4%	5%	6%
HMG_ID	Area per skylight >>	**23.04**	**46.08**	**57.6**	**69.12**	**80.64**	**92.16**	**115.2**	**138.24**
601	Prismatic	$590	$1,119	$1,399	$1,679	$1,959	$2,239	$2,799	$3,358
602	Medium white	$530	$974	$1,218	$1,461	$1,705	$1,949	$2,436	$2,923
603	Low white (AcrSglLWMtl)	$530	$974	$1,218	$1,461	$1,705	$1,949	$2,436	$2,923
604	Ultra Low White	$530	$974	$1,218	$1,461	$1,705	$1,949	$2,436	$2,923
605	Clear - Med.Wht	$495	$990	$1,238	$1,485	$1,733	$1,980	$2,475	$2,970
606	Clear - High.Wht	$495	$990	$1,238	$1,485	$1,733	$1,980	$2,475	$2,970
607	Low.Wht - Clear	$495	$990	$1,238	$1,485	$1,733	$1,980	$2,475	$2,970
608	Ultra Low White	$495	$990	$1,238	$1,485	$1,733	$1,980	$2,475	$2,970
609	Clear - Med.Wht	$579	$1,078	$1,347	$1,617	$1,886	$2,156	$2,695	$3,234
610	Clear - High.Wht	$579	$1,078	$1,347	$1,617	$1,886	$2,156	$2,695	$3,234
611	Low.Wht - Clear	$579	$1,078	$1,347	$1,617	$1,886	$2,156	$2,695	$3,234
612	Ultra Low White	$579	$1,078	$1,347	$1,617	$1,886	$2,156	$2,695	$3,234
613	Clear - Med.Wht	$615	$1,230	$1,537	$1,844	$2,152	$2,459	$3,074	$3,689
614	Prismatic - Prismatic	$650	$1,237	$1,546	$1,855	$2,164	$2,473	$3,092	$3,710
615	Triple Prismatic	$775	$1,488	$1,859	$2,231	$2,603	$2,975	$3,719	$4,463
616	Clear - Clear - Med.Wht	$652	$1,214	$1,518	$1,821	$2,125	$2,428	$3,035	$3,642
617	Clear - Clear - Med.Wht	$652	$1,214	$1,518	$1,821	$2,125	$2,428	$3,035	$3,642
618	Clear - Clear - High.Wht	$652	$1,214	$1,518	$1,821	$2,125	$2,428	$3,035	$3,642
619	Clear-Clear-Clear	$687	$1,374	$1,717	$2,060	$2,404	$2,747	$3,434	$4,121

Table 16: Installed Plastic Skylight Costs for Warehouse Prototype

	Building Area>>	46,656 sq.ft							
		Retail							
	Skylight Fraction Index >>	1%	2%	2.5%	3%	3.5%	4%	5%	6%
HMG_ID	Area per skylight >>	**12.96**	**25.92**	**32.4**	**38.88**	**45.36**	**51.84**	**64.8**	**77.76**
501	Med.Wht Interlayer	$612	$1,040	$1,254	$1,507	$1,758	$2,009	$2,512	$3,014
502	1/4" SS on Clear 8%	$668	$1,336	$1,670	$2,004	$2,338	$2,672	$3,340	$4,008
503	1/4" Bronze single	$637	$1,275	$1,594	$1,912	$2,231	$2,550	$3,187	$3,825
504	Clear - Prismatic	$721	$1,270	$1,545	$1,856	$2,166	$2,475	$3,094	$3,713
505	Evergreen - Prismatic	$805	$1,435	$1,750	$2,103	$2,453	$2,804	$3,505	$4,206
506	1/4" TI on CLR 20%, PRM	$692	$1,384	$1,729	$2,075	$2,421	$2,767	$3,459	$4,151
507	1/4" SS on CLR 8%, MWHT	$703	$1,405	$1,757	$2,108	$2,459	$2,811	$3,514	$4,216
508	EvergreenL - Air - Med.Wht	$992	$1,802	$2,206	$2,650	$3,092	$3,534	$4,417	$5,301
509	ClearL - Air - Med.Wht	$844	$1,530	$1,873	$2,251	$2,626	$3,001	$3,751	$4,501
510	EvergreenL - Arg - Med.Wht	$1,001	$1,823	$2,233	$2,682	$3,129	$3,576	$4,471	$5,365
511	ClearL - Arg - Med.Wht	$760	$1,466	$1,818	$2,183	$2,547	$2,910	$3,638	$4,366
512	ClearL - Air - Clear - Prismatic	$860	$1,516	$1,844	$2,216	$2,585	$2,954	$3,693	$4,431
513	ClearL - Arg - Clear - Prismatic	$868	$1,511	$1,832	$2,202	$2,569	$2,936	$3,670	$4,404
514	1/4" TI on CLR 20%, PRM	$734	$1,467	$1,834	$2,201	$2,568	$2,935	$3,668	$4,402
515	1/4" SS on CLR 8%, MWHT	$745	$1,489	$1,861	$2,234	$2,606	$2,978	$3,723	$4,467

Table 17: Installed Glass Skylight Costs for Retail Big-Box Prototype

	Building Area>>	46,656 sq.ft							
		Retail							
	Skylight Fraction Index >>	1%	2%	2.5%	3%	3.5%	4%	5%	6%
HMG_ID	Area per skylight >>	**12.96**	**25.92**	**32.4**	**38.88**	**45.36**	**51.84**	**64.8**	**77.76**
601	Prismatic	$380	$650	$786	$945	$1,102	$1,259	$1,574	$1,889
602	Medium white	$365	$577	$683	$822	$959	$1,096	$1,370	$1,644
603	Low white (AcrSglLWMtl)	$365	$577	$683	$822	$959	$1,096	$1,370	$1,644
604	Ultra Low White	$365	$577	$683	$822	$959	$1,096	$1,370	$1,644
605	Clear - Med.Wht	$278	$557	$696	$835	$975	$1,114	$1,392	$1,671
606	Clear - High.Wht	$278	$557	$696	$835	$975	$1,114	$1,392	$1,671
607	Low.Wht - Clear	$278	$557	$696	$835	$975	$1,114	$1,392	$1,671
608	Ultra Low White	$278	$557	$696	$835	$975	$1,114	$1,392	$1,671
609	Clear - Med.Wht	$388	$633	$756	$910	$1,061	$1,213	$1,516	$1,819
610	Clear - High.Wht	$388	$633	$756	$910	$1,061	$1,213	$1,516	$1,819
611	Low.Wht - Clear	$388	$633	$756	$910	$1,061	$1,213	$1,516	$1,819
612	Ultra Low White	$388	$633	$756	$910	$1,061	$1,213	$1,516	$1,819
613	Clear - Med.Wht	$346	$692	$865	$1,038	$1,210	$1,383	$1,729	$2,075
614	Prismatic - Prismatic	$416	$717	$868	$1,043	$1,217	$1,391	$1,739	$2,087
615	Triple Prismatic	$485	$858	$1,045	$1,255	$1,464	$1,673	$2,092	$2,510
616	Clear - Clear - Med.Wht	$437	$713	$852	$1,024	$1,195	$1,366	$1,707	$2,049
617	Clear - Clear - Med.Wht	$437	$713	$852	$1,024	$1,195	$1,366	$1,707	$2,049
618	Clear - Clear - High.Wht	$437	$713	$852	$1,024	$1,195	$1,366	$1,707	$2,049
619	Clear-Clear-Clear	$386	$773	$966	$1,159	$1,352	$1,545	$1,932	$2,318

Table 18: Installed Plastic Skylight Costs for Retail Big-Box Prototype

Note that typical construction practices limit skylight sizes to 32 sf per skylight. So that even though the estimates are based upon 36 skylights that increase in size, the cost data here is smoothed and provides a cost break on larger skylight areas. This reflects that the costs of a skylight include both fixed costs and variable costs.

First Cost of Lighting Controls

The installed costs of adding a photocontrol system to each of our prototype buildings is given in Table 19. The costing of controls for the 82,944 sf warehouse, and the 46,656 sf big box retail is based upon 4 controls zones. That is there are 4 different desired illuminance levels in different areas of these buildings. This is perhaps conservative in that there may only be really two zones in a warehouse: one zone that is for shipping and receiving that has higher light levels but also usually without stacks to absorb light, and a second zone for lighting in the stacks. The prototype for the office with a dropped ceiling is only 11,664 sf and thus we consider the costs for this prototype to have only two control zones.

Controls Costs

Control Type		Building Type		
		Warehouse Heated Only	Retail Big Box Flo	Office Dropped Ceiling Flo
None	No Daylight Control	$0	$0	$0
2PosOff	On/Off	$2,849	N/A	N/A
3PosOff	On/50%/Off	$4,522	N/A	$2,849
3Pos33%	On/67%/33%	N/A	$4,522	N/A
4PosOff	On/67%/33%/Off	N/A	N/A	N/A
Dimming	Continuous Dimming	N/A	$37,692	$7,524

Table 19: Cost of Photocontrol Systems for each Prototype Building

On/off control is a single control step; two levels (100%, 50%) plus off is a two step control as is 2/3 or 1/3 switching; (no off) is also a two step control; three levels (100%, 67%, 33%) plus off is a 3 level control. Potentially in a 4 zone building with three level plus off control their need to be as much as 3 x 4 = 12 separately controlled outputs.

Dimming controls for fluorescent systems have a dramatically different light and power relationship than those for HID systems. A fluorescent dimming system consumes approximately 20% of rated power at minimum (10%) light output. A metal halide system typically consumes in excess of 50% of power at minimum (25%) light output. Thus a fluorescent dimming system is better suited for savings energy than HID systems, and we have based our analysis on fluorescent dimming.

Cost of Multi-Level Switching

The purpose of this section is to describe the calculation for costing the addition of multi-level daylighting controls to an ASHRAE 90.1-2004 minimally compliant building.

This minimally compliant (base case) building has:

- Automatic shut-off controls (timeclock) controlling a lighting contactor (relay) that switches fixtures on and off.
- Conduit serving a row of fixtures carries one neutral and one hot conductor
- All of the lights in a given section of the building can be turned on and off together. Bi-level switching or control is not required.

The proposed case is the same building and lighting system except:

- A 3 level plus off photocontrol system is installed. As daylight levels increase, three circuits are sequentially turned off. As daylight levels decrease the circuits are sequentially turned on.
- The lighting system has more lighting contactors but with correspondingly fewer poles per contactor to support the greater levels of control.
- Lighting is circuited so that conduit serving a row of fixtures carries one neutral and three hot conductors so that the three levels of control are available in each row of lighting. Fixtures closest to the skylights are turned off first as daylight levels increase and those furthest away from the skylights are turned off last.

Wiring Description:

We assume a 4-wire (3 hot + 1 neutral) home run from the main control box for both the base case and proposed case design.

For the base case, each branch from the home run is 2-wire (1 hot + 1 neutral)
For the proposed case, each branch from the home run is 4-wire (3 hot + 1 neutral)

Three, 3-pole lighting contactors are used at the control panel (see diagram below) to provide a three phase, multi-level switching system. When possible, good electrical design tries to balance phases across each stage of lighting control. This is not always possible for small daylighting systems.

The calculation method is described below using the warehouse model as an example (the first line in the spreadsheets shown below).

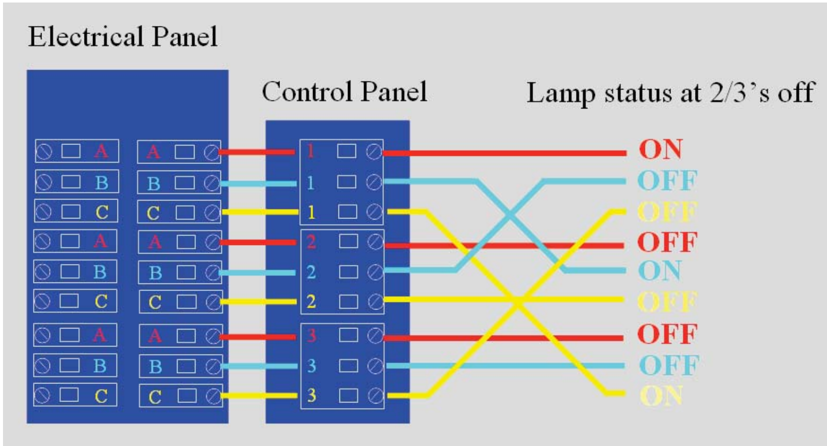

Figure 7: Control Panel Diagram for a 3-level switching control.

Fixture and Circuit Layout

Fixture type assumed is 200W PS Metal Halide - Sylvania M200/PS METALARC M200 series ballast - 232 W input, and 0.9 Amps input current. By picking relatively low wattage fixtures, we are being conservative as the fixture spacing is closer together and thus there is more linear feet of wire per square foot of area served.

For a warehouse that is 83,000 sf at 0.9 W/sf,

232W / 0.9W/sf = 258 sf/fixture

If one divides 83,000 sf by 258 sf per fixture, this yields 322 fixtures.

Assuming a rectangular spacing grid, the square root of 258sf/fixture is 16.1 or approximately a 16ft by 16ft spacing of fixtures.

Thus the design has a regular spacing of 16 feet between conduit runs. If one divides the total building area of 83,000 sf by the 16 feet between conduit runs, this results in a total conduit length of 5,187 linear feet of conduit length for the rows of conduit serving lighting. On average there is 1 linear ft of branch conduit length for each 16 sf of area.

To estimate the design amperes on each circuit we use the following calculation:

Design Amps = Rated Amps x Continuous Duty Derating x Circuit Fill Factor

For 12 gauge wire with a nominal rating of 20 amps, the design amps for lighting circuits with a continuous duty derating factor of 80% and a circuit fill factor of 80%, the design amps are:

Design Amps = 20 x 0.8 x 0.8 = 12.8 Amps.

For the 200W PS Metal Halide with a rating of 0.9 Amps/fixture, the total number of fixtures per circuit is 12.8 Amps / (0.9 Amps/Fixture) = 14.2 Fixtures per circuit rounded down to 14 fixtures per circuit. With 322 fixtures in the building, approximately 322 fixtures / (14 fixtures/circuit) = 23 circuits are needed for the warehouse.

Table 20: Cost of additional wiring

	Area (sf.)	LPD (W/sf.)	Lighting type	Input wattage (W)	Spacing (sf.)	Spacing (ft.) x (ft.)	Total length of branch conduit (ft.)	Length incl.10% for make-up (lin. ft)	Wiring length (lin.ft. per sf.)	RS Means Cost of adding 2 wires ($/lin.ft.)	Additional Wiring Cost ($/sf.)
Warehouse	83,000	0.9	Metal Halide (Pulse Start, Sylvania M200/PS METALARC)	232	258	16 x 16	5,170	5,687	0.07	$1.00	$0.069
Retail	46,700	1.7	Metal Halide (Pulse Start, Sylvania M200/PS METALARC)	232	136	11 x 11	3,998	4,397	0.09	$1.00	$0.094
Office	11,700	1.1	4-lamp T8 Fluorescent (Instant Start, Sylvania QT4X32T8/120-ISN-SC)	114	104	10 x 10	1,149	1,264	0.11	$1.00	$0.108

Table 21: Cost of Additional Lighting Contactors

Building model	Total Fixtures in building	Input Voltage (VAC)	Amps per Fixture	Min Number of circuits @12.8 A*	BASE CASE Lighting Contactors	BASE CASE cost ($)	PROPOSED CASE Lighting Contactors	PROPOSED CASE cost ($)	Additional Lighting Contactors Cost ($/sf)	Wiring & Contactor Added Cost ($/sf)	Wiring & Contactor Added Cost ($/cntrl pt)
Warehouse	322	277	0.90	23	2-10 poles + 1 3pole	$2,288.86	9-3 poles	$3,555.00	$0.015	$0.084	$258
Retail	343	277	0.90	25	2-10 poles + 1 6pole	$2,526.93	9-3 poles	$3,555.00	$0.022	$0.116	$201
Office	113	120	0.95	9	1-10pole	$946.93	3-3 poles	$1,185.00	$0.020	$0.128	$167

*12 ga wire, 20 amp rating, 80% derating, 80% fill =net 12.8 Amps per circuit

Table 22: RS Means CostWorks 2005 CD - Cost for 3-Pole Lighting Contactor

Qty	CSI Number	Description	Crew	Daily Output	Labor Hrs	Unit	Bare Mat.	Bare Labor	Bare Equip.	Bare Total	Total Incl. O&P	Type	Year
1	164202000200	Lighting contactors, 3 pole, electrically held, 600 volt, 30 amp, AC enclosed NEMA 1	1 Elec	3.6	2.222	Ea.	$235.00	$90.50	$0.00	$325.50	**$395.00**	Union	2005

Cost Estimation

To calculate the cost difference between base case with single level switching and proposed case with multi-level switching, we are adding 2 wires to the branch conduits and changing from a 10-pole lighting contactor to three, 3-pole lighting contactors at the control panel. See accompanying spreadsheet for cost data. The cost data is from the 2005 version of the RS Means CostWorks construction cost estimating guide.

The RS Means total installed cost of THHN wire is $50 per 100 linear feet including overhead and profit.. We doubled this amount even though labor costs would be less than double for two wires.

We used the total installed cost of lighting contactors including overhead and profit. However, RS means only has pricing for 3 pole lighting contactors. To calculate the pricing for 10 pole and 6 pole contactors, we used the Square D published list prices for 3, 6 and 10 pole contactors from their 2003 catalog to scale up the RS Means costs to these other contactor sizes.

Table 23: Estimation of Lighting Contactor Costs

Lighting Contactor	2003 Sq D Cat.	Cost Factor	2005 Means	2005 Estimate
3-pole	$370	100%	$395	$395
6-pole	$593	160%		$633
10-pole	$887	240%		$947

The installed costs of adding a photocontrol system to each of our prototype buildings is given in Table 24. The costing of controls for the 82,944 sf warehouse, and the 46,656 sf big box retail is based upon 4 controls zones. That is there are 4 different desired illuminance levels in different areas of these buildings. This is perhaps conservative in that there may only be really two zones in a warehouse: one zone that is for shipping and receiving that has higher light levels but also usually without stacks to absorb light, and a second zone for lighting in the stacks. The prototype for the office with a dropped ceiling is only 11,664 sf and thus we consider the costs for this prototype to have only two control zones.

Table 24: Cost of Photocontrols and Total Control System

Building model	Control description (# levels + off, # of zones)	Cost of Photocontrols	Cost of Photocontrols ($/sf.)	Total Cost (wiring, contactors & photocontrols) ($/sf.)	Total Cost (wiring, contactors & photocontrols) ($/cntrl pt.)
Warehouse	2 level, 4 zones	$4,522	$0.05	$0.14	$425
Retail	2 level, 4 zones	$4,522	$0.10	$0.21	$368
Office	2 level, 2 zones	$2,849	$0.24	$0.37	$483

First Cost of Air Conditioning/ Heating Equipment

Cost of air conditioning is based off of RS Means catalogue data for a rooftop unit with gas furnace sometimes called a “gas pack.”

The incremental cost of increasing the size of a rooftop unit in the 6 to 12 ton range is approximately $740/ton including materials, labor, overhead and profit. This estimate is derived from a regression analysis of RS Means data, the slope of the line is the incremental cost of increasing the size of the air conditioning unit. This incremental cost does not include the cost of duct work as many of the large spaces that would be using skylights as envisioned here would have relatively short duct runs.

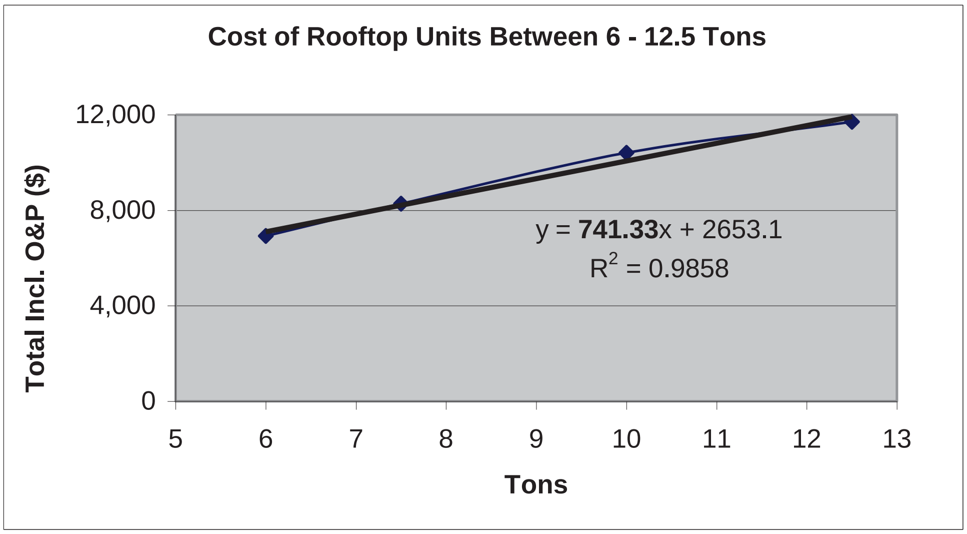

Figure 8: Trend line of RS Means estimated costs for RTU’s – 6 to 12.5 tons

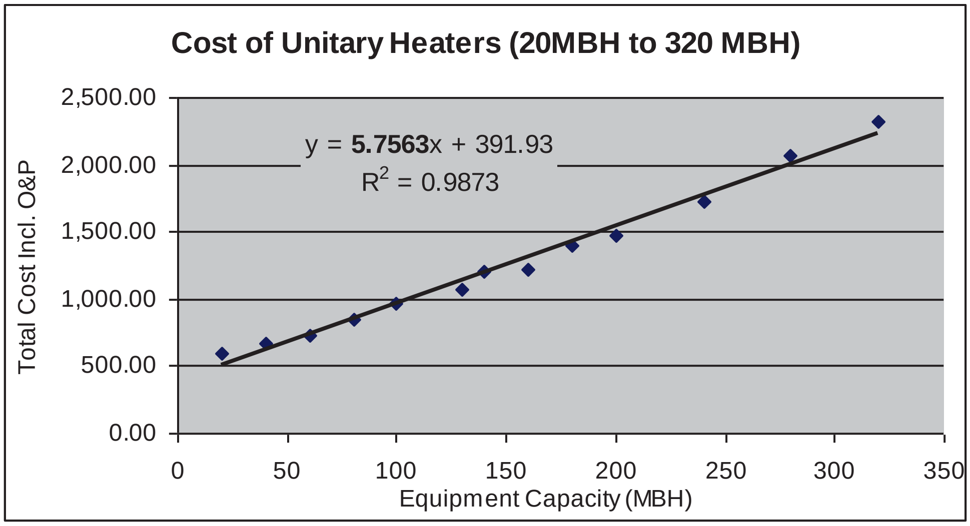

Figure 9: Trend line of RS Means Estimated Costs for Unit Heaters - 20 to 320 MBH

Incremental Maintenance Cost Methodology

Maintenance cost is included in the lifecycle cost analysis. The present value (PV) of maintenance costs (savings) was calculated using a 3 percent discount rate (d) as directed in the LCC Methodology (CEC 2014). The PV of maintenance costs that occurs in the nth year is calculated as follows (where d is the discount rate of 3 percent):

$$\text{PV Maintenance Cost} = \text{Maintenance Cost} \times \left[\frac{1}{1+d}\right]^{n}$$

The estimates of maintenance costs are included from the ASHRAE 90.1-2010 study as repeated below. [PNNL 2008]

Period of Analysis and Life of Equipment

The following estimates of the life of equipment have helped define the parameters used in the life cycle cost analysis.

Life of Skylights – 20 years

In talking with Wal-mart's construction manager, they expect the skylights to last 20 years but could be longer. Wal-Mart has approximately 300,000 skylights – oldest are about 13 years old. Deterioration is small and they expect the skylights to be intact for at least 20 years. A small percentage or damaged by hail. On new buildings in those areas of the country with higher likelihoods of hail they are specifying skylights tougher plastics.

This analysis is conservative in that our period of analysis was only 15 years.

Life of photocontrols – 15 years

In talking with the lighting subcommittee the consensus is that photocontrols should be reasonably expected to last 15 years. When the Heschong Mahone Group conducted their sidelighting survey, one the controls with the greatest energy savings was installed in 1989 or about 15 years prior to the survey. Bi-level wiring would not have to be installed. We expect that the incremental costs will be lower in 15 years but to maintain the conservative approach to estimating life cycle cost, we assume the photocontrol system is replaced after 15 years but that there is no costs associated with bi-level wiring or skylight maintenance.

4.7.2 Cost Savings Methodology

Energy Cost Savings Methodology

The energy cost savings was calculated in the 2013 daylighting CASE study [CASE 2011], but taking the energy savings (for electricity) and increased in energy consumption (for natural gas) as calculated from the detailed energy analysis for ASHRAE 90.-201 and multiplying them by the present valued of electricity costs over a 15 year period from the 2013 Title 24 TDVs (time dependent valuation). More detail is provided below.

4.7.3 Cost-effectiveness Methodology

The Statewide CASE Team calculated the cost-effectiveness using the LCC Methodology (CEC 2014). According to CEC's definitions, a measure is cost effective if it reduces overall lifecycle cost from the current base case (existing conditions). The LCC Methodology clarifies that absolute lifecycle cost of the proposed measure does not need to be calculated. Rather, it is necessary to calculate the change in lifecycle cost from the existing conditions to the proposed conditions.

If the change in lifecycle cost is negative then the measure is cost-effective, meaning that the present value of TDV energy savings is greater than the cost premium, or the proposed measure reduces the total lifecycle cost as compared to the existing conditions. Propane TDV costs are not used in the evaluation of energy efficiency measures.

The Planning Benefit-to-Cost (B/C) Ratio is another metric that can be used to evaluate cost-effectiveness. The B/C Ratio is calculated by dividing the total present value TDV energy cost savings (the benefit) by the present value of the total incremental cost (the cost). If the B/C Ratio is greater than 1.0 (i.e. the present valued benefits are greater than the present valued costs over the period of analysis), then the measure is cost effective.

The methodology of calculating cost-effectiveness is based on the cost-effectiveness analysis of skylighting used in the 2013 daylighting to justify reducing the threshold area down to 5,000 sf to require skylights. This was "Proposal 4" of the 2013 Daylighting CASE report. [CASE 2011] The following paragraphs are verbatim quotes from the 2013 Daylighting CASE report.

Proposal 4: Space Area Threshold for Requiring Skylights [CASE 2011]

This section describes the methodology used to update the minimum space area threshold for requiring skylights in Section 143(c).

The key elements of the methodology were as follows:

Update analysis done for ASHRAE 90.1 in 2008 to determine minimum space area where skylights can be required cost effectively

Update Analysis for ASHRAE 90.1

The CASE Team leveraged analysis done for the ASHRAE 90.1 skylighting requirements code change proposal from 2008 (PNNL, 2008). Per this analysis, a 'breakpoint area' is calculated for every ASHRAE climate zone. Breakpoint area is the minimum building area for which the BC ratio of requiring skylights will be at least 1.0, calculated using the following formula:

$$Breakpoint\ Area = \frac{Cost\ of\ Controls}{(Energy\ Savings - All\ Other\ Costs)} \times Building\ Area$$

Equation 1

Where

Cost of Controls: is the cost of photocontrols

Energy Savings: is the dollar value of annual energy savings over 15 yrs

All Other Costs: is the sum of all other costs except Cost of Controls, namely cost of skylights, cost of extra cooling/heating capacity and cost of bi-level wiring. These costs are dependent on the area of the building, while cost of controls is independent of the building area.

For a description of the methodology used for the analysis and the energy simulations runs using eQuest (DOE2.2) for each climate zone, please refer to the ASHRAE report [PNNL, 2008]

The following is an excerpt of the calculation procedure used in in the referenced PNNL (Pacific Northwest National Laboratory) sponsored analysis of minimum skylight area for the ASHRAE 90.1 building energy efficiency standard. A key input to note is that these models sized the skylighting system so that it had a 3% skylight area to skylit daylit area ratio and an effective aperture of approximately 1%. This is the minimum skylight area that is proposed in this CASE study.

REASON AND SUBSTANTIATION FOR CHANGES ENVELOPE SECTION [PNNL 2008]

Data developed for this proposal indicate that high transmittance skylights applied in conjunction with photocontrols reduce the life cycle cost of buildings. We believe that prescriptively requiring a minimum skylight area and photocontrols for large open buildings such as warehouses and big box retail can assist ASHRAE in its goal of cost-effectively reducing energy consumption in building by 30%. This prescriptive requirement for skylights in big box buildings is similar to the minimum skylighting requirements in the 2005 version of the

California Title 24 energy code.[5] [NOTE: This proposal is preliminary pending additional review of simulation studies. This proposal has not yet been reviewed by the 90.1 Committee.]

Minimum Skylight Area Requirement Analysis

For the analysis of requiring skylights, we looked at results from the DOE2 simulations and analyzed the savings from adding skylights to each of the three building types. The runs with skylights and photocontrols were compared to the runs without skylights and no photocontrols. The total costs of adding skylights were added up, which included the following components:

2. Cost of the skylights. This includes the cost of skylight wells for Office only, which had a dropped ceiling.
3. Cost of photocontrols
4. Cost of adding bi-level wiring
5. Cost of increased (or decreased) equipment capacity for heating and cooling due to increased (or decreased) heating/cooling loads.

We also calculated the savings from skylights obtained from the DOE2 runs, and used a scalar of 8.8 for a 15 yrs analysis period. A benefit to cost ratio was calculated for each climate zone.

Figure 11 and Figure 12 show the Benefit to Cost ratios calculations for all climate zones for two building types: Warehouse and Retail. We added an additional analysis for a warehouse with lower ceiling height: Warehouse (32ft Ceiling), Warehouse (24ft Ceiling). [*Ed note: the Tables originally referenced are replaced here with the Figures from the 2013 CASE study which updated analysis with California energy costs. The warehouse with the 24 foot ceiling height is* Figure 13.]

By lowering the ceiling height, additional skylights are required to maintain daylight uniformity, which adds to the cost part of the equation. We calculated that for a 24ft ceiling height a total of 64 skylights will be required, as compared to 36 skylights require for a warehouse with a 32 ft ceiling height. These skylights would be of a smaller size to maintain the same skylight to floor area ratio (SFR). A detailed explanation of the other three models is provided in Section 1.c.

To calculate the savings, we compared a DOE2 run with no skylights and no photocontrols to a run with skylights and added photocontrols. We used a thermally broken, double glazed medium white skylight for Climate Zones 1 through 5 and thermally broken, triple glazed medium white skylight for Climate Zones 6 through 8. For Climate Zones 6 through 8, a triple glazed skylight was chosen to keep with the minimum prescriptive skylight u-factor requirements in ASHRAE 90.1.

Skylight to Floor area Ratio (SFR) of 3% was chosen for Retail and Warehouse, which results in an Effective Aperture (EA) of approximately 0.010 for all three building types. *[Ed note: bolded and underlined here to add emphasis]*

[5] Section 143c Title 24, Part 6

The photocontrols used were switching controls with On/50%/Off stepped switching pattern for warehouse and On/66%/33% stepped switching for Retail.

The period of analysis was 15 yrs (Scalar of 8.8)

Cost of energy used was $0.0942/kWh and $1.25/therm.

In the tables the following nomenclature has been followed:

"Lighting Savings"	Savings in kWh from reduction in lighting energy use due to skylights
"Cooling Savings"	Savings in kWh from cooling energy reduction due to skylights (negative means cooling energy use increased with skylights)
"Total kWh Savings"	The total of all electric energy savings. This includes lighting, cooling, and ventilation energy use due to skylights
"Heating Savings"	Savings in therms from heating energy reduction due to skylights (negative means heating energy use increased with skylights)
"Lifecycle Energy Cost Savings (Scalar 8.8)"	Shows the Energy Savings in $, calculated from the DOE2 simulations multiplied by the scalar of 8.8 for a 15 yrs analysis period.
"Cost of Controls"	Gives the cost of photocontrols. When the period of analysis equals or exceeds 15 yrs, an additional cost of replacement for the photocontrols is calculated using a single present value factor of 0.362. Calculated using the following formula: $\text{Single Present Value Factor} = \frac{1}{(1 + \text{Discount Rate})^{\text{Yrs.of Analysis}}}$
"Cost of Skylights"	Gives the costs for skylights in $
"Cost of Bi-level Wiring"	Gives the incremental cost of adding additional wiring for a bi-level switching control
"Cost of Extra Heating / Cooling Capacity"	Gives the incremental cost of higher (or lower) capacity heating or cooling equipment based on the increased (or decreased) cooling and heating requirement. If the loads decreased due to the addition of skylights, this was treated as a negative cost.

"Total Costs"	Gives the sum of all the above cost
"Benefit to Cost Ratio"	(BC Ratio) Gives the ratio of the energy cost savings and the total costs. BC ratios above 1 are indicated with yellow, lower than 1, but greater than 0 are indicated with grey, and lower than 0 are indicated with pink.

All the costs mentioned here are explained in detail in *Section 4.7.1 Incremental Cost Methodology*.

Finally we also calculated a "Breakpoint Area" based on BC ratio of 1.0. This is the minimum building area for which the BC ratio will be at least 1.0, calculated using the following formula:

$$Breakpoint\ Area = \frac{Cost\ of\ Controls}{(Energy\ Savings - All\ Other\ Costs)} \times Building\ Area$$

Here:

"Energy Savings" is the lifecycle energy cost savings (Scalar 8.8)

"All Other Costs" is the sum of all other costs except "Cost of Controls", namely Cost of Bi-level Wiring, Cost of Skylights, and Cost of Extra Cooling/Heating Capacity. These costs are dependent on the area of the building, while cost of controls is independent of the building area.

We also calculate the "Percent of Total Cost Reduction" using the following formula:

$$Percent\ of\ Total\ Cost\ Reduction = \frac{Energy\ Cost\ Savings\ due\ to\ Skylights}{Energy\ Cost\ without\ Skylights}$$

Here:

"Energy Cost Savings due to Skylights" is the difference in total energy cost with skylights and without skylights.

"Energy Cost without Skylights" is the total energy cost for the no skylight run.

4.8 Environmental Impacts Methodology

4.8.1 Greenhouse Gas Emissions Impacts Methodology

The Statewide CASE Team calculated avoided GHG emissions assuming an emission factor of 353 metric tons of carbon dioxide equivalents ($MTCO_2e$) per GWh of electricity savings. As described in more detail in Appendix A, the electricity emission factor represents savings from avoided electricity generation and accounts for the GHG impacts if the state meets the Renewable Portfolio Standard (RPS) goal of 33 percent renewable electricity generation by 2020. Avoided GHG emissions from natural gas savings were calculated using an emission factor of 5,303 $MTCO_2e$/million therms (U.S. EPA 2011).

5. ANALYSIS AND RESULTS

Results from the energy, demand, cost, and environmental impacts analyses are presented in this section.

5.1 Energy Impacts Results

5.1.1 Statewide Energy Impacts Results

The first year statewide energy impacts of the proposed measure are presented in Table 25. During the first year buildings complying with the 2016 Title 24 Standards are in operation, the proposed measure is expected to reduce annual statewide electricity use by 7.67 GWh. Natural gas use is expected to increase by 0.2 Million therms (savings of -0.02 Million therms).

Table 25: First YearStatewide Energy Impacts

			First Year Energy Savings		Present Value
Title 24 Code Cycle	Threshold Area (sf)	Fraction of Zone	Elec Savings GWh/yr	Gas Savings Million therms/yr	TDV PV Savings[1] ($ Millions)
2005	25,000	50%	25.46		$46.6
2008	8,000	50%	4.48	-0.10	$6.9
2013	5,000	75%	46.74	-0.09	$84.4
Totals			76.68	-0.19	$137.9
2016 Estimate @ 10% of total			7.67	-0.02	$13.8

[1]. Energy savings multiplied by 2016 average TDV

All assumptions and calculations used to derive per unit and statewide energy savings are presented in Section *4.6 Energy Impacts Methodology* of this report. Savings from assuring that minimum skylight area is achieved are based upon a 10% savings estimate of the savings of the skylighting code requirements that have incrementally aggregated over the last three code cycles.

The electricity savings and the increased gas consumption (negative savings) from the previous CASE reports have been converted into present valued energy cost savings by multiplying by the 15 year nonresidential average TDV unit costs for the 2016 Title 24 code cycle. These average present valued costs are contained in Table 26. As noted in the notes to the table the 2016 TDV's are in 2017 present valued dollars.

Table 26: TDV Average Present Valued Energy Costs for 2008, 2013 and 2016 Title 24 Code Cycles

Time Period	2008	2013	2016
30 Year Residential			
Natural Gas (NPV$/Therm)	$24.32	$27.68	$28.64
Electricity (NPV $/kWh)	$2.33	$3.62	$3.73
15 Year Non-Residential			
Natural Gas (NPV$/Therm)	$12.72	$14.59	$12.75
Electricity (NPV $/kWh)	$1.63	$1.85	$1.83
30 Year Non-Residential			
Natural Gas (NPV$/Therm)	$23.97	$25.96	$23.62
Electricity (NPV $/kWh)	$2.66	$3.36	$3.19

TDVs for 2008 are expressed in $2008, 2013 are in $2011 and 2016 are in $2017

The rationale behind the 10% savings estimate resulting from restoring the 3% minimum skylight area to skylit daylit area ratio is based upon the ASHRAE simulation of savings from high transmittance skylights for big box retail, heated only warehouses and heated and cooled warehouses. The majority of warehouses are heated only or unconditioned but it is desirable to also consider heated ad cooled warehouses as it can also be a proxy for human comfort. Refrigerated warehouses are specifically exempted from the minimum daylighting requirements in Section 140.3(c) as the heating gains and losses for these cold internal environments outweigh the lighting savings benefits. The lighting controls simulated are two levels plus OFF controls.

Table 27: Coastal California (ASHRAE CZ 3C)- Percent Saving benefit from 3% minimum skylight to daylit area ratio

CA Coast ASHRAE CZ 3C (San Francisco)			Cost Savings PV$/sf			Percent Diff from 3% SDR	
Building Type	Skylight Type	Bldg sf	1%	2%	3%	1%	2%
Retail	Plastic	46,656	$2.95	$6.92	$8.57	-66%	-19%
Heated only warehouse	Glass	82,944	$2.31	$2.97	$3.33	-31%	-11%
Heated only warehouse	Plastic	82,944	$2.87	$3.50	$3.83	-25%	-9%
Heated/Cooled warehouse	Glass	82,944	$2.47	$3.06	$3.32	-26%	-8%
Heated/Cooled warehouse	Plastic	82,944	$3.01	$3.49	$3.67	-18%	-5%

If one reviews the skylight area to skylit daylit area ratio (SDR) in Table 4 of Section 2.1.3 Existing 2013 Title 24 Standards, one will see that even for large 4 foot by 8 foot skylights, when ceiling heights are above 24 feet, the SDR's of minimally compliant skylighting systems are less than 2% and when ceiling heights are greater than 36 feet then SDR's or minimally compliant skylighting systems are less than 1%. For tubular daylighting devices, Table 5 of the same section indicates that the minimally compliant systems need only have a 0.6% SDR to comply with the minimum 15 foot ceiling height with even less SDR's required for compliance for taller ceiling heights.

As shown in Table 27, for high transmittance glass (clear over medium white) skylights and high transmittance plastic (clear over high white) skylights, even for 2% SDR's the lost energy cost savings in Coastal Climates are 19% (for retail) to 9% (for heated only warehouses). Table 28 represents the energy savings in California's hot Central Valley but uses the weather file for El Paso, Texas (the reference city for ASHRAE climate zone 3B and the proxy for the California Central Valley). In the Central Valley the energy cost savings are less but still vary from 3% (for retail) to 6% (for heated only warehouses). Note that even in the Central Valley, the losses increase dramatically between 2% and 1% SDR. At 1% SDR the lost savings are between 25% for retail and 16% for heated only warehouses.

Table 28: Central Valley California (ASHRAE CZ 3B) - Percent Saving benefit from 3% minimum skylight to daylit area ratio

Central Valley ASHRAE CZ 3B (El Paso, TX)			Cost Savings PV$/sf			Percent Diff from 3%	
Building Type	Skylight Type	Bldg sf	1%	2%	3%	1%	2%
Retail	Plastic	46,656	$6.91	$8.92	$9.23	-25%	-3%
Heated only warehouse	Glass	82,944	$2.51	$3.03	$3.35	-25%	-9%
Heated only warehouse	Plastic	82,944	$3.07	$3.42	$3.65	-16%	-6%
Heated/Cooled warehouse	Glass	82,944	$2.80	$3.14	$3.25	-14%	-3%
Heated/Cooled warehouse	Plastic	82,944	$3.31	$3.30	$3.17	4%	4%

5.2 Cost-effectiveness Results

The cost-effectiveness results are based upon the findings listed in the Daylighting CASE study for the 2013 Title 24 standards. [CASE 2013] This in turn was based upon a study for the development of the ASHRAE 90.1-2010 standards. [PNNL 2008] This analysis was conducted on various prototypes at 3% skylight to floor area ratio with the entire space skylighted. The following is a verbatim excerpt from the 2013 CASE report except that tables and figures are renumbered to be consistent with consecutive numbering in this report.

This section describes the analysis used to derive a new minimum area threshold for the skylighting requirement in Section 143(c).

Breakpoint Area Analysis

To determine if the space area that triggers the requirement for skylights in Section 143 can be lowered, we built on an earlier ASHRAE analysis (PNNL, 2008) that found skylighting was cost-effective down to a threshold area of 5,000 sf. The analysis used DOE2.2 simulation across all ASHRAE climate zones for three building types:

- Retail
- Warehouse - Low Ceiling
- Warehouse - High Ceiling

This ASHRAE analysis was based on electricity cost of $0.0942/kWh a natural gas cost of $1.25/therm and a scalar (present worth factor) of 8.8. This analysis was re-evaluated using same energy results but using the economic values that underlie the time dependent valuation of energy efficiency measures for Title 24: average electricity costs of $0.1547/kWh, average natural gas costs of $1.22/therm and a 3% (real) societal discount rate resulting in a scalar of 11.9 for a 15 year period of analysis.   As a result, one could cost-effectively justify threshold areas even smaller than 5,000 sf under the California cost-effectiveness evaluation methodology as shown in Figure 11 through Figure 13 below

Out of all ASHRAE climate zones, we consider four climate zones as being representative of California: climate zones 3C (San Francisco, CA), 2B (Phoenix, AZ), 4C (Salem, OR) and 5B (Boise, ID). As seen in Figure 10, 3C covers most of central and coastal California, 4C and 5B cover northern California, and 2B covers a small region in southern California.

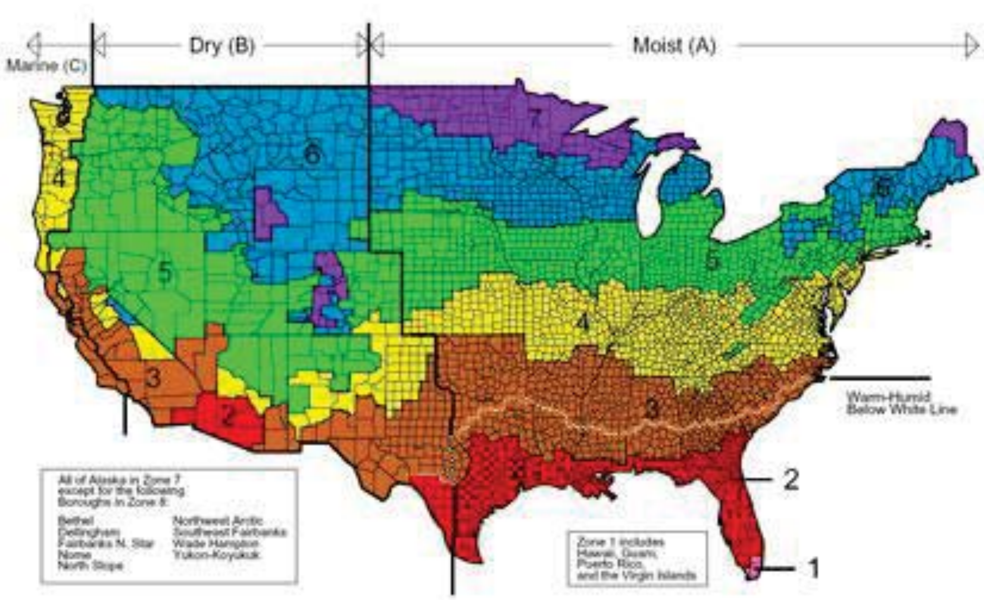

Figure 10: ASHRAE Climate Zones

Figure 11 through Figure 13 below give the results of this analysis for each building type. The four climate zones are highlighted in green.

The following are the explanations of terms using in the analysis:

- **Lighting, Cooling and Heating Savings:** gives savings calculated from DOE2.2 simulation runs.
- **Lifecycle Energy Cost Savings**: shows the Energy Savings calculated from the DOE2.2 simulations multiplied by the scalar of 11.9 for a 15 yrs analysis period.
- **Cost of Controls and Skylights**: gives the cost of photocontrols and skylights.
- **Cost of Extra Heating / Cooling Capacity**: gives the incremental cost of higher (or lower) capacity heating or cooling equipment based on the increased (or decreased) cooling and heating requirement. If the loads decreased due to the addition of skylights, this was treated as a negative cost.

Benefit to Cost Ratio (BC Ratio): gives the ratio of the energy cost savings and the total costs.

Breakpoint Area: is the minimum building area for which the B/C ratio will be at least 1.0. The breakpoint area is calculated according to **Equation 1** in Section *4.7.3 Cost-effectiveness Methodology*

Building Type: RETAIL **46,656 sf Area** **24 ft Ceiling**

	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7	8
	Miami, FL	Houston, TX	Phoenix, AZ	Memphis, TN	El Paso, TX	San Francisco, CA	Baltimore, MD	Albqurque, NM	Salem, OR	Indianapolis, IN	Boise, ID	Burlington, VT	Helena, MT	Duluth, MN	Fairbanks, AK
	Double - Clear - Med.Wht											**Triple - Clear - Med.Wht**			
Lighting Savings (kWh)	129,413	120,731	135,815	116,597	131,715	117,750	106,180	127,648	96,584	113,913	113,589	92,155	95,657	92,375	62,246
Cooling Savings (kWh)	10,661	10,737	6,108	5,182	385	2,194	5,038	686	3,467	4,354	2,295	3,072	3,315	4,688	1,865
Total kWh Savings (kWh)	145,221	138,197	156,010	123,065	131,467	123,364	111,646	127,776	122,567	119,911	116,805	107,494	122,568	114,490	57,580
Heating Savings (Therms)	-227	-1,037	-1,021	-1,671	-1,315	-2,118	-2,291	-2,061	-2,656	-2,635	-2,688	-2,301	-2,718	-3,133	-1,590
Lifecycle Energy Cost Savings in $ (Scalar 11.9)	$264,882	$240,136	$273,264	$202,976	$223,667	$197,031	$172,876	$206,007	$187,739	$183,139	$176,633	$165,064	$186,839	$165,889	$83,222
Cost of Controls ($)	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161
Cost of Skylights ($)	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$35,639	$35,639	$35,639	$35,639
Cost of Bi-Level Wiring ($)	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412	$5,412
Cost of Extra Cooling Capasity ($)	$785	-$997	-$578	$153	$412	$253	-$859	$2,128	-$3,537	-$1,159	-$1,771	-$3,836	-$3,037	-$5,651	$2,195
Cost of Extra Heating Capasity ($)	$146	$247	$242	$251	$242	$200	$288	$266	$334	$353	$294	$329	$476	$439	-$115
Total Cost ($)	$44,147	$42,465	$42,879	$43,619	$43,869	$43,668	$42,644	$45,609	$40,012	$42,409	$41,738	$43,704	$44,652	$42,000	$49,291
Benefit to Cost Ratio	**6.00**	**5.65**	**6.37**	**4.65**	**5.10**	**4.51**	**4.05**	**4.52**	**4.69**	**4.32**	**4.23**	**3.78**	**4.18**	**3.95**	**1.69**
Breakpoint Area (sf)	1,267	1,410	1,215	1,737	1,546	1,802	2,107	1,726	1,868	1,957	2,038	2,254	1,938	2,210	7,170
Percent of Total Cost Reduction	12%	11%	13%	9%	12%	12%	8%	11%	10%	8%	9%	7%	9%	6%	3%

Figure 11: Breakpoint Area Analysis - Retail Building

Building Type: WAREHOUSE HIGH CEILING **82,944 sf Area** **32 ft Ceiling**

	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7	8
	Miami, FL	Houston, TX	Phoenix, AZ	Memphis, TN	El Paso, TX	San Francisco, CA	Baltimore, MD	Albqurque, NM	Salem, OR	Indianapolis, IN	Boise, ID	Burlington, VT	Helena, MT	Duluth, MN	Fairbanks, AK
	Double - Clear - Med.Wht											**Triple - Clear - Med.Wht**			
Lighting Savings (kWh)	247,726	245,071	247,571	247,782	251,020	243,743	243,864	249,485	237,902	236,952	238,023	240,926	236,415	237,940	187,108
Cooling Savings (kWh)	11,574	14,184	-5,069	13,758	-1,114	2,755	14,538	-41	3,159	4,840	1,096	5,480	3,139	12,465	14,848
Total kWh Savings (kWh)	254,917	253,529	234,401	253,983	242,840	243,272	252,412	243,551	238,326	237,629	234,588	245,105	239,673	249,422	194,842
Heating Savings (Therms)	-228	-1,758	-1,258	-2,645	-1,746	-2,502	-4,501	-3,088	-4,879	-4,731	-4,936	-4,989	-4,946	-5,971	-6,340
Lifecycle Energy Cost Savings in $ (Scalar 11.9)	$467,444	$442,641	$414,585	$430,586	$423,076	$412,885	$400,707	$404,882	$369,199	$370,063	$361,468	$380,119	$370,713	$373,817	$267,660
Cost of Controls ($)	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161
Cost of Skylights ($)	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$35,639	$35,639	$35,639	$35,639
Cost of Bi-Level Wiring ($)	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967
Cost of Extra Cooling Capasity ($)	$2,320	$2,201	$3,501	$4,722	$2,648	$1,203	$2,196	$2,102	$919	$2,180	$1,656	$3,982	-$67	-$56	-$2,857
Cost of Extra Heating Capasity ($)	$275	$425	$346	$498	$434	$324	$565	$475	$490	$371	$513	$86	$118	-$3	$516
Total Cost ($)	$47,365	$47,396	$48,618	$49,991	$47,852	$46,298	$47,531	$47,348	$46,180	$47,322	$46,939	$52,835	$48,818	$48,708	$46,426
Benefit to Cost Ratio	**9.87**	**9.34**	**8.53**	**8.61**	**8.84**	**8.92**	**8.43**	**8.55**	**7.99**	**7.82**	**7.70**	**7.19**	**7.59**	**7.67**	**5.77**
Breakpoint Area (sf)	1,199	1,273	1,373	1,321	1,340	1,371	1,422	1,405	1,552	1,554	1,593	1,533	1,558	1,543	2,247
Percent of Total Cost Reduction	33%	32%	27%	32%	33%	37%	30%	32%	30%	29%	28%	29%	28%	26%	18%

Figure 12: Breakpoint Area Analysis - Warehouse High Ceiling Building

Building Type: WAREHOUSE LOW CEILING **46,656 sf Area** **24 ft Ceiling**

	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7	8
	Miami, FL	Houston, TX	Phoenix, AZ	Memphis, TN	El Paso, TX	San Francisco, CA	Baltimore, MD	Albqurque, NM	Salem, OR	Indianapolis, IN	Boise, ID	Burlington, VT	Helena, MT	Duluth, MN	Fairbanks, AK
	Double - Clear - Med.Wht											Triple - Clear - Med.Wht			
Lighting Savings (kWh)	139,204	137,594	139,118	139,220	141,005	136,856	136,967	140,153	133,456	132,992	133,687	135,244	132,585	133,670	104,937
Cooling Savings (kWh)	6,259	7,987	-3,071	7,453	-895	1,503	7,869	-212	1,683	2,449	514	2,956	1,685	6,730	8,167
Total kWh Savings (kWh)	142,844	142,337	131,219	142,286	135,880	136,313	141,233	136,458	133,411	132,761	131,474	137,247	134,142	139,703	108,949
Heating Savings (Therms)	-128	-995	-716	-1,515	-1,001	-1,454	-2,575	-1,772	-2,796	-2,705	-2,829	-2,864	-2,838	-3,434	-3,644
Lifecycle Energy Cost Savings in $ (Scalar 11.9)	$261,931	$248,392	$231,916	$240,740	$236,381	$230,596	$223,387	$226,241	$205,730	$205,852	$201,673	$211,825	$206,469	$208,075	$148,229
Cost of Controls ($)	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161	$6,161
Cost of Skylights ($)	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$31,642	$35,639	$35,639	$35,639	$35,639
Cost of Bi-Level Wiring ($)	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967
Cost of Extra Cooling Capasity ($)	$6,711	$1,319	$1,719	$2,051	$2,753	$685	$716	$1,204	$538	$1,384	$745	$647	$19	$800	-$1,575
Cost of Extra Heating Capasity ($)	-$2,361	$245	$199	$286	$249	$186	$323	$273	$280	$220	$295	$75	$73	$12	$291
Total Cost ($)	$49,121	$46,334	$46,689	$47,107	$47,773	$45,641	$45,809	$46,247	$45,589	$46,374	$45,810	$49,489	$48,859	$49,580	$47,484
Benefit to Cost Ratio	**5.33**	**5.36**	**4.97**	**5.11**	**4.95**	**5.05**	**4.88**	**4.89**	**4.51**	**4.44**	**4.40**	**4.28**	**4.23**	**4.20**	**3.12**
Breakpoint Area (sf)	1,313	1,380	1,502	1,439	1,476	1,504	1,564	1,544	1,728	1,735	1,774	1,706	1,755	1,746	2,689
Percent of Total Cost Reduction	32%	31%	27%	32%	32%	37%	30%	32%	30%	28%	28%	28%	28%	26%	17%

Figure 13: Breakpoint Area Analysis - Warehouse Low Ceiling Building

Cost-Effectiveness Conclusions

These results above originally published in the 2013 CASE report indicate that a 3% skylight to daylit are ratio is extremely cost effective for all California climate zones and for all building types simulated. Thus restoring the prescriptive minimum skylight area to skylit daylit area ratio of 3% is cost-justified.

This finding replicates overall outcome of the results in the skylighting CASE studies for the 2005 standards (CASE 2002) and for the 2008 Title 24 building efficiency standards (CASE 2006). The skylighting CASE study for the 2005 Title 25 found that a 3% skylight area to daylit area ratio was found to be cost effective in retail buildings and heated warehouses in the representative climate zones of 1, 3, 7, 10, 12, 14, 16. Similarly, in the daylighting CASE study for 2008 Title 24 standards a 3% skylight area to skylit daylit area ratio in retail buildings and heated warehouses was found to be cost-effective for the representative climate zones of 3, 7, 10 12 and 14.

5.3 Environmental Impacts Results

5.3.1 Greenhouse Gas Emissions Results

Table 29 presents the estimated first year avoided GHG emissions of the proposed code change. During the first year the 2016 Standards are in effect the proposed measure will result in avoided GHG emissions of 2,606 $MTCO_2e$. By the end of the third year the reduced emissions per year will be three times as much or a 7,818 MMT CO2e/yr reduction.

Table 29: Statewide Greenhouse Gas Emissions Impacts

Description	Electricity	Natural Gas	
Annual Energy Savings	7.67	-0.02	
Units	GWh/yr	Mtherms/yr	
GHG Emission Factors	353	5,303	
Units	MMT CO2e /GWh	MMT CO2e /Mtherms	**Totals**
GHG Savings	2,707	-101	**2,606**
Units	MMT CO2e	MMT CO2e	MMT CO2e

5.3.2 Water Use and Water Quality Impacts

This measure has no impact on water use.

6. Proposed Language

The proposed changes to the Standards, Reference Appendices, and the ACM Reference Manuals are provided below. Changes to the 2013 documents are marked with underlining (new language) and ~~strikethroughs~~ (deletions).

6.1 Standards

SECTION 100.1 – DEFINITIONS AND RULES OF CONSTRUCTION

FENESTRATION: Includes the following:

….

WINDOW is fenestration that is not a skylight and that is an assembled unit consisting of a frame and sash component holding one or more pieces of glazing.

WINDOW AREA is the area of the surface of a window, plus the area of the frame, sash, and mullions.

WINDOW FILM is fenestration attachment products which consist of a flexible adhesive-backed polymer film which may be applied to the interior or exterior surface of an existing glazing system.

WINDOW HEAD HEIGHT is the height from the floor to the top of the window.

WINDOW WALL RATIO is the ratio of the window area to the gross exterior wall area.

SECTION 130.1 – INDOOR LIGHTING CONTROLS THAT SHALL BE INSTALLED

(d) **Automatic Daylighting Controls.**

1. Daylit Zones shall be defined as follows:

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

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

   B. **PRIMARY SIDELIT DAYLIT ZONE** is the area on a plan directly adjacent to each vertical glazing, one window head height deep into the area, and window width plus 0.5 times window head height wide on each side of the rough opening of the window, minus any area on a plan beyond a permanent obstruction that is 6 feet or taller as measured from the floor. Any areas that overlap in the primary sidelit daylit zone and the skylit daylit zone are considered part of the skylit daylit zone and not part of the primary sidelit daylit zone.

   C. **SECONDARY SIDELIT DAYLIT ZONE** is the area on a plan directly adjacent to each vertical glazing, two window head heights deep into the area, and window width plus 0.5 times window head height wide on each side of the rough opening of the window, minus any area on a plan beyond a permanent obstruction that is 6 feet or taller as measured from the floor. Any areas that overlap in the secondary sidelit daylit zone and the skylit daylit zone are considered part of the skylit daylit zone and not part of the secondary sidelit daylit zone. Any areas that overlap in the secondary sidelit daylit zone and the primary sidelit daylit zone are considered part of the primary sidelit daylit zone and not part of the secondary sidelit daylit zone.

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

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

   A. All Skylit Daylit Zones and Primary Sidelit Daylit Zones shall be shown on the plans.

   B. Luminaires in the Skylit Daylit Zone shall be controlled separately from those in the Primary Sidelit Daylit Zones.

   C. Luminaires that fall in both a Skylit and Primary Sidelit Daylit Zone shall be controlled as part of the Skylit Daylit Zone.

   D. **Automatic Daylighting Control Installation and Operation**. For luminaires in daylight zones, automatic daylighting controls shall be installed and configured to operate according to all of the following requirements:

      i. Photosensors shall be located so that they are not readily accessible to unauthorized personnel., and the The location where calibration adjustments are made to automatic daylighting controls shall not be readily accessible to unauthorized personnel but may be inside a locked case or under a cover which requires a tool for access.

      ii. Automatic daylighting controls shall provide functional multi-level lighting having at least the number of control steps specified in TABLE 130.1-A.

      EXCEPTION 1 to Section 130.1(d)2Dii: Controlled lighting having a lighting power density less than 0.3 W/ft^2 is not required to provide multi-level lighting controls.

      EXCEPTION 2 to Section 130.1(d)2Dii: When skylights are replaced or added to an existing building where there is an existing general lighting system that is not being altered, multi-level lighting controls are not required.

      iii. For each space, the combined illuminance from the controlled lighting and daylight shall not be less than the illuminance from controlled lighting when no daylight is available.

      iv. In areas served by lighting that is daylight controlled, when the illuminance received from the daylight is greater than 150 percent of the design illuminance received from the general lighting system at full power, the general lighting power in that daylight zone shall be reduced by a minimum of 65 percent.

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

   EXCEPTION 2 to Section 130.1(d)2: Rooms which have a total glazing area of less than 24 square feet.

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

3. **Parking Garage Daylighting Requirements**. In a parking garage area with a combined total of 36 square feet or more of glazing or opening, luminaires providing general lighting that are in the combined primary and secondary sidelit daylit zones shall be controlled independently from other lighting in the parking garage by automatic daylighting controls, and shall meet the following requirements as applicable:

   A. All primary and secondary sidelit daylit zones shall be shown on the plans.

B. Automatic Daylighting Control Installation and Operation. Automatic daylighting control shall be installed and configured to operate according to all of the following requirements:

i. Automatic daylighting controls shall have photosensors that are located so that they are not readily accessible to unauthorized personnel~~, and the~~ The location where calibration adjustments are made to automatic daylighting controls shall ~~not~~ be readily accessible to ~~un~~authorized personnel but may be inside a locked case or under a cover which requires a tool for access

ii. Automatic daylighting controls shall be multi-level, continuous dimming or ON/OFF.

iii. The combined illuminance from the controlled lighting and daylight shall not be less than the illuminance from controlled lighting when no daylight is available.

iv. When the ~~primary and sidelit zones receive~~ illuminance levels measured at the farthest edge of the secondary sidelit zone away from the glazing or opening is greater than 150 percent of the illuminance provided by the controlled lighting when no daylight is available, the controlled lighting power consumption shall be zero.

EXCEPTION 1 to Section 130.1(d)3: Luminaires located in the daylight transition zone and luminaires for only dedicated ramps. Daylight transition zone and dedicated ramps are defined in Section 100.1.

EXCEPTION 2 to Section 130.1(d)3: The total combined general lighting power in the primary sidelit daylight zones is less than 60 watts.

SECTION 140.3 – PRESCRIPTIVE REQUIREMENTS FOR BUILDING ENVELOPES

A building complies with this section by being designed with and having constructed and installed either: (1) envelope components that comply with each of the requirements in Subsection (a) for each individual component and the requirements of Subsection (c) where they apply; or (2) an envelope that complies with the overall requirements in Subsection (b) and the requirements of Subsection (c) where they apply.

…

(c) **Minimum Daylighting Requirement for Large Enclosed Spaces.** In climate zones 2 through 15, conditioned enclosed spaces, and unconditioned enclosed spaces, that are greater than 5,000 ft² and that are directly under a roof with ceiling heights greater than 15 feet, shall meet the following requirements:

1. ~~A combined total of at~~ At least 75 percent of the floor area, as determined in building floor plan (drawings) view, shall be within one or more of the following areas in the space:

   A. Areas within a horizontal distance of 0.5 window head heights from windows in the direction parallel to the windows and within one window head height perpendicular to windows. ~~Primary Sidelight Daylight Zone in accordance with Section 130.1(d)1B, or~~

   B. Areas within a horizontal distance of 0.7 times the average ceiling height from the edge of rough opening of skylights ~~Skylit Daylit Zone in accordance with Section 130.1(d)1A.~~

2. All Skylit Daylit Zones and Primary Sidelit Daylit Zones shall be shown on building plans.

3. General lighting in daylit zones shall be controlled in accordance with Section 130.1(d).

4. The total skylight area is at least 3% of the total floor area in the space within a horizontal distance of 0.7 times the average ceiling height from the edge of rough opening of skylights; or the product of the total skylight area and the average skylight visible transmittance is no less than 1.5% of the total floor area in the space within a horizontal distance of 0.7 times the average ceiling height from the edge of rough opening of skylights.

~~4. Skylights shall:~~

~~A.~~

5. All skylights have ~~Have~~ a glazing material or diffuser that has a measured haze value greater than 90 percent, tested according to ASTM D1003 (notwithstanding its scope) or another test method approved by the Commission;~~ and~~

6.~~B. If the space is conditioned, meet the requirements in~~ Skylights for conditioned and unconditioned spaces have an area-weighted average Visible Transmittance (VT) no less than the applicable value required by Section 140.3(a)6D.

EXCEPTION 1 to Section 140.3(c): Auditoriums, churches, movie theaters, museums, and refrigerated warehouses.

EXCEPTION 2 to Section 140.3(c): In buildings with unfinished interiors, future enclosed spaces for which there are plans to have:

A. A floor area of less than or equal to 5,000 square feet; or

B. Ceiling heights of less than or equal to 15 feet. This exception shall not be used for S-1 or S-2 (storage), or for F-1 or F-2 (factory) occupancies.

EXCEPTION 3 to Section 140.3(c): Enclosed spaces having a designed general lighting system with a lighting power density less than 0.5 watts per square foot.

SECTION 140.6 – PRESCRIPTIVE REQUIREMENTS FOR INDOOR LIGHTING

A building complies with this section if:

i. The Calculation of Actual Indoor Lighting Power Density of all proposed building areas combined, calculated under Subsection (a) is no greater than the Density Calculation of Allowed Indoor Lighting Power Density, Specific Methodologies calculated under Subsection (c); and

ii. The Calculation of Allowed Indoor Lighting Power Density, General Rules comply with Subsection (b); and

iii. General lighting complies with the Automatic Daylighting Controls in Secondary Daylit Zone requirements in Subsection (d).

…

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

1. Be controlled independently from all other luminaires by automatic daylighting controls that meet the applicable requirements of Section 110.9; and

2. Be controlled in accordance with the applicable requirements in Section 130.1(d)2; and

3. All Secondary Sidelit Daylit Zones shall be shown on the plans submitted to the enforcing agency.

EXCEPTION 1 to Section 140.6(d): Luminaires in Secondary Sidelit Daylit Zone(s) in areas where the total wattage of general lighting is less than 120 Watts.

EXCEPTION 2 to Section 140.6(d): Luminaires in parking garages complying with Section 130.1(d)3.

6.2 ACM Reference Manual

The Nonresidential ACM (Alterative Compliance Method) Manual needs to be updated to set a minimum skylight area of 3% for the reference building for large open spaces with ceiling heights greater than 15 feet directly under a roof. The modelled skylights must have material properties that comply with Section 140.3(a). If the space is unconditioned the visible light transmittance of the skylights must meet the requirements of Section 140.3(a)6D.

6.3 Compliance Manual and Compliance Forms

Chapter 4 of the Nonresidential Compliance Manual will need to be revised. The primary changes are describing the daylit area that is, *"building floor plan (drawings) view, shall be within a horizontal distance of one head height from windows or within 0.7 times average ceiling height from the edge of rough opening of skylights."* This must be clarified how this is different than the skylit daylit zone which is a lighting control zone versus a description of the envelope geometry. The primary difference between the two is that the daylight control zone must take into account partial ceiling height partitions and racks.

Compliance Form 2013-NRCC-ENV-04-E Minimum Skylight Area Worksheet has to be modified to include the skylight area and then compare this to the skylit daylit area. The skylit daylit area is already calculated to show compliance with the requirement that the skylit daylit area is at least 75% of the total area of the large tall spaces that must comply with the minimum daylighting area requirement. The instructions must be modified to indicate the easier way to calculate the areas under consideration. Instead of the skylit daylit area the area calculated would be the total area that is within 0.7 times the ceiling height from skylights (i.e. they are not truncating the daylit zone to account for partial ceiling height partitions or racks).

7. References and Other Research

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8. APPENDICES

Appendix A: 2005 Title 24 Minimum Daylight Area Code Language

SECTION 131 – INDOOR LIGHTING CONTROLS THAT SHALL BE INSTALLED

(c) **Daylit Area**s. Luminaires 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. The daylit 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, or one half the horizontal distance to the edge of the closest skylight or vertical glazing. The daylit area illuminated by vertical glazing shall be the daylit depth multiplied by the daylit width, where the daylit depth is 15 feet, 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 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.

SECTION 143 – PRESCRIPTIVE REQUIREMENTS FOR BUILDING ENVELOPES

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

1. **Daylit Area.** At least one half of the floor area shall be in the daylit area under skylights.
2. **Minimum Skylight Area or Effective Aperture.** Areas that are daylit shall have a minimum skylight area to daylit area ratio or minimum skylight effective aperture as shown in TABLE 143-F. Skylight effective aperture shall be determined as specified in Equation 146-A.
3. **Skylight Characteristics.** Skylights shall:
   A. Have a glazing material or diffuser that has a measured haze value greater than 90%, tested according to ASTM D1003 (notwithstanding its scope) or other test method approved by the Commission; and
   B. If the space is conditioned, meet the requirements in Section 143 (a) 6 or 143 (b).
4. **Controls.** Electric lighting in the daylit area shall be controlled as described in Section 131 (c) 2.

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

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

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

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

SECTION 146 – PRESCRIPTIVE REQUIREMENTS FOR INDOOR LIGHTING

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:

….

C. For daylighting control credits, the luminaire is controlled by the daylighting control, and the luminaire is located within the daylit area. The power adjustment factor is a function of the lighting power density of the general lighting in the space and the effective aperture of the skylights determined using Equation 146-A.

EQUATION 146-A – EFFECTIVE APERTURE OF SKYLIGHTS

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

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

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

Daylight 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

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

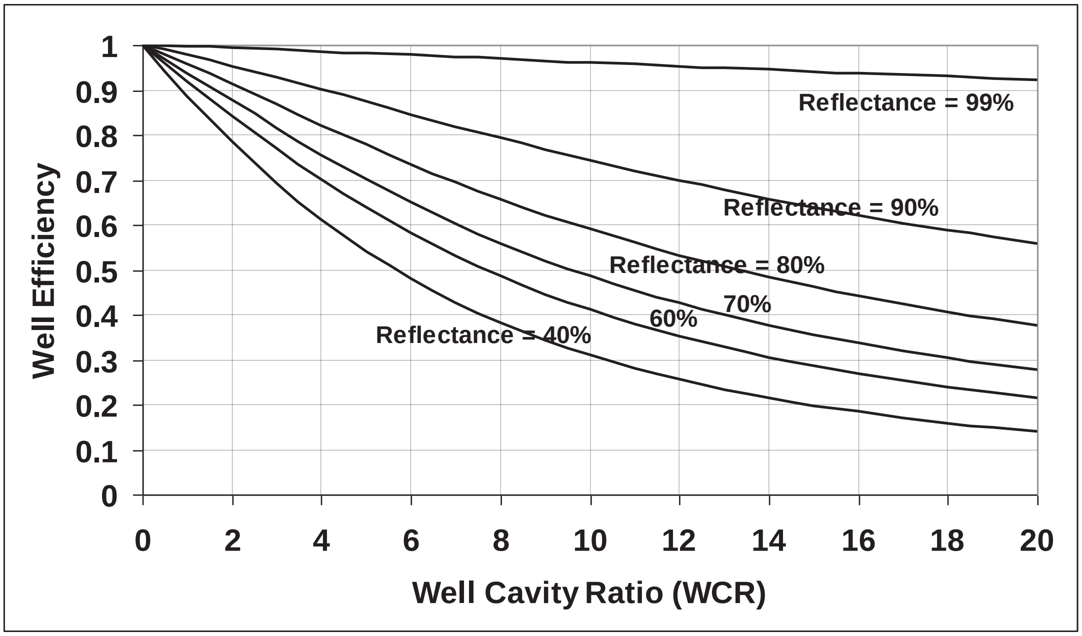

FIGURE 146-A WELL EFFICIENCY NOMOGRAPH

Appendix B: 2008 Title 24 Minimum Daylight Area Code Language

SECTION 131 – INDOOR LIGHTING CONTROLS THAT SHALL BE INSTALLED

(c) **Daylight Area**s.

1. Daylight areas shall be defined as follows:

   A. **DAYLIGHT AREA** the total daylight area shall not double count overlapping areas with any primary sidelit daylight area, secondary sidelit daylight area, or skylit daylight area.

   B. **DAYLIGHT AREA, PRIMARY SIDELIT** is the combined primary sidelit area without double counting overlapping areas. The floor area for each primary sidelit area is directly adjacent to vertical glazing below the ceiling with an area equal to the product of the sidelit width and the primary sidelit depth.

   The primary sidelit width is the width of the window plus, on each side, the smallest of:

   i. 2 feet; or

   ii. The distance to any 5 feet or higher permanent vertical obstruction.

   The primary sidelit depth is the horizontal distance perpendicular to the glazing which is the smaller of:

   i. One window head height; or

   ii. The distance to any 5 feet or higher permanent vertical obstruction.

   C. **DAYLIGHT AREA. SECONDARY SIDELIT** is the combined secondary sidelit area without double counting overlapping areas. The floor area for each secondary sidelit area is directly adjacent to primary sidelit area with an area equal to the product of the sidelit width and the secondary sidelit depth.

   The secondary sidelit width is the width of the window plus, on each side, the smallest of:

i. 2 feet; or

ii. The distance to any 5 feet or higher permanent vertical obstruction; or

iii. The distance to any skylit daylight area.

The secondary sidelit depth is the horizontal distance perpendicular to the glazing which begins from one window head height, and ends at the smaller of:

i. Two window head heights;

ii. The distance to any 5 feet or higher permanent vertical obstruction; or

iii. The distance to any skylit daylight area.

D. **DAYLIGHT AREA, SKYLIT** is the combined daylight area under each skylight without double counting overlapping areas. The daylight area under each skylight is bounded by the rough opening of the skylight, plus horizontally in each direction the smallest of:

i. 70 percent of the floor-to-ceiling height; or

ii. The distance to any primary sidelit area, or the daylight area under rooftop monitors; or

iii. The distance to any permanent partition or permanent rack which is farther away than 70 percent of the distance between the top of the permanent partition or permanent rack and the ceiling.

SECTION 143 – PRESCRIPTIVE REQUIREMENTS FOR BUILDING ENVELOPES

(c) **Minimum Skylight Area for Large Enclosed Spaces in Buildings with Three or Fewer Stories.** In climate zones 2 through 15, low rise conditioned or unconditioned enclosed spaces that are greater than 8,000 ft^2 directly under a roof with ceiling heights greater than 15 feet shall meet Sections 143(c)1-4 below.

1. **Daylit Area.** At least one half of the floor area shall be in the skylit daylight area, the primary sidelit daylight area, or a combination of the skylit and primary sidelit daylight areas. The skylit and primary sidelit daylight areas shall be shown on the building plans. Skylit and primary sidelit daylight areas are defined in Section 131(c)1.

2. **Minimum Skylight Area or Effective Aperture.** Areas that are skylit shall have a minimum skylight area to skylit area ratio of at least 3.3 percent or minimum skylight effective aperture of at least 1.1 percent. Skylight effective aperture shall be determined as specified in Equation 146-C. If primary sidelit area is used to comply with Section 143(c)1, the primary sidelit daylight areas shall have an effective aperture greater than 10 percent. The effective aperture for primary sidelit daylight areas is specified in Section 146(a)2E.

3. **Skylight Characteristics.** Skylights shall:

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

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

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

EXCEPTION 1to Section 143(c): Auditoriums, churches, movie theaters, museums, and refrigerated warehouses.

EXCEPTION 2 to Section 143(c): In buildings with unfinished interiors, future enclosed spaces where it is planned to have less than or equal to 8,000 square feet of floor area, or ceiling heights less than or equal to 15 feet, based on proposed future interior wall and ceiling locations as delineated in the plans. This exception shall not apply to these future enclosed spaces when interior walls and ceilings are installed for the first time, the enclosed space floor area is greater than 8,000 square feet, and the ceiling height is greater than 15 feet (see

Section 149(b)1M). This exception shall not be used for S-1 or S-2 (storage), or for F-1 or F-2 (factory) occupancies.

EXCEPTION 3 to Section 143(c): Enclosed spaces having a designed general lighting system with a lighting power density less than 0.5 watts per square foot.

SECTION 146 – PRESCRIPTIVE REQUIREMENTS FOR INDOOR LIGHTING

2. **Reduction of wattage through controls.** The controlled watts of any luminaire may be reduced by the number of controlled watts times the applicable Power Adjustment Factor (PAF) from TABLE 146-C if:

E. For automatic daylighting control PAFs, the luminaire(s) shall be controlled by the automatic daylighting control(s) complying with applicable requirements of Section 119 and installed according to Section 131(c)2D. The PAF's are calculated based on PAFs described below in Section 146(a) 2E (i through iii), and at least 50 percent of the controlled luminaires shall be located within the daylit area. Daylight controls shall not control lamps that are outside of the daylight area (skylit, primary sidelit, and/or secondary sidelit daylight areas). The daylight area associated with the daylighting control receiving the PAF shall be shown on the building plans. PAFs shall not be available for automatic daylighting controls required by Section 131(c)2B and C.

ii. Power Adjustment Factor for controlling skylit areas.

The PAF is a function of the lighting power density of the general lighting in the space and the effective aperture of the skylights shall be determined in accordance with Equation 146-C.

EQUATION 146-C – EFFECTIVE APERTURE OF SKYLIGHTS

$$\text{Skylit Effective Aperture} = \frac{0.85 \times \sum \text{Skylight Area} \times \text{VT} \times \text{Well Efficiency}}{\text{Skylit Daylight Area}}$$

Where:

Skylight Area = the area of each individual skylight

Skylit Daylight Area = see Section 131(c)1D daylight area, skylit

VT = visible light transmittance. The VT 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.

Well Efficiency equals the ratio of the amount of visible light leaving a skylight well to the amount of visible light entering the skylight well. Well Efficiency shall be determined from Equation 146- F or Table 146-B for specular and tubular light wells and from Table 146-A for all other light wells, based on the weighted average reflectance of the walls of the well and the geometry of the light well, or other test method approved by the Commission.

The well efficiency for non-specular or non-tubular light wells is based on the average weighted reflectance of the walls of the light well and the well cavity ratio. The well cavity ratio (WCR) is determined by the geometry of the skylight well and shall be determined using either Equation 146-D or Equation 146-E.

EQUATION 146-D WELL CAVITY RATIO FOR RECTANGULAR WELLS

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

EQUATION 146-E 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 well perimeter and well area are measured at the bottom of the well.

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

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

Where:

ρ = specular reflectance of interior light well wall

L/D = ratio of light well length to light well interior diameter

TABLE 146-A WELL EFFICIENCY FOR NON-SPECULAR OR NON-TUBULAR LIGHT WELLS

	light well wall reflectance					
WCR	ρ = 99%	ρ = 90%	ρ = 80%	ρ = 70%	ρ = 60%	ρ = 40%
0	1.00	1.00	1.00	1.00	1.00	1.00
1	1.00	0.98	0.96	0.94	0.92	0.89
2	0.99	0.95	0.91	0.88	0.84	0.78
4	0.99	0.90	0.82	0.76	0.70	0.61
6	0.98	0.85	0.74	0.65	0.58	0.48
8	0.97	0.79	0.66	0.56	0.49	0.38
10	0.96	0.74	0.59	0.49	0.41	0.31
12	0.95	0.70	0.53	0.43	0.35	0.26
14	0.95	0.66	0.48	0.38	0.31	0.22
16	0.94	0.62	0.44	0.34	0.27	0.18
18	0.93	0.59	0.41	0.31	0.24	0.16
20	0.92	0.56	0.38	0.28	0.21	0.14

TABLE 146-B WELL EFFICIENCY FOR SPECULAR TUBULAR LIGHT WELLS

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

Appendix C: 2013 Title 24 Minimum Daylight Area Code Language

SECTION 130.1 – INDOOR LIGHTING CONTROLS THAT SHALL BE INSTALLED

(d) **Automatic Daylighting Controls.**

1. Daylit Zones shall be defined as follows:

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

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

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

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

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

A. SECTION 140.3 – PRESCRIPTIVE REQUIREMENTS FOR BUILDING ENVELOPES

(a) **Envelope Component Approach.**

6. **Skylights.** Skylights shall:

   A. Have an area no greater than 5 percent of the gross exterior roof area (SRR); and

…

   D. Have an Area-Weighted Performance Rating VT no less than the applicable value in TABLE 140.3-B or C; and

   EXCEPTION to Section 140.3(a)6D: For skylights containing chromogenic type glazing:

   i. the higher-rated labeled VT shall be used used with automatic controls to modulate the amount of heat flow into the space in multiple steps in response to daylight levels or solar intensity and;

   ii. chromogenic glazing shall be considered separately from other skylights; and

   iii. area-weighted averaging with other skylights that are not chromogenic shall not be permitted.

   E. Have a glazing material or diffuser that has a measured haze value greater than 90 percent, determined according to ASTM D1003, or other test method approved by the Energy Commission.

Excerpted from: Table 140.3-B – Prescriptive Envelope Criteria For Nonresidential Buildings

			Glass, Curb Mounted	Glass, Deck Mounted	Plastic, Curb Mounted
Skylights	Area-Weighted Performance Rating	Max U-factor	0.58	0.46	0.88
		Max SHGC	0.25	0.25	NR
	Area-Weighted Performance Rating	Min VT	0.49	0.49	0.64
	Maximum SRR%	5%			

(c) **Minimum Daylighting Requirement for Large Enclosed Spaces.** In climate zones 2 through 15, conditioned enclosed spaces, and unconditioned enclosed spaces, that are greater than 5,000 ft² and that are directly under a roof with ceiling heights greater than 15 feet, shall meet the following requirements:

1. A combined total of at least 75percent of the floor area, as determined in building floor plan (drawings) view, shall be within one or more of the following:

   A. Primary Sidelight Daylight Zone in accordance with Section 130.1(d)1B, or

   B. Skylit Daylit Zone in accordance with Section 130.1(d)1A.

2. All Skylit Daylit Zones and Primary Sidelit Daylit Zones shall be shown on building plans.

3. General lighting in daylit zones shall be controlled in accordance with Section 130.1(d).

4. Skylights shall:

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

   B. If the space is conditioned, meet the requirements in Section 140.3(a)6.

EXCEPTION 1 to Section 140.3(c): Auditoriums, churches, movie theaters, museums, and refrigerated warehouses.

EXCEPTION 2 to Section 140.3(c): In buildings with unfinished interiors, future enclosed spaces for which there are plans to have:

A. A floor area of less than or equal to 5,000 square feet; or

B. Ceiling heights of less than or equal to 15 feet. This exception shall not be used for S-1 or S-2 (storage), or for F-1 or F-2 (factory) occupancies.

EXCEPTION 3 to Section 140.3(c): Enclosed spaces having a designed general lighting system with a lighting power density less than 0.5 watts per square foot.

Appendix D: 2012 IECC Minimum Daylight Area Code Language

C402.3.2 Minimum skylight fenestration area.[6]

In an enclosed space greater than 10,000 square feet (929 m^2), directly under a roof with ceiling heights greater than 15 feet (4572 mm), and used as an office, lobby, atrium, concourse, corridor, storage, gymnasium/exercise center, convention center, automotive service, manufacturing, non-refrigerated warehouse, retail store, distribution/sorting area, transportation, or workshop, the total daylight zone under skylights shall be not less than half the floor area and shall provide a minimum skylight area to daylight zone under skylights of either:

1. Not less than 3 percent with a skylight VT of at least 0.40; or
2. Provide a minimum skylight effective aperture of at least 1 percent determined in accordance with Equation 4-1.

$$\text{Skylight Effective Aperature} = \frac{0.85 \times \text{Skylight Area} \times \text{Skylight VT} \times \text{WF}}{\text{Daylight zone under skylight}}$$ **(Equation 4-1)**

where:

Skylight area	=	Total fenestration area of skylights.
Skylight VT	=	Area weighted average visible transmittance of skylights.
WF	=	Area weighted average well factor, where well factor is 0.9 if light well depth is less than 2 feet (610 mm), or 0.7 if light well depth is 2 feet (610 mm) or greater.
Light well depth	=	Measure vertically from the underside of the lowest point of the skylight glazing to the ceiling plane under the skylight.

[6] http://publicecodes.cyberregs.com/icod/iecc/2012/icod_iecc_2012_ce4_par023.htm

Exception: Skylights above daylight zones of enclosed spaces are not required in:

1. Buildings in climate zones 6 through 8.
2. Spaces where the designed general lighting power densities are less than 0.5 W/ft2 (5.4 W/m2).
3. Areas where it is documented that existing structures or natural objects block direct beam sunlight on at least half of the roof over the enclosed area for more than 1,500 daytime hours per year between 8 am and 4 pm.
4. Spaces where the daylight zone under rooftop monitors is greater than 50 percent of the enclosed space floor area.