CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Nonresidential Daylighting

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team October 2011

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1. Purpose

This document describes the code change proposals for 2013 Title 24 - Part 6 Building Energy Efficiency Standards, for the topic of Daylighting.

2. Overview

This table summarizes the major components of this proposal to expand and simplify the daylighting requirements in the 2013 Title 24 part 6.

a. Measure Title	Proposed changes to the daylighting requirements in Title 24-Part6
b. Description	Four code changes are being proposed as part of this report that increase stringency of daylight code requirements, resulting in greater energy savings, and simplify the daylighting code implementation process, removing key barriers to code compliance for greater and more widespread use. The proposed code changes apply to all non-residential, high-rise residential and hotel/motel occupancies. **Proposal 1 - Watt Calculation Method:** This proposes a new performance method to determine savings from controlling electric lighting in daylit spaces. This proposal modifies performance approach language in Section 141, and provides a new sidelighting calculation methodology for the ACM. **Proposal 2 - Photocontrols Requirement Threshold:** This proposal modifies the mandatory requirement for photocontrols in sidelit and toplit spaces under Section 131(c) and Section 149(b) and prescriptive requirement in Section 146(d) **Proposal 3 - Minimum Skylight Area Requirement:** This proposal modifies the prescriptive requirements for building envelopes - Section 143(c) by increasing the minimum skylight area requirement. **Proposal 4 – Space Area Threshold for Requiring Skylights:** This proposal modifies the prescriptive requirements for building envelopes - Section 143(c) by decreasing the minimum space area that triggers the requirement for skylights. *A fifth proposal was evaluated, but is not being proposed as a code change for the 2013 energy code but does point to a cost-effective method of complying with the reach code in spaces under a roof with ceilings as low as 12 feet.* **Proposal 5 - Lower Ceiling Height Threshold for Skylight Area Requirement:** This proposal looked at modifying the prescriptive requirements for building envelopes - Section 143(c) by reducing the minimum ceiling height that triggers the requirement for skylights.

c. Type of Change	**Modeling** - The change proposed in proposal 1 would modify the calculation procedures used in complying with prescriptive requirements for photocontrols in sidelit and top light spaces. **Mandatory Measure -** The change proposed in proposal 2 would modify the mandatory measure under 131(c). **Prescriptive Requirement -** The change proposed in proposals 2, 3 and 4 would modify the prescriptive requirements in Section 143(c) and 149(b). The documents that would need to be modified in order to implement the proposed change are the Standards, ACM, Manuals and Compliance Forms. None of the proposed changes would add a compliance option or a new requirement.

d. Energy Benefits: **Measure 1:** Photocontrols Requirement Threshold for Sidelighting
Prototype: Office Sidelit Building (See Section 4.7 for assumptions about prototype building)

Office Sidelit Building Prototype		Electricity Savings (kWh/yr)	Demand Savings (kW)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings (kBtu)	TDV Gas Savings (kBtu)
CZ 1 Savings	Per sf of Primary Daylit Zone*	2.43	1.17	-0.0005	76.13	-0.49
	Per Prototype Building	32,442	14,086	-4.91	553,521	-2,454
	Per Building sf	0.95	0.41	-0.0001	16.28	-0.07
CZ 2 Savings	Per sf of Primary Daylit Zone*	2.43	1.17	-0.0005	75.82	-0.49
	Per Prototype Building	32,442	14,086	-4.91	551,380	-2,445
	Per Building sf	0.95	0.41	-0.0001	16.22	-0.07
CZ 3 Savings	Per sf of Primary Daylit Zone*	2.43	1.17	-0.0005	75.87	-0.49
	Per Prototype Building	32,442	14,086	-4.91	551,747	-2,446
	Per Building sf	0.95	0.41	-0.0001	16.23	-0.07
CZ 4 Savings	Per sf of Primary Daylit Zone*	2.43	1.17	-0.0005	76.02	-0.49
	Per Prototype Building	32,442	14,086	-4.91	552,665	-2,450
	Per Building sf	0.95	0.41	-0.0001	16.25	-0.07
CZ 5 Savings	Per sf of Primary Daylit Zone*	2.99	1.12	-0.0018	71.43	-1.25
	Per Prototype Building	18,392	7,427	-12.44	522,235	-10,352
	Per Building sf	0.54	0.22	-0.0004	15.36	-0.30
CZ 6 Savings	Per sf of Primary Daylit Zone*	2.99	1.12	-0.0018	69.24	-1.21
	Per Prototype Building	18,392	7,427	-12.44	506,587	-10,042
	Per Building sf	0.54	0.22	-0.0004	14.90	-0.30
CZ 7 Savings	Per sf of Primary Daylit Zone*	2.99	1.12	-0.0018	70.00	-1.23
	Per Prototype Building	18,392	7,427	-12.44	512,274	-10,155
	Per Building sf	0.54	0.22	-0.0004	15.07	-0.30
CZ 8 Savings	Per sf of Primary Daylit Zone*	2.99	1.12	-0.0018	69.44	-1.22
	Per Prototype Building	18,392	7,427	-12.44	508,112	-10,073
	Per Building sf	0.54	0.22	-0.0004	14.94	-0.30
CZ 9 Savings	Per sf of Primary Daylit Zone*	2.99	1.12	-0.0018	68.79	-1.21
	Per Prototype Building	18,392	7,427	-12.44	503,123	-9,974
	Per Building sf	0.54	0.22	-0.0004	14.80	-0.29
CZ 10 Savings	Per sf of Primary Daylit Zone*	2.99	1.12	-0.0018	69.32	-1.22
	Per Prototype Building	18,392	7,427	-12.44	506,660	-10,044
	Per Building sf	0.54	0.22	-0.0004	14.90	-0.30
CZ 11 Savings	Per sf of Primary Daylit Zone*	2.16	0.84	-0.0056	52.79	-3.99
	Per Prototype Building	15,199	6,275	-41.58	390,278	-31,285
	Per Building sf	0.45	0.18	-0.0012	11.48	-0.92
CZ 12 Savings	Per sf of Primary Daylit Zone*	2.16	0.84	-0.0056	52.48	-3.96
	Per Prototype Building	15,199	6,275	-41.58	388,064	-31,108
	Per Building sf	0.45	0.18	-0.0012	11.41	-0.91
CZ 13 Savings	Per sf of Primary Daylit Zone*	1.87	0.77	-0.0006	38.77	-0.36
	Per Prototype Building	16,859	7,683	-3.72	287,830	-1,859
	Per Building sf	0.50	0.23	-0.0001	8.47	-0.05
CZ 14 Savings	Per sf of Primary Daylit Zone*	1.87	0.77	-0.0006	38.99	-0.36
	Per Prototype Building	16,859	7,683	-3.72	289,308	-1,869
	Per Building sf	0.50	0.23	-0.0001	8.51	-0.05
CZ 15 Savings	Per sf of Primary Daylit Zone*	1.87	0.77	-0.0006	38.49	-0.35
	Per Prototype Building	16,859	7,683	-3.72	285,672	-1,845
	Per Building sf	0.50	0.23	-0.0001	8.40	-0.05
CZ 16 Savings	Per sf of Primary Daylit Zone*	2.43	1.17	-0.0005	76.15	-0.49
	Per Prototype Building	32,442	14,086	-4.91	553,562	-2,454
	Per Building sf	0.95	0.41	-0.0001	16.28	-0.07

* Total Saving in Primary and Seconday Daylit Zones per Primary Daylit Zone Area

Measure 2: Photocontrols Requirement Threshold for Toplighting
Prototype: Small Retail Toplit Building (See Section 4.7 for assumptions about prototype building)

Small Retail Toplit Building Prototype		Electricity Savings (kWh/yr)	Demand Savings (W/sf)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings (kBtu)	TDV Gas Savings (kBtu)
CZ 1 Savings	Per sf of Skylit Zone	1.89	0.89	0.000	62.66	-0.01
	Per Prototype Building	4,547	2,148	-0.022	150,376	-21.46
	Per Building sf	0.79	0.37	0.000	26.11	0.00
CZ 2 Savings	Per sf of Skylit Zone	2.54	0.89	0.000	61.74	-0.01
	Per Prototype Building	6,107	2,148	-0.040	148,186	-28.52
	Per Building sf	1.06	0.37	0.000	25.73	0.00
CZ 3 Savings	Per sf of Skylit Zone	2.53	0.89	0.000	62.95	-0.01
	Per Prototype Building	6,071	2,148	-0.017	151,089	-12.08
	Per Building sf	1.05	0.37	0.000	26.23	0.00
CZ 4 Savings	Per sf of Skylit Zone	2.78	0.89	0.000	61.61	0.00
	Per Prototype Building	6,668	2,148	-0.018	147,861	-11.73
	Per Building sf	1.16	0.37	0.000	25.67	0.00
CZ 5 Savings	Per sf of Skylit Zone	2.72	1.05	0.000	68.65	0.00
	Per Prototype Building	6,530	2,522	-0.011	164,759	-8.10
	Per Building sf	1.13	0.44	0.000	28.60	0.00
CZ 6 Savings	Per sf of Skylit Zone	2.78	1.05	0.000	67.44	0.00
	Per Prototype Building	6,662	2,522	-0.009	161,853	-6.12
	Per Building sf	1.16	0.44	0.000	28.10	0.00
CZ 7 Savings	Per sf of Skylit Zone	2.85	1.05	0.000	66.59	0.00
	Per Prototype Building	6,837	2,522	-0.009	159,823	-6.18
	Per Building sf	1.19	0.44	0.000	27.75	0.00
CZ 8 Savings	Per sf of Skylit Zone	2.88	1.05	0.000	66.57	0.00
	Per Prototype Building	6,920	2,522	-0.013	159,772	-8.95
	Per Building sf	1.20	0.44	0.000	27.74	0.00
CZ 9 Savings	Per sf of Skylit Zone	2.79	1.05	0.000	65.96	-0.01
	Per Prototype Building	6,700	2,522	-0.035	158,293	-24.38
	Per Building sf	1.16	0.44	0.000	27.48	0.00
CZ 10 Savings	Per sf of Skylit Zone	2.82	1.05	0.000	67.39	-0.01
	Per Prototype Building	6,766	2,522	-0.025	161,738	-17.46
	Per Building sf	1.17	0.44	0.000	28.08	0.00
CZ 11 Savings	Per sf of Skylit Zone	2.64	1.14	0.000	66.85	-0.01
	Per Prototype Building	6,341	2,733	-0.033	160,438	-24.31
	Per Building sf	1.10	0.47	0.000	27.85	0.00
CZ 12 Savings	Per sf of Skylit Zone	2.78	1.14	0.000	65.81	-0.01
	Per Prototype Building	6,673	2,733	-0.035	157,932	-24.52
	Per Building sf	1.16	0.47	0.000	27.42	0.00
CZ 13 Savings	Per sf of Skylit Zone	2.92	1.14	0.000	68.94	-0.01
	Per Prototype Building	7,016	2,727	-0.028	165,462	-19.48
	Per Building sf	1.22	0.47	0.000	28.73	0.00
CZ 14 Savings	Per sf of Skylit Zone	2.91	1.14	0.000	70.42	-0.08
	Per Prototype Building	6,978	2,727	-0.286	169,010	-202.66
	Per Building sf	1.21	0.47	0.000	29.34	-0.04
CZ 15 Savings	Per sf of Skylit Zone	3.04	1.14	0.000	69.78	0.00
	Per Prototype Building	7,292	2,727	-0.016	167,476	-10.92
	Per Building sf	1.27	0.47	0.000	29.08	0.00
CZ 16 Savings	Per sf of Skylit Zone	2.41	0.89	0.000	61.98	-0.28
	Per Prototype Building	5,791	2,148	-0.886	148,757	-666.73
	Per Building sf	1.01	0.37	0.000	25.83	-0.12

Measure 3a & 4: Increase Min Skylight Area Requirement and Decrease Minimum Area Threshold
Prototype: Large Retail Toplit Building (See Section 4.7 for assumptions about prototype)
Note: *The energy benefits of Measures 3 and 4 are presented together as the same prototype building was applied to both measures.*

	Large Retail Toplit Building Prototype	Electricity Savings (kWh/yr)	Demand Savings (kW)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings (kBtu)	TDV Gas Savings (kBtu)
	Per sf of Skylit Zone	2.00	0.79	-0.012	52.46	-9.39
CZ 1	Per Prototype Building	7,493	2,975	-45.751	196,734	-35,195.99
Savings	Per Building sf	1.50	0.60	-0.009	39.35	-7.04
	Per sf of Skylit Zone	2.00	0.79	-0.012	52.43	-9.38
CZ 2	Per Prototype Building	7,493	2,975	-45.751	196,625	-35,176.63
Savings	Per Building sf	1.50	0.60	-0.009	39.33	-7.04
	Per sf of Skylit Zone	2.00	0.79	-0.012	53.34	-9.54
CZ 3	Per Prototype Building	7,493	2,975	-45.751	200,044	-35,788.20
Savings	Per Building sf	1.50	0.60	-0.009	40.01	-7.16
	Per sf of Skylit Zone	2.00	0.79	-0.012	52.44	-9.38
CZ 4	Per Prototype Building	7,493	2,975	-45.751	196,636	-35,178.62
Savings	Per Building sf	1.50	0.60	-0.009	39.33	-7.04
	Per sf of Skylit Zone	2.25	1.05	-0.002	59.94	-1.28
CZ 5	Per Prototype Building	8,437	3,922	-6.135	224,760	-4,788.66
Savings	Per Building sf	1.69	0.78	-0.001	44.95	-0.96
	Per sf of Skylit Zone	2.25	1.05	-0.002	59.38	-1.27
CZ 6	Per Prototype Building	8,437	3,922	-6.135	222,662	-4,743.96
Savings	Per Building sf	1.69	0.78	-0.001	44.53	-0.95
	Per sf of Skylit Zone	2.25	1.05	-0.002	58.31	-1.24
CZ 7	Per Prototype Building	8,437	3,922	-6.135	218,666	-4,658.83
Savings	Per Building sf	1.69	0.78	-0.001	43.73	-0.93
	Per sf of Skylit Zone	2.25	1.05	-0.002	58.64	-1.25
CZ 8	Per Prototype Building	8,437	3,922	-6.135	219,893	-4,684.97
Savings	Per Building sf	1.69	0.78	-0.001	43.98	-0.94
	Per sf of Skylit Zone	2.25	1.05	-0.002	58.57	-1.25
CZ 9	Per Prototype Building	8,437	3,922	-6.135	219,621	-4,679.16
Savings	Per Building sf	1.69	0.78	-0.001	43.92	-0.94
	Per sf of Skylit Zone	2.02	1.05	-0.008	59.90	-7.15
CZ 10	Per Prototype Building	7,560	3,922	-30.784	224,607	-26,798.25
Savings	Per Building sf	1.51	0.78	-0.006	44.92	-5.36
	Per sf of Skylit Zone	1.85	0.99	-0.014	48.48	-10.57
CZ 11	Per Prototype Building	6,951	3,721	-51.726	181,792	-39,639.69
Savings	Per Building sf	1.39	0.74	-0.010	36.36	-7.93
	Per sf of Skylit Zone	1.85	0.99	-0.014	47.57	-10.37
CZ 12	Per Prototype Building	6,951	3,721	-51.726	178,390	-38,897.96
Savings	Per Building sf	1.39	0.74	-0.010	35.68	-7.78
	Per sf of Skylit Zone	2.01	1.03	-0.011	51.08	-8.37
CZ 13	Per Prototype Building	7,522	3,858	-42.054	191,543	-31,378.77
Savings	Per Building sf	1.50	0.77	-0.008	38.31	-6.28
	Per sf of Skylit Zone	2.01	1.03	-0.011	52.64	-8.62
CZ 14	Per Prototype Building	7,522	3,858	-42.054	197,395	-32,337.49
Savings	Per Building sf	1.50	0.77	-0.008	39.48	-6.47
	Per sf of Skylit Zone	2.01	1.03	-0.011	51.94	-8.51
CZ 15	Per Prototype Building	7,522	3,858	-42.054	194,790	-31,910.70
Savings	Per Building sf	1.50	0.77	-0.008	38.96	-6.38
	Per sf of Skylit Zone	2.00	0.79	-0.012	52.62	-9.41
CZ 16	Per Prototype Building	7,493	2,975	-45.751	197,325	-35,301.77
Savings	Per Building sf	1.50	0.60	-0.009	39.46	-7.06

Measure 3b & 4: Increase Min Skylight Area Requirement and Decrease Minimum Area Threshold
Prototype: Large Warehouse Toplit Building (See Section 4.7 for assumptions about prototype)
Note: *The energy benefits of Measures 3 and 4 are presented together as the same prototype building was applied to both measures.*

	Large Warehouse Toplit Building Prototype	Electricity Savings (kWh/yr)	Demand Savings (kW)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings (kBtu)	TDV Gas Savings (kBtu)
	Per sf of Skylit Zone	1.03	0.43	0.000	28.69	0.00
CZ 1	Per Prototype Building	3,846	1,606	0.000	107,578	0.00
Savings	Per Building sf	0.77	0.32	0.000	21.52	0.00
	Per sf of Skylit Zone	1.03	0.43	0.000	28.64	0.00
CZ 2	Per Prototype Building	3,846	1,606	0.000	107,395	0.00
Savings	Per Building sf	0.77	0.32	0.000	21.48	0.00
	Per sf of Skylit Zone	1.03	0.43	0.000	29.09	0.00
CZ 3	Per Prototype Building	3,846	1,606	0.000	109,073	0.00
Savings	Per Building sf	0.77	0.32	0.000	21.81	0.00
	Per sf of Skylit Zone	1.03	0.43	0.000	28.62	0.00
CZ 4	Per Prototype Building	3,846	1,606	0.000	107,322	0.00
Savings	Per Building sf	0.77	0.32	0.000	21.46	0.00
	Per sf of Skylit Zone	1.12	0.52	0.000	30.05	0.00
CZ 5	Per Prototype Building	4,200	1,959	0.000	112,691	0.00
Savings	Per Building sf	0.84	0.39	0.000	22.54	0.00
	Per sf of Skylit Zone	1.12	0.52	0.000	29.79	0.00
CZ 6	Per Prototype Building	4,200	1,959	0.000	111,700	0.00
Savings	Per Building sf	0.84	0.39	0.000	22.34	0.00
	Per sf of Skylit Zone	1.12	0.52	0.000	29.29	0.00
CZ 7	Per Prototype Building	4,200	1,959	0.000	109,840	0.00
Savings	Per Building sf	0.84	0.39	0.000	21.97	0.00
	Per sf of Skylit Zone	1.12	0.52	0.000	29.41	0.00
CZ 8	Per Prototype Building	4,200	1,959	0.000	110,299	0.00
Savings	Per Building sf	0.84	0.39	0.000	22.06	0.00
	Per sf of Skylit Zone	1.12	0.52	0.000	29.37	0.00
CZ 9	Per Prototype Building	4,200	1,959	0.000	110,129	0.00
Savings	Per Building sf	0.84	0.39	0.000	22.03	0.00
	Per sf of Skylit Zone	1.08	0.52	0.000	30.03	0.00
CZ 10	Per Prototype Building	4,067	1,959	0.000	112,601	0.00
Savings	Per Building sf	0.81	0.39	0.000	22.52	0.00
	Per sf of Skylit Zone	1.04	0.56	0.000	28.28	0.00
CZ 11	Per Prototype Building	3,895	2,108	0.000	106,058	0.00
Savings	Per Building sf	0.78	0.42	0.000	21.21	0.00
	Per sf of Skylit Zone	1.04	0.56	0.000	27.80	0.00
CZ 12	Per Prototype Building	3,895	2,108	0.000	104,265	0.00
Savings	Per Building sf	0.78	0.42	0.000	20.85	0.00
	Per sf of Skylit Zone	1.18	0.59	0.000	30.11	0.00
CZ 13	Per Prototype Building	4,418	2,206	0.000	112,924	0.00
Savings	Per Building sf	0.88	0.44	0.000	22.58	0.00
	Per sf of Skylit Zone	1.18	0.59	0.000	30.96	0.00
CZ 14	Per Prototype Building	4,418	2,206	0.000	116,103	0.00
Savings	Per Building sf	0.88	0.44	0.000	23.22	0.00
	Per sf of Skylit Zone	1.18	0.59	0.000	30.57	0.00
CZ 15	Per Prototype Building	4,418	2,206	0.000	114,625	0.00
Savings	Per Building sf	0.88	0.44	0.000	22.93	0.00
	Per sf of Skylit Zone	1.03	0.43	0.000	28.79	0.00
CZ 16	Per Prototype Building	3,846	1,606	0.000	107,959	0.00
Savings	Per Building sf	0.77	0.32	0.000	21.59	0.00

The savings from this/these measures results in the following statewide first year savings:

	Total Electric Energy Savings (GWh)	Total Gas Energy Savings (MMtherms)	Total TDV Savings (Mil. $)
Measure 1	45.57	-0.03	$93.52
Measure 2	2.89	0.00	$6.11
Measure 3 & 4	46.74	-0.06	110.30
TOTAL Statewide	95.19	-0.09	209.93

e. Non-Energy Benefits	Several studies have been conducted on the productivity benefits of daylighting or view. Daylighting has been shown to have a strong positive effect on occupant wellbeing by various studies. Daylighting is linked with higher student performance, higher retail sales and better office worker productivity. We are not aware of any study showing that daylight responsive electric lighting controls (photocontrols) promote improved quality or productivity. However, well designed daylighting controls can result in the illuminance levels in the space to be more uniform with the control enabled than with the electric lighting not responding to daylight. The IESNA (Illuminating Engineering Society of North America) has set a number of consensus design standards based on uniformity as one measure of the goodness of the design. Thus it is likely that these controls do improve the quality of the visual environment

f. Environmental Impact

Material Increase (I), Decrease (D), or No Change (NC): (All units are lbs/year)

We investigated if photocontrols include any lead content, and confirmed the new generation of wireless and wired photosensors are RoHS compliant which means they are lead-free or have negligible amount of lead. Details of how the environmental impact was calculated is given in Appendix E.

	Mercury	Lead	Copper	Steel	Plastic	Others (Indentify)
Measure 1: Photocontrols Requirement Threshold for Sidelighting						
Per Primary Daylit Zone	0.0005	0	0.338	0.1	0.25	0
Per Prototype Building	0.004	0	2.14	0.8	2	0
Measure 2: Photocontrols Requirement Threshold for Toplighting						
Per Primary Daylit Zone	0.0005	0	0.62	0.1	0.25	0
Per Prototype Building	0.0005	0	0.62	0.1	0.25	0
Measure 3b & 4: Increase Min Skylight Area Requirement and Decrease Minimum Area Threshold						
Per Primary Daylit Zone	0.0005	0	0.62	0.1	0.25	0
Per Prototype Building	0.0025	0	3.1	0.5	1.25	0

Water Consumption:

	On-Site (Not at the Powerplant) Water Savings (or Increase) (Gallons/Year)
Per Unit Measure[1]	NA
Per Prototype Building[2]	NA

Water Quality Impacts:

	Mineralization (calcium, boron, and salts)	Algae or Bacterial Buildup	Corrosives as a Result of PH Change	Others
Impact (I, D, or NC)	NA	NA	NA	NA

g. Technology Measures	The proposed measure encourages use of photocontrols for sidelighting. **Measure Availability:** Photocontrols have been available for several decades. However, the current market share for photocontrols has traditionally been very small. There is less than 1% penetration of daylighting controls into the market (Saxena 2011). This is changing with utility programs providing incentives for photocontrols. In addition, the 2005 and 2008 Title 24 standards require photocontrols in the daylit area under skylights and large sidelit spaces. This should increase the market and use for photocontrols in advance of the 2013 Standards implementation date. Photocontrols are available in the US market from multiple manufacturers. For our cost survey we found 30 products from 10 manufacturers offered by multiple vendors. The manufacturers have a distributor network to meet a high market demand. The technology is not proprietary and the market can scale up production to meet the projected demand. **Useful Life, Persistence, and Maintenance:** Photocontrols have no moving parts that wear outside of the relay contacts for switching systems. A field study of 123 spaces in the Pacific Northwest conducted in 2001 found that approximately half of systems in sidelit spaces were disabled or otherwise mis-calibrated. An earlier study for toplit spaces found that 32 out of the 33 spaces were working well and providing savings very close to simulated savings. However, once a system was working well it could work for a long time. A common finding of this study and similar studies is that it is very important to commission the control correctly the first time to prevent dissatisfaction from space occupants. The proposals in this report and earlier Title 24 code requirements, reduce the risk of failure by careful definition of the luminaires that are to be controlled as a zone and acceptance tests that assure the controls operate as per the intent of the energy code.
h. Performance Verification of the Proposed Measure	The 2005 standards introduced acceptance tests for a wide range of HVAC and lighting controls including photocontrols. These acceptance tests in principle will help assure that the controls are working the way the standards and the designer intended. Proper installation and commissioning of photosensors if critical to the success of photocontrols. These acceptance tests have been improved over the last two code cycles.

i. Cost Effectiveness: (See Section 4.7 for assumptions about prototype building and photocontrols costs)

		Measure Life (Years)	Additional Costs- Current Measure Costs (Relative to Basecase) (Dollars)		Additional Cost - Post-Adoption Measure Costs (Relative to Basecase) (Dollars)		PV of Additional Maintenance Costs (Savings) (Relative to Basecase) (PV Dollars)		PV of Energy Cost Savings (PV Dollars)	Δ LCC Per Prototype Building (Dollars)	
	Measure Name		Per Unit	Per Proto Building	Per Unit	Per Proto Building	Per Unit	Per Proto Building	Per Proto Building	Based on Current Costs	Based on Post-Adoption Costs
CZ 1	Measure 1	15	-	$7,889	-	$7,889	-	$0	$49,043	-$41,154	-$41,154
	Measure 2	15	-	$1,809	-	$1,809	-	$0	$13,381	-$11,572	-$11,572
	Measure 3	15	-	$2,187	-	$2,187	-	$0	$19,160	-$16,974	-$16,974
CZ 2	Measure 1	15	-	$7,889	-	$7,889	-	$0	$48,853	-$40,964	-$40,964
	Measure 2	15	-	$1,809	-	$1,809	-	$0	$13,186	-$11,377	-$11,377
	Measure 3	15	-	$2,187	-	$2,187	-	$0	$19,141	-$16,954	-$16,954
CZ 3	Measure 1	15	-	$7,889	-	$7,889	-	$0	$48,886	-$40,997	-$40,997
	Measure 2	15	-	$1,809	-	$1,809	-	$0	$13,445	-$11,637	-$11,637
	Measure 3	15	-	$2,187	-	$2,187	-	$0	$19,460	-$17,274	-$17,274
CZ 4	Measure 1	15	-	$7,889	-	$7,889	-	$0	$48,967	-$41,078	-$41,078
	Measure 2	15	-	$1,809	-	$1,809	-	$0	$13,158	-$11,349	-$11,349
	Measure 3	15	-	$2,187	-	$2,187	-	$0	$19,136	-$16,950	-$16,950
CZ 5	Measure 1	15	-	$7,889	-	$7,889	-	$0	$45,556	-$37,667	-$37,667
	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,662	-$12,854	-$12,854
	Measure 3	15	-	$2,187	-	$2,187	-	$0	$23,685	-$21,498	-$21,498
CZ 6	Measure 1	15	-	$7,889	-	$7,889	-	$0	$44,191	-$36,302	-$36,302
	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,404	-$12,595	-$12,595
	Measure 3	15	-	$2,187	-	$2,187	-	$0	$23,468	-$21,281	-$21,281
CZ 7	Measure 1	15	-	$7,889	-	$7,889	-	$0	$44,687	-$36,798	-$36,798
	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,223	-$12,414	-$12,414
	Measure 3	15	-	$2,187	-	$2,187	-	$0	$23,057	-$20,870	-$20,870
CZ 8	Measure 1	15	-	$7,889	-	$7,889	-	$0	$44,324	-$36,435	-$36,435
	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,218	-$12,410	-$12,410
	Measure 3	15	-	$2,187	-	$2,187	-	$0	$23,175	-$20,989	-$20,989
CZ 9	Measure 1	15	-	$7,889	-	$7,889	-	$0	$43,889	-$36,000	-$36,000
	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,085	-$12,277	-$12,277
	Measure 3	15	-	$2,187	-	$2,187	-	$0	$23,144	-$20,958	-$20,958
CZ 10	Measure 1	15	-	$7,889	-	$7,889	-	$0	$44,197	-$36,308	-$36,308
	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,393	-$12,584	-$12,584
	Measure 3	15	-	$2,187	-	$2,187	-	$0	$22,100	-$19,914	-$19,914
CZ 11	Measure 1	15	-	$7,889	-	$7,889	-	$0	$31,949	-$24,060	-$24,060
	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,276	-$12,468	-$12,468
	Measure 3	15	-	$2,187	-	$2,187	-	$0	$17,672	-$15,485	-$15,485
CZ 12	Measure 1	15	-	$7,889	-	$7,889	-	$0	$31,768	-$23,879	-$23,879
	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,053	-$12,245	-$12,245
	Measure 3	15	-	$2,187	-	$2,187	-	$0	$17,355	-$15,168	-$15,168
CZ 13	Measure 1	15	-	$7,889	-	$7,889	-	$0	$25,450	-$17,561	-$17,561
	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,724	-$12,915	-$12,915
	Measure 3	15	-	$2,187	-	$2,187	-	$0	$19,443	-$17,257	-$17,257
CZ 14	Measure 1	15	-	$7,889	-	$7,889	-	$0	$25,581	-$17,692	-$17,692
	Measure 2	15	-	$1,809	-	$1,809	-	$0	$15,023	-$13,215	-$13,215
	Measure 3	15	-	$2,187	-	$2,187	-	$0	$20,018	-$17,831	-$17,831
CZ 15	Measure 1	15	-	$7,889	-	$7,889	-	$0	$25,260	-$17,371	-$17,371
	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,904	-$13,095	-$13,095
	Measure 3	15	-	$2,187	-	$2,187	-	$0	$19,758	-$17,571	-$17,571
CZ 16	Measure 1	15	-	$7,889	-	$7,889	-	$0	$49,047	-$41,158	-$41,158
	Measure 2	15	-	$1,809	-	$1,809	-	$0	$13,180	-$11,371	-$11,371
	Measure 3	15	-	$2,187	-	$2,187	-	$0	$19,222	-$17,035	-$17,035

j. Analysis Tools	This proposal contains both mandatory measures and prescriptive measures; only the prescriptive portion of the proposal impacts the performance method calculation. The mandatory portion of the proposal requires photocontrols in the primary daylit zones and skylit zones and is not subject to whole building performance trade-offs. The prescriptive portion of the proposal recommends photocontrols in the secondary daylit zones, which would be subject to whole building performance trade-offs. To estimate savings from daylighting in the primary and secondary daylit zones, we have developed the "Watt Calculation Method" described in Sections 4.1 and 5.1. This method must be incorporated into the Alternative Compliance Method performance approach in software such as EnergyPro, eQuest etc. to enable them to estimate the savings from daylighting in the primary and secondary daylit zones without requiring a geometric model.
k. Relationship to Other Measures	The proposed measures in the Daylighting CASE have a relation to two other measures that are concurrently being proposed for the 2013 Title-23 update. These have a very direct effect on the estimated energy savings and costs associated with the proposed measures. (1) Non-Residential Fenestration CASE: This IOU CASE proposal is recommending a Min VT for glazing along with other fenestration properties updates. This allows the Daylighting CASE to remove many exceptions that ensure savings from daylighting, and simplifies the compliance process by getting rid of multiple exceptions. (2) Non-Residential Controllable Ballasts IOU CASE: This CASE proposal is recommending multi-level ballasts for most nonresidential occupancies. Cost effectiveness of adding multi-level ballasts is shown for this measure in the CASE report, therefore the Daylighting CASE does not consider the additional cost of a multi-level ballasts in its cost effectiveness calculations. This reduces the incremental cost for the daylighting measures as the cost for dimming ballasts is already paid for by the controllable lighting measure.

3. Rationale for Watt Calculation Method

The proposed Watt Calculation Method provides a means of calculating savings from sidelighting, in the primary and secondary daylit zones, which enables a significant simplification of the Title-24 daylighting code.

A repeated concern voiced by stakeholders has been that the current method to show compliance with the daylighting portion of the code is too complicated. This includes mandatory measures in Sections 131(c)2B, and 131(c)2C as well as the prescriptive measures in Section 146(a)2E. Others have echoed this concern to the HMG CASE team such as energy consultants (members of CABEC), architects and educators responsible for teaching the code.

To determine the cause of this concern, the CASE team reviewed the decision process required for the calculation method in the current code. This is shown as a decision tree diagram in Figure 1.

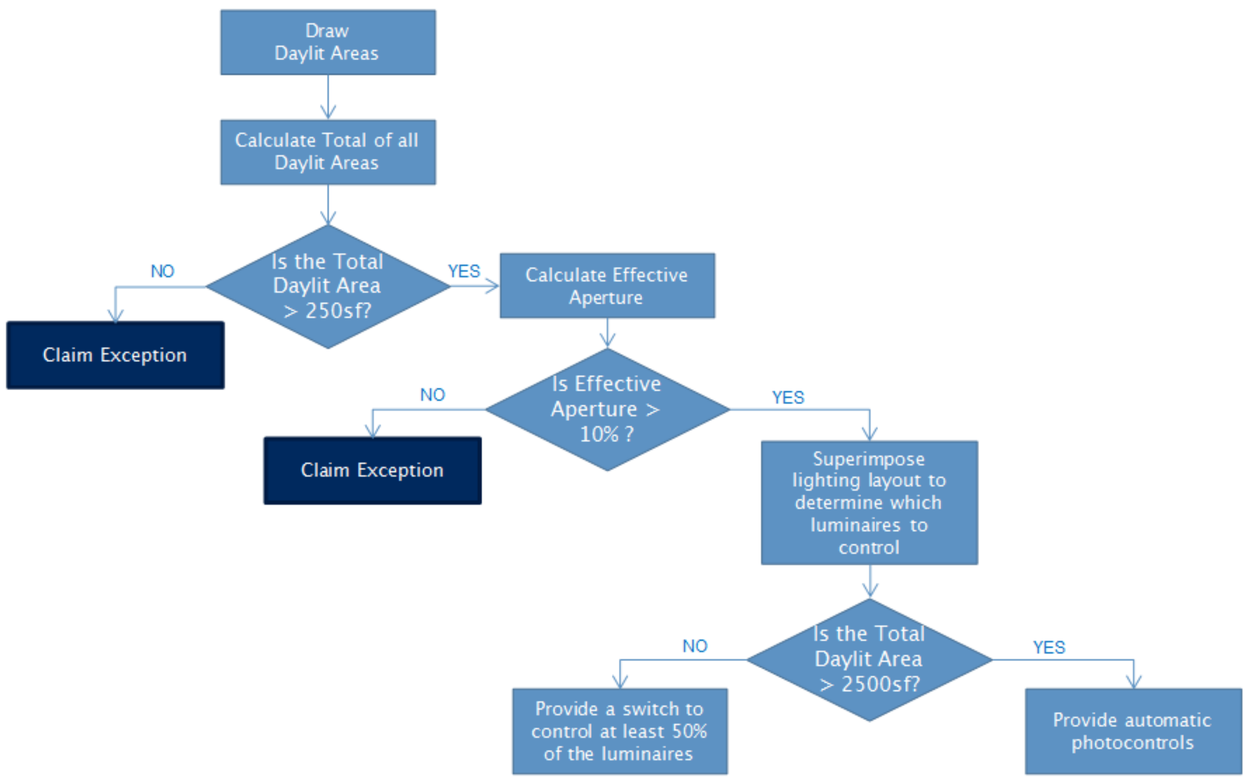


Figure 1: Decision Tree - Current Daylighting Code

The process required to make the decisions for compliance involves:

(a) A graphical process of drawing and then calculating total daylit areas on a plan. The calculation involves accounting for overlapping daylit areas, and truncation due to permanent partitions

(b) Calculation of effective aperture, a function of the total daylit area to determine exception

(c) Superimposing electric lighting layout over the daylit area polygons, which necessitates knowledge of electric lighting layout.

This process can take a considerable amount of time and effort to ensure accuracy. Furthermore, it also requires that the building code official checking for compliance, also spend a considerable amount of time to make sure that all calculations were correctly done and all processes correctly implemented.

An alternate method of compliance described in **Proposal 2** of this CASE report simplifies the process considerably. In this approach, we first do away with the process of calculating daylit areas. Instead, daylit zones are drawn on plans to determine which luminaires to control together in the primary daylit, secondary daylit and skylit zones. Instead of totaling up areas of the daylit zones, total wattage of installed lighting in each zone is calculated. Photocontrols are a mandatory requirement in all primary daylit and skylit zones (Section 131(d)), and a prescriptive requirement in the secondary daylit zones (Section 146(d) and Section 149(b)). Exceptions are determined by total watts of electric lighting controlled in each zone, and by area of glazing, thus doing away with the Effective Aperture calculation and also Power Adjustment Factors (PAFs).

Central to this approach is a calculation procedure or formula that can estimate energy savings by photocontrols in the secondary daylit zone as well as primary daylit zone for the performance approach (Section 141) through the Alternative Calculation Method (ACM). This calculation procedure described in **Proposal 1** is termed the Watt Calculation Method.

4. Methodology

This section describes the methodology that the HMG CASE team followed to determine the code change proposals, collect costs and calculate energy savings and cost effectiveness.

The methodology section is sub-divided into four sections, one for each code change proposal as described below:

1. **Watt Calculation Method:** A proposal to calculate photocontrol savings in primary and secondary daylit zones in sidelit spaces for a daylighting performance approach.
2. **Photocontrols Requirement Threshold:** A proposal to change the threshold for requiring photocontrols in sidelit and toplit spaces in new construction and additions and alterations.
3. **Minimum Skylight Area Requirement:** A proposal to increase the minimum skylight area required for large enclosed spaces, and decrease the minimum space area that triggers the requirement for skylights.
4. **Space Area Threshold for Requiring Skylights:** A proposal to decrease the minimum space area required that triggers the requirement for skylights.
5. **Ceiling Height Threshold for Requiring Skylights:** A proposal that looked at reducing the ceiling height trigger for skylights in large enclosed spaces.
6. **Stakeholder Outreach Process:** A description of the stakeholder outreach process.
7. **Energy Benefits Estimation:** A description of the prototype building and analysis to determine the energy benefits of the proposed code language.

This work was publicly vetted through our stakeholder outreach process, which through in-person meetings, webinars, email correspondence and phone calls, requested and received feedback on the direction of the proposed changes. The stakeholder meeting process is described at the end of the Methodology section.

4.1 Proposal 1: Watt Calculation Method

This section describes the methodology used to develop a new calculation method for determining energy savings from photocontrols in the primary and secondary zones.

The key elements of the methodology are:

- Basic Concept for the Watt Calculation Method
- Dataset Development
- Formula Development Methodology

4.1.1 Basic Concept for the Watt Calculation Method

The concept for a Watt Calculation Method is that given a specific set of inputs that describe a façade design and physical characteristics of a given space, the energy savings from photocontrols in the primary and secondary daylit zones can be calculated using a mathematical formula.

The formula was developed by conducting regression analysis on a set of detailed annual daylighting simulation runs. The simulation runs were done using Dynamic Radiance Approach (Saxena, 2010), a method that allows the use of Radiance[1] for annual daylighting simulations. A diverse dataset of façade design options and physical space characteristics were developed using a process of creating 'template' spaces with various façade designs. This 'façade-templates approach' was developed for the CEC PIER Office Daylighting Potential study and is described in further detail in Section 4.1.2.

4.1.2 Dataset Development

To develop a sufficiently diverse dataset of templates, the project team first identified a range of variables over which the proposed formula was expected to perform. This included an extensive list of variables that were likely to influence daylighting availability in a space. These variables were then combined where possible (eg. the two variables of window area and wall area were combined to form a single variable of window to wall ratio) to form the final list of variables, given in Figure 2 below.

A range of parameters for each variable was then determined based on the variety of façade types found typically in office buildings in California, as documented in a study of the CEUS database in the CEC PIER Office Daylighting Potential report (Saxena, 2011). A total of 432 template-spaces were developed. The list of variables and parameters used to develop the template-spaces are given in Figure 2 below.

Variable	Number of Parameters	Range
Orientation	4	N, S, E, W
Window to Wall Ratio	3	0%, 26%, 52%
Average VLT	3	10%, 40%, 70%
Average Sill Height and Average Head Height	3	0ft/5ft, 2.5ft/7.5ft, 5ft/10ft
Average ceiling heights	2	8', 10'
Furniture	2	Yes/No
Furniture height	3	30", 45", 60"

Figure 2: Simulation Variables and Range of Parameters

[1]Radiance is a reverse ray-tracing based daylighting simulation program. http://radsite.lbl.gov/radiance

Façade-Templates Approach

As mentioned earlier, to develop a sufficiently diverse dataset, we leveraged a process of creating template-spaces of various façade designs, used in the CEC PIER Office Daylighting study (Saxena, 2011). In this method a space 60ft x 40ft in dimension, was modeled with virtual horizontal illuminance "sensors" at 31inches from floor, on a 2ft x 2ft grid across the entire space. One of the two 60ft sides of this template-space had windows, and the template-space could be orientated to face any direction. Various façade design options, or 'façade-templates', were generated for the 60ft side with windows, that represented typical window layouts, window areas as well as sill and head heights. These spaces were then run in Dynamic Radiance for an annual daylighting simulation using California climate zone weather files. This resulted in a sufficiently large and diverse dataset to form the "base" or "training" data for the development of the Watt Calculation Method formula. Figure 3 shows a sketch of a template-space used in this analysis, and below it shows a daylighting autonomy plot from Dynamic Radiance for that template. The metric of daylight autonomy is described in further detail later in this section.

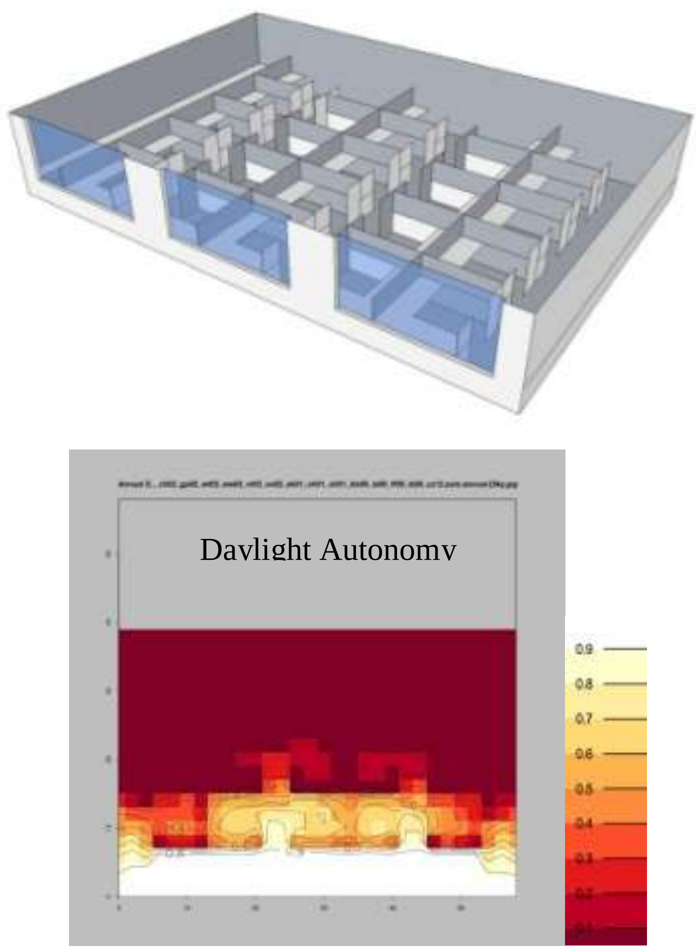


Figure 3: Template Space 60ft x 40ft with 60" Furniture and Daylight Autonomy Plot

Dynamic Radiance simulations provide a highly accurate reverse ray-tracing method of daylighting simulation that accounts for window blinds/shades and their operation by occupants; an important factor that can affect quantity and distribution of daylight in a space. Details about the daylighting simulation parameters used and assumptions for blinds operation are available in the PIER Daylight Metrics (Heschong, 2011) final report. The Dynamic Radiance approach also allows modeling of furniture of different heights inside the template-space. For this and other reasons, Dynamic Radiance was preferred as the simulation method for modeling for this exercise instead of other available software such as DOE2 or Energy Plus.

Simulation Outputs

The output from the Dynamic Radiance simulations of the template-spaces was daylight illuminance values (in lux) for each hour of the year, reported by every virtual sensor in the simulated space. This output (in lux of incident daylight illuminance) was processed into the metric of Daylight Autonomy for each sensor in the space. Daylight Autonomy for each sensor is the percent of occupied hours of the year that the daylight illuminance falling on the sensor meets or exceeds a threshold illuminance level. For all of the evaluations conducted for this study, the threshold illuminance used was 300 lux (~30 foot candles); this value is used because general lighting requirements for most spaces are 30 fc or less. For each simulation run, Daylight Autonomy plots were generated as shown in Figure 3.

Another metric was calculated, that of spatial Daylight Autonomy ($sDA_{50\%}$). This reports the space area (in square feet) that has achieved 50% Daylight Autonomy or more. This is simply counts the number of sensors receiving more than 30 fc more than half of the time (daylight autonomy ≥ 50%) multiplied by the area they are representing (4 square feet when the “sensors” are on a 2 foot by 2 foot grid) and divided by total area to calculate percent $sDA_{50\%}$, (or $\%sDA_{50\%}$).

4.1.3 Formula Development Methodology

The development of the Watt Calculation Method formula was done in two steps.

Step 1 was the development of a formula to predict the $sDA_{50\%}$ metric for a given space using inputs from the user about the physical characteristics of the space and façade.

Step 2 was development of a formula for the estimation of energy savings in the primary and secondary daylit zones using the $sDA_{50\%}$ metric and inputs from the user about the total installed watts in each daylit zones.

For the **first step**, i.e. development of a formula to predict the $sDA_{50\%}$ metric for a given space, the following tasks were performed:

- **Formula type assessment:** The format of the formula was determined and variables identified as the key components of the formula. Through statistical methods, the formula format was tested to determine interaction between variables.
- **Formula coefficient characterization:** Two statistical methods were identified to determine the format of the formula and the different formula coefficients:
  - Linear least square regression method on multiple variables
  - Least square regression on single variable

The linear least square regression method consists of developing the formula in a linear equation with multiple variables which can be functions of chosen variables. Different coefficients of the equation can then be calculated. These coefficients can be transformed to get back to the initial formula based on the chosen variables.

The least square regression on single variable method involves using a regression analysis tool to define the formula for each set of data. This does not require the initial equation to be transformed into a linear equation, and thus has more predictive power for that set of data but is less predictive for a broad range applications. The different coefficients for each data set are reconciled through statistical analysis as well as visual assessment of graphed data.

For the **second step**, i.e. development of a formula for the estimation of energy savings in the primary and secondary daylit zones, the following tasks were performed:

- **Cumulative Spatial Daylight Autonomy curve:** The calculated daylight autonomy values are plotted on a time vs. space curve. The area under this curve gives the theoretical maximum full load hour savings from daylighting in the entire space if simple on/off controls are used. Dimming controls are not directly simulated as no daylight autonomy credit is given for partial daylight below the threshold. However, the space has multiple control zones, where each zone is modeled as 4 square feet, one per virtual sensor.
- **Daylit Zone Savings Estimation:** Applying user input of installed wattage in primary and secondary daylit zones over the cumulative daylight autonomy curve, the estimated energy savings each daylit zone are calculated.

4.2 Proposal 2: Photocontrols Requirement Threshold

This section describes the methodology used to update the minimum daylit area threshold for photocontrols for sidelit and toplit spaces in Sections 131(c)2B and 131(c)2C, for new construction and Section 149(b)2I for alterations to a more aggressive requirement based on updated costs of photocontrols, and updated energy costs compared to the 2008 code change proposal.

The key elements of the methodology were as follows:

- Photocontrols Cost Survey
- Analysis

4.2.1 Photocontrols Cost Survey

The CASE team conducted a market assessment of the purchase price for photosensors and associated equipment (e.g. controllers, dimmers, switches, power packs). In preparation for this data collection effort, the CASE team created a database including a photosensor product list with 30 products from 10 manufacturers. For each manufacturer, the CASE team collected distributor contacts from across California. A sample of these 184 distributors was contacted from six regions of the state (Sacramento, SF Bay Area, LA, Riverside County/Fresno, San Diego and Other). Each distributor was asked to provide the cost for photosensor and associated equipment needed for two sample projects:

1. 800sf sidelit open office area; 250sf daylit area; 4 fixtures controlled

2. 1120sf toplit warehouse space; 896sf daylit area; 14 fixtures controlled

Cost data was broken down into two categories:

(d) Fixed Cost: cost of equipment and labor which is fixed for any size daylit space.

(e) Variable Cost: cost of equipment and labor, which vary by the size of the daylit space.

Both costs were combined to determine the cost of photocontrols for different sizes of daylit spaces.

Labor costs for installations in retrofit projects were collected in a separate survey with Ecology Action, a California based non-profit that installs efficiency upgrades.

4.2.2 Analysis

Cost data from the photocontrols cost survey was used to determine the cost of photocontrols for a range of daylit space sizes. A threshold of daylight sufficiency was then used to determine energy savings at each daylit space size. Daylight sufficiency was measured in terms of daylight autonomy, or percent of time that daylight in the space is equal to or greater than 300 lux of illuminance. This translates to percent hours that a simple on-off photocontrol can turn electric lights off.

Once savings were calculated, benefit-to-cost ratios were generated for each daylit space size to determine a new threshold where photocontrols should be required.

Cost-benefit analysis was also performed on retrofit projects to determine when photocontrols requirements should be triggered on luminaire alterations.

4.3 Proposal 3: Minimum Skylight Area Requirement

This section describes the methodology used to derive a new minimum skylit area requirement for Section 143(c).

The key elements of the methodology were as follows:

- Rooftop Survey
- Analysis

4.3.1 Rooftop Survey

The CASE team conducted a visual survey of building rooftops to determine the existence of typical rooftop obstructions. The CASE team used data collected by the Western Cooling Energy Center (WCEC) and the Cool Ducts CASE team to establish a sample of target buildings to survey. The original data provided by the WCEC included address and lot characteristics, such as building size and end use, as well as information on the presence and area of exposed ducts, for a sample of 500 commercial buildings throughout Climate Zone 12. From this dataset, HMG's CASE team developed a targeted sample of building types likely to be required to have skylights. The targeted building types (as described in the survey data) were general commercial, shopping centers, retail stores, grocery stores, and industrial. The survey does not provide detailed information about the use of each building, but it is expected that these targeted building types could correspond to one or more of the following space types defined in Title 24: auto repair, commercial and industrial storage, exercise center/gymnasium, general commercial and industrial work, grocery sales, grocery store, mall, office, retail merchandise sales, or tenant lease space.

For each of the five target building types, the CASE team surveyed 25% of the original sample (125 buildings), targeting 70 buildings most likely to trigger skylighting requirements if built under current 2008 code (i.e. single story, high ceilinged buildings with enclosed spaces (rooms) over 8,000 square feet, such as big-box retail, industrial factory or warehouses). Final quantities of surveyed buildings are as follows:

	Number of Buildings
General Commercial	36
Shopping Centers	5
Retail Sales	7
Grocery Stores	1
Industrial	21
Total	**70**

Figure 4: Number of Buildings Surveyed

Each of the 70 buildings was visually surveyed for rooftop obstructions using satellite imagery from Bing maps (www.bing.com/maps). Area (square footage) of rooftop obstructions, such as packaged HVAC units was calculated using tools available in Bing maps. Area of exposed ducts was already included in the original data set from WCEC. Because the objective of the survey was to determine the amount of roof space available for skylights, existing skylights were not considered to be rooftop obstructions.

4.3.2 Analysis

Following the rooftop survey, a metric of percent obstructed area was analyzed for the dataset, and based on findings, a new minimum skylight area requirement was recommended. See section 5.3.

4.4 Proposal 4: Space Area Threshold for Requiring Skylights

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

4.4.1 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).

4.5 Proposal 5: Ceiling Height Threshold for Skylight Area Requirement

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

The key elements of the methodology were as follows:

- Cost survey for light wells and new skylight products for dropped ceilings
- Update 2008 Title 24 life cycle cost analysis for skylights with light wells

4.5.1 Cost Survey for Light Wells and New Skylights for Dropped Ceilings

A cost survey was conducted to collect costs from contractors for building light wells for dropped ceilings. These costs were determined in the PG&E 2008 Title 24 Daylighting CASE study (PG&E, 2008b) to be close to $2,000 (labor and materials) for building a single light well on-site. The new survey was intended to determine if the cost of building a light well has changed since the 2008 T-24 study. We collected costs from two contractors with experience in on-site light well fabrication to collect this data.

Since the previous study, new products are now available for spaces with dropped ceilings that can be used instead of traditional skylights with light wells. These products such as Tubular Daylighting Devices (TDDs) and Hybrid TDDs come with pre-assembled, specular, tubular light wells that are well suited for delivering daylight in buildings with dropped ceilings. The cost survey also collected costs for these new products from two of the leading manufacturers.

4.5.2 Update 2008 Title 24 Life Cycle Cost Analysis for Skylights with Light Wells

Cost effectiveness analysis done for the 2008 Title 24 Daylighting CASE work was updated with

(a) New costs for photocontrols, from the survey described in Section 0

(b) New costs for electric and gas energy, and new scalar for life cycle cost analysis

(c) Updated costs for traditional light wells

(d) Updated costs for new skylight products for dropped ceilings

4.6 Stakeholder Outreach Process

All of the main approaches, assumptions and methods of analysis used in this proposal have been presented for review at one of three public Daylighting Stakeholder Meetings.

At each meeting, the utilities' CASE team invited feedback on the proposed language and analysis thus far, and sent out a summary of what was discussed at the meeting, along with a summary of outstanding questions and issues.

A record of the Stakeholder Meeting presentations, summaries and other supporting documents can be found at www.calcodes.com. Stakeholder meetings were held on the following dates and locations:

- First daylighting stakeholder meeting: June 23rd 2010, California Lighting Technology Center, Davis, CA
- Second daylighting stakeholder meeting: December 15th 2010, Webinar event
- Additional stakeholder webinar to review Watt Calculation Method: March 17th 2011, Webinar event

4.7 Energy Benefits Estimation

In this section we have outlined the methodology used to come up with the energy savings estimations and cost effectiveness calculations in items (d) Energy Benefits and (i) Cost Effectiveness, of the Overview table in Section 2.

4.7.1 Prototype Buildings Description

This section describes the prototype buildings used for the energy savings estimation analysis.

Office Building Prototype

This prototype building was used to determine energy savings from code proposal to reduce the wattage threshold for a photocontrols requirement in sidelit spaces. The prototype building, shown in Figure 5 below, is an office building we have found to be typical of California’s office buildings as it provides a mix of private offices, open cubicle office spaces and core non-daylit spaces. Total area of the building (assumed to be single story) is 34,000sf. We identified that as compared to the 2008 code, all spaces adjacent to the façade in this building will trigger the new requirement for photocontrols in the primary daylit zone (mandatory) and secondary daylit zone (prescriptive).

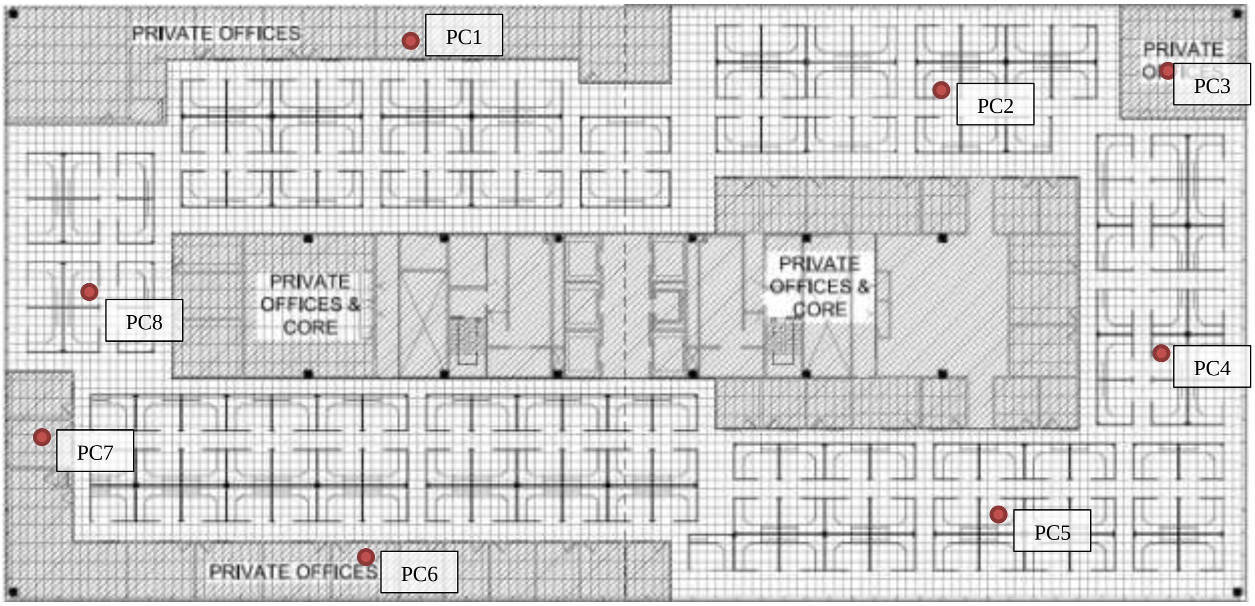


Figure 5: Prototype Office Sidelit Building - Floor Plan showing interior layout

Small Retail Building Prototype

This prototype building was used to determine energy savings from code proposal to reduce the wattage threshold for a photocontrols requirement in toplit spaces. The prototype building, shown in Figure 6 is a small retail store of 5,760 sf area. This open space in the building has 5, 4’x4’ skylights and a 15’ high ceiling height. The ceiling is open so there is no cost for a light well and the effective light well height is 1 foot to account for losses in the skylight curb but no additional light well is modeled. The daylit area calculated using the Title 24-2008 method (shaded dark in the figure) is 2,400 sf, which is below the 2,500 sf daylit area threshold for photocontrols in Title 24-2008. Per the new requirement proposed in this CASE report, this space would trigger the requirements for photocontrols.

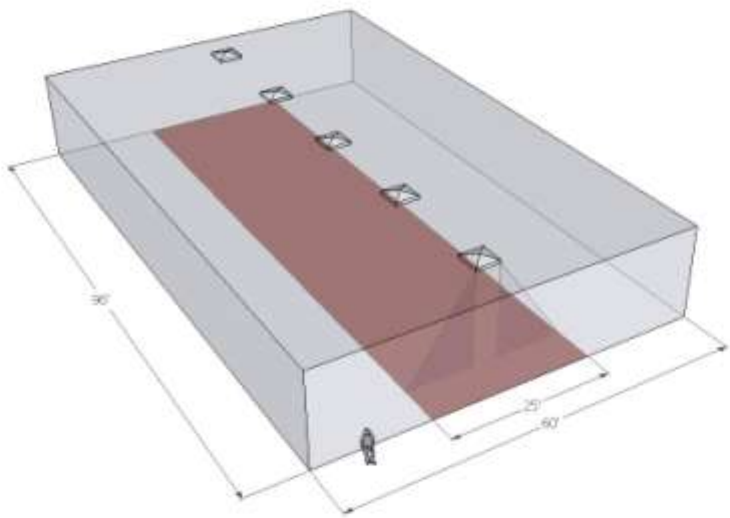


Figure 6: Prototype Small Retail Toplit Building - 2,500 sf of daylit area from toplighting

The prototype building was modeled in SkyCalc™ 3.0 to estimate the energy savings per CA Climate Zone. Figure 7, Figure 8 and Figure 9 provide the assumptions for the SkyCalc™ Model:

SkyCalc Parameter (Small Retail Store Toplit Prototype)	Value
Bldg area	2400 sf
Ceiling height	15 ft
Shelf/rack height	7 ft
Shelf/rack width	8 ft
Aisle width	8 ft
Lighting system	Flourescent
Lighting control	Dimming 5%
Lighting Setpoint	65 fc
SFR	1.39%
Glazing type	Acrylic dome
Glazing layers	Double glazed
Glazing color	Medium White
Visible transmittance	0.49
Solar heat gain coefficient	0.542
Unit U-value (Btu/h-°F-ft2)	0.97
Light well height	1 ft
Air Conditioning	Mech. A/C
Heating System	Gas Furnace

Figure 7: Prototype Small Retail Toplit Building - SkyCalc™ Parameters and Values

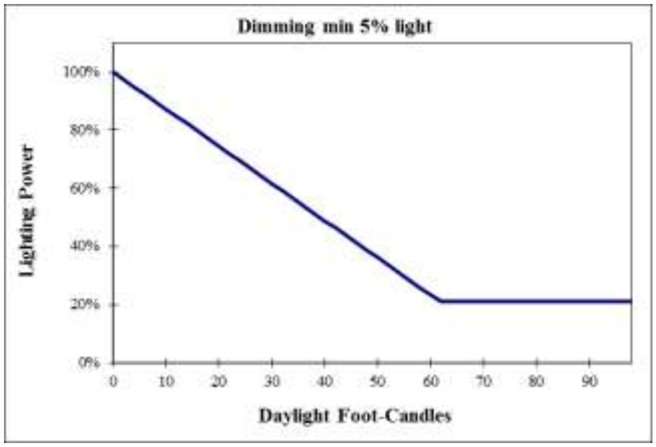


Figure 8: Prototype Small Retail Toplit Building - Lighting Controls - 5% Dimming

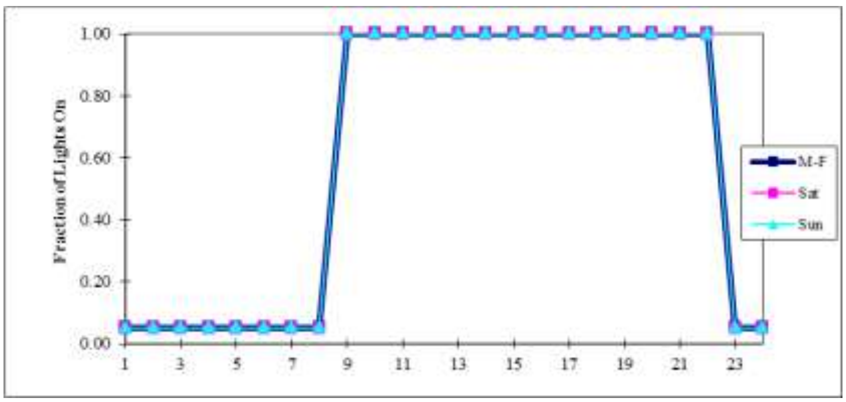


Figure 9: Prototype Small Retail Toplit Building - Lighting Schedule

Large Warehouse and Large Retail Building Prototype

These two prototype buildings were used to determine energy savings from the code change proposal to increase minimum skylit area for large enclosed spaces. The prototype building, shown in Figure 10 is an 8,000 sf space area with a 15 ceiling height. This space would trigger the requirement for skylights with a minimum skylit area of half the floor area, per Title 24-2008. Per the new requirement proposed in this CASE report, this space would trigger the requirements for a minimum skylit area of 3/4th the floor area, shown in dark shading in Figure 10.

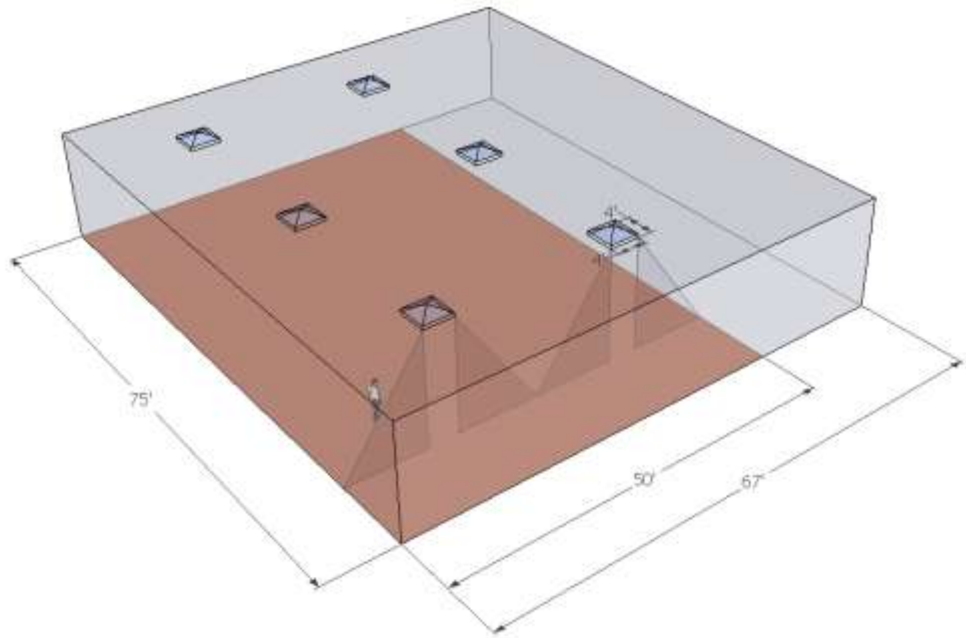


Figure 10: Prototype 5000sf area toplit building - sketch showing daylit areas in dark color

The two prototype buildings and their assumptions are described in detail in the 2008 CASE report (PG&E, 2008b).

4.8 Statewide Savings Estimates

The statewide energy savings associated with the proposed measures will be calculated by multiplying the energy savings per square foot with the statewide estimate of new construction in 2014. Details on the method and data source of the nonresidential construction forecast are in Appendix D.

5. Analysis and Results

This section describes the analysis done for each of the four proposals described in the Methodology section and the associated results.

5.1 Proposal 1: Watt Calculation Method

This section describes the analysis steps undertaken to develop a formula for estimating energy savings in primary and secondary daylit zones, and a method to apply the calculation results to daylit spaces. The key sub-sections of this section are as follows:

- Formula Inputs
- Formula Development: Step 1 - Development of a Formula to Predict *sDA50%*
- Formula Development: Step 2 - Energy Savings Estimation in Primary and Secondary Daylit Zones
- Application of Formula for Multiple Façade Orientation

5.1.1 Formula Inputs

The following are the inputs that are required for the Watt Calculation Method to determine energy savings in the secondary daylit zone.

	Input	Units	Calculated Per
1	Space Area	Square feet	Space
2	Lighting Power Density	Watts/square feet	
3	Ceiling Height	Feet	
4	Expected Furniture Height	Classrooms (No partitions above 30”) or Office/Retail (Up to 60” partitions or higher)	
5	Climate Zone	CZ 1 through CZ 16	
6	Installed Lighting Wattage in Primary Daylit Zone	Watts	
7	Installed Lighting Wattage in Secondary Daylit Zone	Watts	
8	Façade length	Feet	Façade
9	Façade orientation	South or Non-South. South defined as all angles within 45 degrees of magnetic South	
10	Window VLT	Percent (area weighted average)	
11	Net Window to wall Ratio	Percent	
12	Window sill ht.	Feet (area weighted average)	
13	Window head ht.	Feet (area weighted average)	

Figure 11: Watt Calculation Method Inputs Table

Using the above inputs we first developed two metrics that were likely to have a direct correlation with the daylight and its distribution in a sidelit space. These two metrics were **‘Effective Aperture’**, and **‘Window Location Coefficient’**.

Effective Aperture (EA)

Effective Aperture (EA) is defined as in the ‘classic’ definition of the term shown in Equation 2. EA is calculated for each façade orientation as shown below:

$$EA = \frac{\boldsymbol{Glazing\ Area}}{\boldsymbol{Net\ Wall\ Area}} \times \boldsymbol{Visible\ Transmittance}$$

Equation 2

Where:

Glazing Area: Total of area of all windows in a given orientation

Net Wall Area: Total area of wall in a given orientation, from finished floor level to ceiling height where the ceiling meets the wall. (Note that this is different from Gross Wall Area which is the total wall area including plenum)

Visible Transmittance: Area weighted average visible transmittance of all windows in a given orientation.

This form of the equation (also known as the 'classic' EA definition) differs from the current Title 24 form of the Effective Aperture definition in that the Title 24 definition uses daylit area in the denominator instead of wall area. The change from classic EA was made in the Title 24 definition because the desired metric was not the average amount of daylight entering the room, but the amount of daylight entering the daylit area. In the Daylit area Calculation Method, the metric of interest is now the amount of daylight entering the room, as the new formula calculates minimum daylit area in the room. Here the percentage is relative to the total space area.

This choice of the 'classic' EA definition helps alleviate some of the confusion with the EA term that has been a source of confusion, and perceived complexity with the daylighting code. Note we are not calling the [Glazing Area] / [Net wall area] the "Window to Wall Ratio" as this would create confusion with a pre-existing window to wall ratio definition. For the evaluation of allowed window area, Window Wall Ratio (WWR) is defined as "the ratio of the window area to the gross exterior wall area"[2]. Including "net window to wall ratio" into the definition of Effective Aperture would re-introduce the confusion around WWR as was the case in pre-2008 versions of the code which used this "classic" definition of EA. So we are not proposing using the concept of "net WWR" in the effective aperture equation or other definitions.

Window Location Coefficient (WLC)

Window Location Coefficient is defined as a measure of the vertical placement of a window on a wall. WLC is calculated for each façade orientation as shown below:

$$WLC = \frac{2 \times Average\ Sill\ Height + Average\ Window\ Height}{Ceiling\ Height}$$

Equation 3

[2] Section §101 – Definitions and Rules of Construction.

Where:

Average Sill Height: Area weighted average sill height of all windows in a given orientation

Average Window Height: Area weighted average height (sill to head) of all windows in a given orientation

Ceiling Height: Average ceiling height at the point where the ceiling meets the wall

A thin window placed at the bottom of the wall with sill height = 0ft will have a low WLC, close to 0. On the other hand, a thin window placed at the top of a wall with head height same a ceiling height will have a high WLC, close to 2. WLC will be 1 for a window placed at the center of a wall.

The formula was derived keeping in mind that a window placed higher on a wall will provide better daylight coverage than a window placed lower. Equation 3 was selected from a set of multiple equations, each describing the vertical location of the window based on the window vertical dimension, head height, sill height, and ceiling height including.

- $\frac{\text{Sill Height}}{\text{Window Head Height} - \text{Ceiling Height}}$
- $\frac{\text{Sill Height}}{\text{Ceiling Height}}$
- $\frac{\text{Sill Height}}{\text{Ceiling Height} - \text{Sill Height}}$
- $\frac{\text{Sill Height}}{\text{Head Height}}$

We analyzed each of them in terms of relation with daylight coverage from simulation data and looked for the closest fit. Equation 3 was chosen not only because it had the best fit, but also because it provides a finite range of 0 to 2 with WLC = 1 (or neutral) for a window placed in the center of a wall.

5.1.2 Formula Development: Step 1 - Development of a Formula to Predict $sDA_{50\%}$

As described in section 4.1.3, the development of the Watt Calculation Method formula was done in two steps. The first step was development of a formula to predict the $sDA_{50\%}$. Terms used in this section are described below:

$sDA_{50\%}$ is the space area (in square feet) that achieves 50% Daylight Autonomy or more.

$\%sDA_{50\%}$ is the percent of space area (in %) that achieves 50% Daylight Autonomy or more

Daylight Autonomy is the percent of occupied hours of the year that the sensor achieves a threshold illuminance level from daylighting set at 300 lux (~30 foot candles)

Formula Type Assessment

The first task was to determine the shape of the formula. As described in Section 4.1.2, the formula was developed using template-spaces with a single façade orientation with glazing, and the results added together for more than one façade orientation. This is because our pilot runs showed that overlapped daylighting from two adjacent facades result in more or less the same area with 50% Daylight Autonomy, as when daylight from the two facades are calculated separately and added together (See Section5.1.4). A formula was thus developed to be used for one façade orientation at a time, summing up the result from multiple orientations for a space with more than one façade orientation.

Five variables were identified as key components of the formula:

- **Effective Aperture:** A measure of how much daylight is available from a façade. EA is a value that ranges from 0% for a wall with no windows to 100% for a theoretically fully glazed façade with 100% VT glass. Calculation described in Section 5.1.1
- **Window Location Coefficient:** A measure of the vertical placement of the windows on a façade. WLC values range from 0 to 2. Calculation described in Section 5.1.1
- **Orientation:** Orientation of the façade, as South or Non-South. South is defined as all angles in 45 degrees of magnetic South.
- **Expected Furniture Height:** Furniture layout and partition heights were categorized in two simple categories which could be applied by space activity type, namely
  - ***30" furniture heights***: Spaces like classrooms will have desks at about 30" work plane level, but no partitions above that height
  - ***Up to 60" or higher partition heights***: Spaces like offices and retail will have partitions or stacks up to 60" or higher.
- **Climate Zone:** Title 24 California Climate Zones.

We postulated that the effect of furniture type, orientation and climate zones could be accounted for by simple coefficients, modulating the core formula. The core formula itself would be the product of a function of effective aperture and a function of the window location coefficient. The five variables were all assumed to be independent, i.e. interactive effects between these variables would be minimal or null. This assumption was later tested and found to be correct. Equation 4 below gives the basic form of the formula. The formula predicts $sDA_{50\%}$, or space area in sf that will have daylight autonomy of 50% or more.

$$sDA_{50\%} = C1_{orientation} \times C2_{furniture\ ht} \times C3_{cz} \times f_1(EA) \times f_2(WLC) \times Facade\ Length$$

Equation 4

Where:

$C1_{orientation}$ = Value looked up from a table for orientation, from Figure 14

$C2_{furniture\ ht}$ = Value looked up from a table for appropriate furniture height, from Figure 14

$C3_{cz}$ = Value looked up from a table for climate zone, from Figure 14

$f_1(EA)$ = A function of effective aperture, from Equation 5

$f_2(WLC)$ = A function of window location coefficient, from Equation 6

Façade Length = Total length of façade in a given orientation, in ft

To test our assumptions about the shape of the formula, we analyzed our façade template dataset both statistically and graphically.

If two variables are independent, plotting series of curves of one variable (say WLC) for different values of the other (say EA), will either return parallel curves if they can be described by affine or polynomial equation, or curves with different slopes if their descriptive function is linear. In addition to validating these assumptions, the graphical analysis provided an understanding of the specific formulation of effective aperture function and the window location coefficient function.

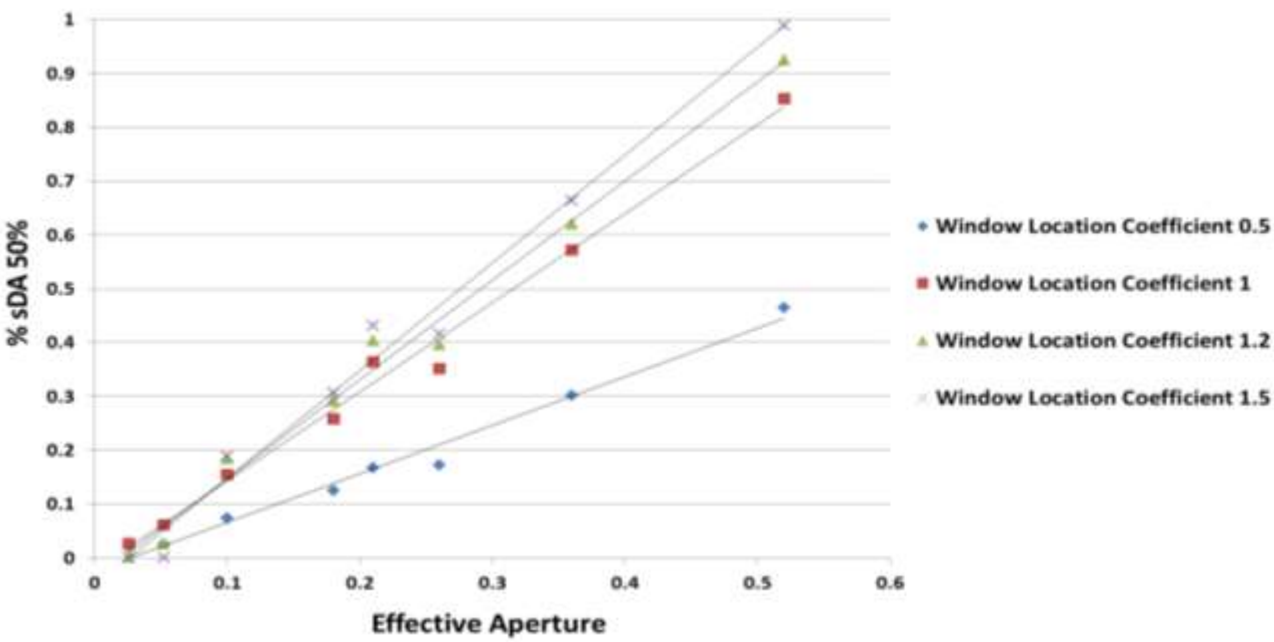


Figure 12: Percent $sDA_{50\%}$ vs. Effective Aperture for Different Window Location Coefficients

Figure 12 shows the curves for different window location coefficients as a function of effective apertures. Here when the window location coefficient value is fixed, the percent $sDA_{50\%}$ varies as an affine function of effective aperture.

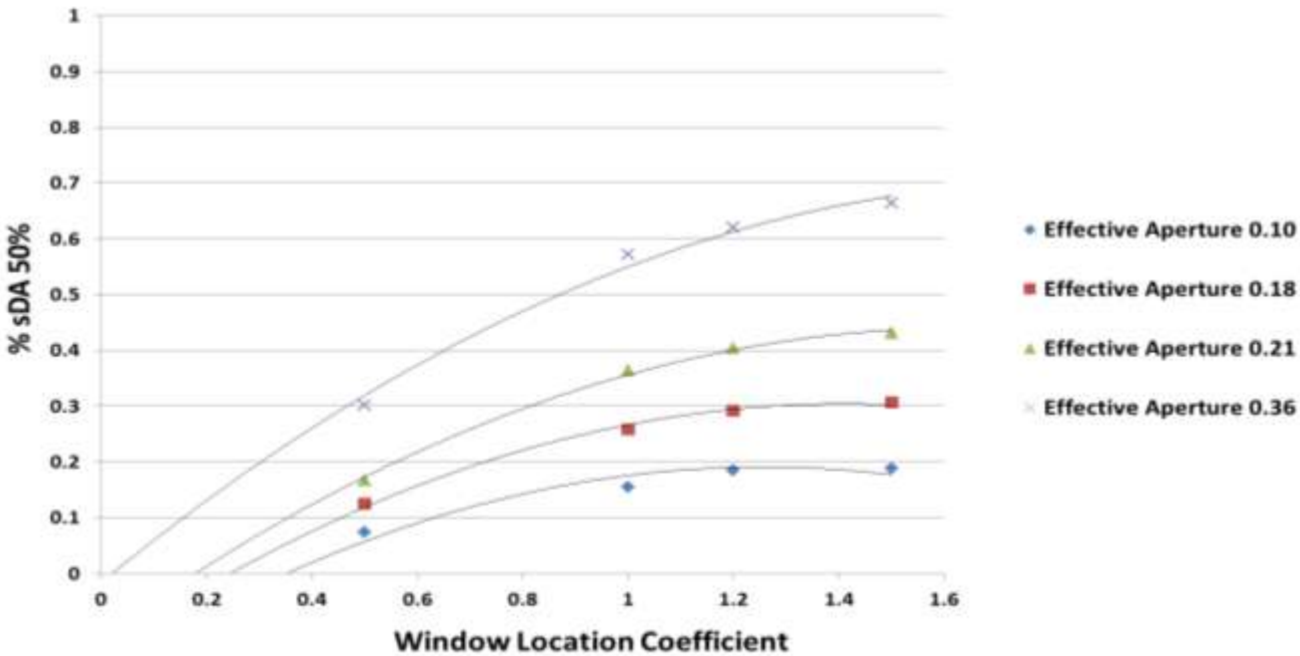


Figure 13: Percent *sDA*$_{50\%}$ vs. Location Coefficient for Different Effective Aperture Values

Similarly Figure 13 shows the curves for different effective apertures as a function of window location coefficients. The curves follow a polynomial equation, based on a least square regression analysis.

Based on this observation, the effective aperture function and the window location coefficient function have the following shape:

$$f_1\ EA\ = a * EA + b$$

Equation 5

$$f_2\ WLC\ = c * LC^2 + d * LC + e$$

Equation 6

Where

EA = Effective aperture calculated using Equation 2

WLC = Window location coefficient calculated using Equation 3

a, b, c, d, e = Coefficients values looked up from table in Figure 14

The same formula format is applied to spaces with more than one façade orientation with windows. As described in Section 5.1.4, two adjacent facades will result in more or less the same *sDA*$_{50\%}$, as when daylight from the two facades are calculated separately and added together. Thus, for spaces with multiple façade orientations, *sDA*$_{50\%}$ can be expressed as the sum of the *sDA*$_{50\%}$ calculated for each façade orientation separately.

$$sDA_{50\%} = \sum_{Facade} C1_{orientation} \times C2_{furniture\ ht} \times C3_{cz} \times f_1(EA) \times f_2(WLC) \times Facade\ Length$$

Equation 7

Where:

***C1**_{orientation}* = Value looked up from a table for orientation, from Figure 14

***C2**_{furniture ht}* = Value looked up from a table for appropriate furniture height, from Figure 14

***C3**_{cz}* = Value looked up from a table for climate zone, from Figure 14

f_1(EA) = A function of effective aperture, from Equation 5

f_2(WLC) = A function of window location coefficient, from Equation 6

Façade Length = Total length of façade in a given orientation, in ft

Formula Coefficient Characterization

To determine the value of the $C1_{orientation}$, $C2_{furniture\ ht}$ and $C3_{cz}$ coefficients, as well as the effective aperture and window location coefficient function coefficients (*a*,*b*,*c*,*d* and *e*) two separate approaches were evaluated:

- Linear least square regression method on multiple variables
- Least square regression on single variable

In the first approach, the formula is developed into a linear equation with multiple variables.

$$sDA_{50\%}/facade\ length = C1 \times C2 \times C3 \times (a * EA + b) \times (c * WLC^2 + d * WLC + e)$$

$$\begin{aligned} sDA_{50\%}/facade\ length &= C1 \times C2 \times C3 \\ &\times (a * c * EA * WLC^2 + a * d * EA * WLC + a * e * EA + b * c * WLC^2 + b * d * WLC + b * e) \end{aligned}$$

It can be rewritten as

$$sDA_{50\%}/facade\ length = A * EA * WLC^2 + B * EA * WLC + C * EA + D * WLC^2 + E * WLC + F$$

Where $A = C1 * C2 * C3 * a * c$

$B = C1 * C2 * C3 * a * d$

$C = C1 * C2 * C3 * a * e$

$D = C1 * C2 * C3 * b * c$

$E = C1 * C2 * C3 * b * d$

$F = C1 * C2 * C3 * b * e$

This linear equation has five variables namely *EA, WLC, WLC^2, EA * WLC, and EA * WLC^2*.

A linear regression analysis can determine each A, B, C, D, E, F coefficients from which each a, b, c, d, e can be evaluated. The $C1_{orientation}$, $C2_{furniture\ ht}$ and $C3_{cz}$ coefficients can be found by using the data with exactly the same value for each parameter but varying one parameter at a time.

In the second approach, we performed regression analyses on the dataset to define a set of location coefficient functions for different effective apertures for each orientation. Further regression analyses were carried out on this pool of location coefficient functions to determine a set of effective aperture functions. This exercise enabled us to define each location coefficient and effective aperture function coefficients for each orientation.

We then defined orientation coefficients (*C1*) by setting one orientation as the origin and assessing the others as the average of the ratio of the two orientation coefficients.

We developed the furniture height coefficients (*C2*) by dividing each data point with specific furniture type by the same data point with no furniture (same effective aperture, location coefficient, orientation, climate zone but different furniture height) calculated by the formula previously generated. We took the average on these ratios. The same method was used to define the climate zone coefficients (*C3*).

When we applied both approaches to the data set, we found that the accuracy of both approaches was very similar. The first approach turned out to be very sensitive to the dataset, and was delivering different coefficients (a, b, c, d, e) for each orientation. The second approach had the advantage of reducing the number of coefficients while maintaining accuracy. It also simplified the shape of the formula. The second approach was adopted to evaluate the different coefficients.

Because the South orientation has very different daylight availability, we couldn't achieve a good fit for all orientations using a single set of coefficients. We hence developed two sets of coefficients, one fitting the North, East and West orientations, and another one fitting South.

The sidelighting coefficients for each orientation are summarized in Figure 14 below.

Coefficients		South	North, East, West
a		7.6	1.86
b		0.27	0
c		-0.07	-0.34
d		0.21	1.04
e		0.02	-0.13
C1		40	60
C2	Classrooms (30" or less furniture ht.)	0.8	0.8
	Office, Retail (Up to 60" or higher furniture ht.)	0.56	0.46
C3	Climate Zone 01	0.81	
	Climate Zone 02	0.99	
	Climate Zone 03	0.97	
	Climate Zone 04	1.02	
	Climate Zone 05	1.04	
	Climate Zone 06	1.00	
	Climate Zone 07	1.03	
	Climate Zone 08	1.03	
	Climate Zone 09	1.05	
	Climate Zone 10	1.06	
	Climate Zone 11	1.00	
	Climate Zone 12	1.00	
	Climate Zone 13	1.01	
	Climate Zone 14	1.13	
	Climate Zone 15	1.10	
	Climate Zone 16	1.03	

Figure 14 Sidelighting Formula Coefficients

Regression Equation Validation

To test this concept we applied the regression equation to calculate *%sDA*$_{50\%}$ to 104 different spaces. These spaces included a mix of different space dimensions, single and multiple orientations, non-rectilinear spaces, asymmetrical window layouts, different window to wall ratios and all four cardinal directions (North, South, East and West). This exercise was conducted to test if the regression equation worked for spaces that were sufficiency different from the façade-template used to develop the regression equation.

%sDA$_{50\%}$ was first calculated using Equation 7 for all 104 spaces. This was then compared to *%sDA*$_{50\%}$ results from annual Radiance daylighting simulations of each of these spaces and a percent error was calculated. Detailed results of this comparison are given Appendix B.

The average percent error was -12%. The negative sign indicates that on average, the regression equation under-predicted the results by 12% as compared to the simulations. The maximum percent error was 13% for a shallow 60' wide by 10' deep space. The minimum error -51% for a non-rectilinear space shaped as an 'L' with windows on four adjacent walls. Overall, we found that the equation was doing a sufficiently accurate job of predicting *%sDA*$_{50\%}$ for a vast majority of spaces expected to be encountered, and equation error's on the side of being conservative by under-predicting the result.

We also plotted the simulated and predicted value of *%sDA*$_{50\%}$, for each of the 104 spaces in the study as shown in Figure 15. Most values, as seen in Figure 15 are on, or very close to the 45deg line shown in dotted green line. The cases where the results deviate from the line are mostly under-predictions of the *%sDA*$_{50\%}$ value and are limited to specific cases such as L-shaped spaces and spaces with windows in 4 orientations. A linear straight trend line with a 0 constant across the data had a slope of 0.84 and an r^2 of 0.851.

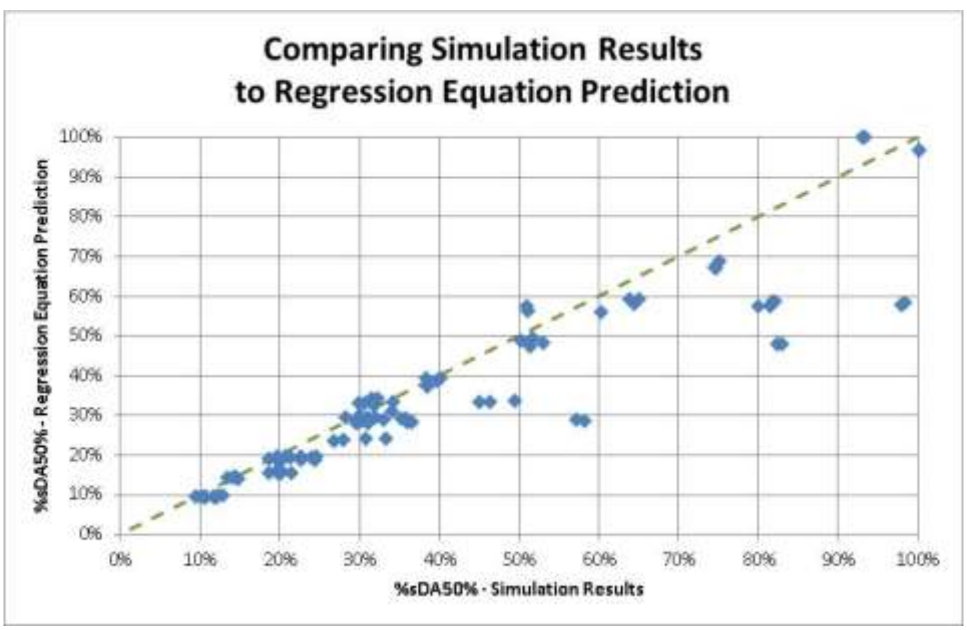


Figure 15: Comparing Simulation Results to Regression Equation Predictions

Our conclusion from this exercise was that the regression based equation used in the Watt Calculation Method to predict $\%sDA_{50\%}$ was estimating its value fairly closely to the simulation results in most space and façade geometries within acceptable margins of error for most cases. The error was typically on the side of underestimation.

5.1.3 Formula Development: Step 2 - Energy Savings Estimation in Primary and Secondary Daylit Zones

As described in section 4.1.3, the development of the Watt Calculation Method formula was done in two steps. The second step was energy savings estimation in the primary and secondary zones. Terms used in this section are described below:

$sDA_{50\%}$ is the space area (in square feet) that achieves 50% Daylight Autonomy or more.

$\%sDA_{50\%}$ is the percent of space area (in %) that achieves 50% Daylight Autonomy or more

Daylight Autonomy is the percent of occupied hours of the year that the modeled sensor receives at least 300 lux (~30 foot candles)

PDZarea is the primary daylit zone area (in square feet). Here primary daylit zone is as calculated by the method described in Title 24-2013.

% PDZarea is the percent of space area (in %) that is primary daylit zone. Here primary daylit zone is as calculated by the method described in Title 24-2013.

SDZarea is the secondary daylit zone area (in square feet). Here secondary daylit zone is as calculated by the method described in Title 24-2013.

% SDZarea is the percent of space area (in %) that is secondary daylit zone. Here secondary daylit zone is as calculated by the method described in Title 24-2013.

PDZsavings is the savings estimated for the primary daylit zone.

SDZsavings is the savings estimated for the secondary daylit zone

Cumulative Spatial Daylight Autonomy Curve

Daylighting energy savings that can be achieved in a space is best understood by plotting a curve representing the Daylight Autonomy (percent time) on y-axis, and space area (percent space) on x-axis. This curve called a 'Cumulative sDA Curve' shows how much space area (read on the x-axis) is covered by a minimum threshold of daylight autonomy (read on the y-axis). Figure 16 shows an example of a cumulative sDA Curve. The blue arrow on the figure shows percent area (31%) with at least 50% DA ($\%sDA_{50\%}$). Where:

$$\%sDA_{50\%} = \frac{sDA_{50\%}}{Space\ Area}$$

Equation 8

Where:

$sDA_{50\%}$: is area that achieves 50% Daylight Autonomy or more, calculated using Equation 7

Space Area: is the area of the space

From the cumulative sDA curve, the following can be determined:

- The entire area under the curve represents total annual energy savings possible due to daylighting in the entire space from a theoretically perfect on/off daylight harvesting system with a 300lux set point and control zones for every 4 square feet.
- The area under the curve, up to the 31% mark on the x-axis (shaded in blue) represents the total annual energy savings possible from a theoretically perfect on/off daylight harvesting system with a 300lux set point and control zones for every 4 square feet, in the area with 50% daylight autonomy.
- The rectangular area under the horizontal red line at 50% daylight autonomy and vertical red line at 31% space area represents total annual daylight energy savings from a simple on/off photocontrol system with a 300 lux set point and a single control zone, in the area with 50% daylight autonomy.

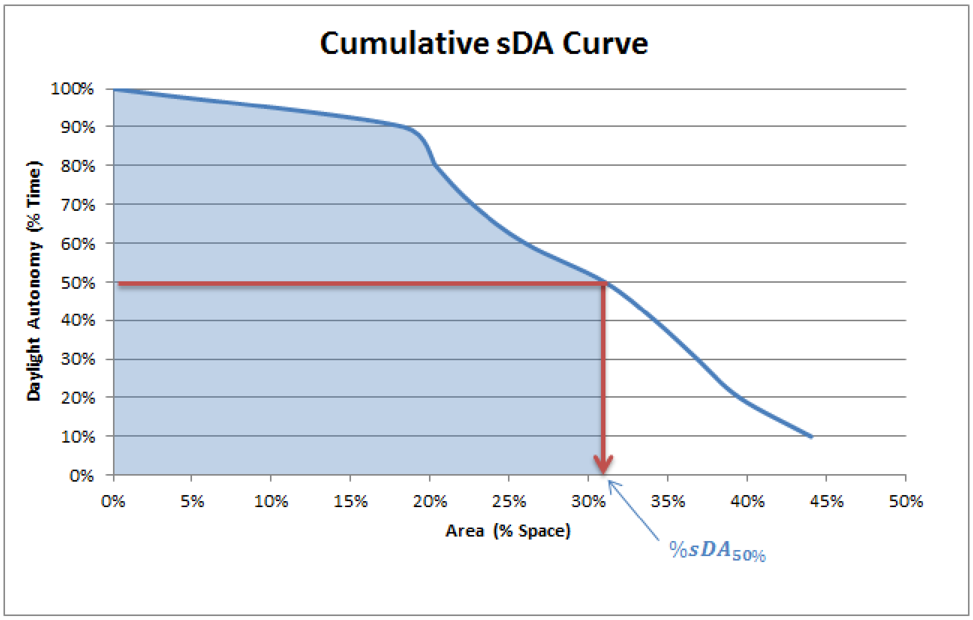


Figure 16: Example of a Cumulative sDA Curve

On this curve, the percent primary daylit zone areas (*%PDZarea)* and secondary daylit zone areas (*%PDZarea +%SDZarea*) can be indicated on the x-axis as shown in Figure 17 below. In this example the primary sidelit area is 10% of the room area and the secondary sidelit area is another 10% of the room area so that the combined primary and secondary sidelit area add up to 20% of the room area. Implicit is this methodology is that the primary sidelit area will have higher daylight autonomy than any other portion of the room and that after the primary sidelit area the secondary sidelit area will have higher levels of daylight autonomy than the rest of the room. The darkest part of the primary zone must limit the extent that electric lights can be dimmed so that all areas of the primary zone have sufficient combined electric light and daylight. Thus the daylight autonomy at 10% of space area is representative of the electric lighting savings that can be expected in the primary daylit zone, similarly the daylight autonomy at 20% of space area is representative of savings in the secondary sidelit zone.

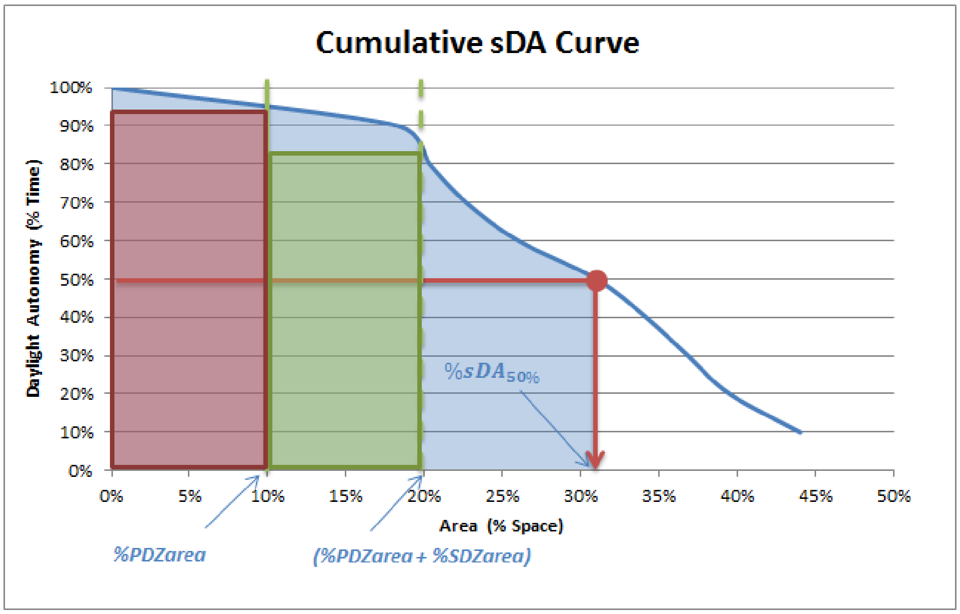


Figure 17: Cumulative sDA Curve with %PDZarea and %SDZarea

Extending the *(%PDZarea)* and *(%PDZarea + %SDZarea)* points on the x-axis vertically, we draw two rectangular areas. The area shaded in red, bound by the extended vertical line on the *(%PDZarea)* on one side, and y-axis on the other side, and a straight horizontal line from the point where the *(%PDZarea)* line hits the cumulative sDA curve on top represents the energy savings in the primary daylit zone. Similarly the area shaded in green in Figure 17 represents energy savings in the secondary daylit zone:

$$PDZarea = \frac{Installed\ Watts\ in\ the\ Primary\ Daylit\ Zone}{LPD}$$

Equation 9

$$\%PDZarea = \frac{PDZarea}{Space\ Area}$$

Equation 10

$$SDZarea = \frac{Installed\ Watts\ in\ the\ Seconday\ Daylit\ Zone}{LPD}$$

Equation 11

$$\%SDZarea = \frac{SDZarea}{Space\ Area}$$

Equation 12

Primary and Secondary Daylit Zone Savings Estimation

Using the formula to calculate $sDA_{50\%}$, one point on the cumulative sDA curve ($\%sDA_{50\%}$,50%) can be plotted, shown as a red dot on in Figure 18. From that point, a straight line, shown as the solid black line, to the (0%,100%) point can be drawn. This line is a simplified, but close approximation of the cumulative sDA curve up to the $sDA_{50\%}$ point. The equation for this solid black line can be written as:

$$y = -\ \frac{0.5}{\%sDA_{50\%}}\ x + 1$$

Equation 13

Where:

$\%sDA_{50\%}$: is area that achieves 50% Daylight Autonomy or more, calculated using Equation 8

Similarly a straight line from the ($sDA_{50\%}$,50%) point to the (0,100%) point, shown in dotted gray line in Figure 18 can be drawn. However this line is not a very close representation of the cumulative sDA curve. Depending on the characteristics of the cumulative sDA curve, this line is likely to over predict the value of $sDA_{50\%}$,. In the example shown in Figure 18, the dotted line diverges from the cumulative sDA curve line as the x-axis values increase. A closer representation of the curve is likely for a line that goes from the ($sDA_{50\%}$,50%) point to the mid-point between $\%sDA_{50\%}$ and 100% on the x-axis or the ($\frac{sDA_{50\%}+1}{2}$,0) point. This line is shown as the dotted black line. This dotted line gives a fairly close representation of the cumulative sDA curve for x-axis values close to the $\%sDA_{50\%}$ point. The equation for this dotted black line can be written as:

$$y = -\ \frac{1}{1 - \%sDA_{50\%}}\ x + \ \frac{1 + \%sDA_{50\%}}{1 - \%sDA_{50\%}}\ \times 0.5$$

Equation 14

Where:

$\%sDA_{50\%}$: is area that achieves 50% Daylight Autonomy or more, calculated using Equation 8

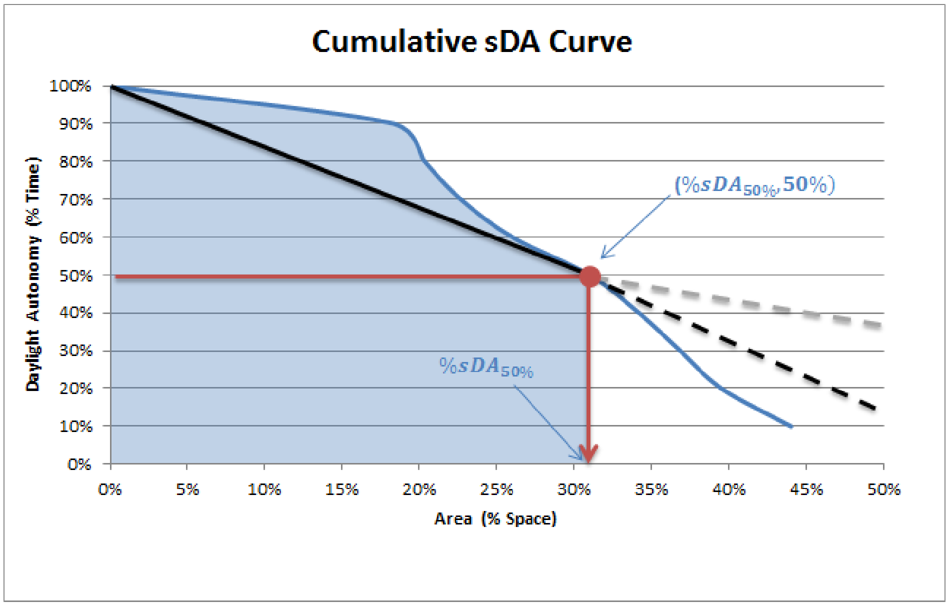


Figure 18: Estimating *PDZsavings* and *SDZsavings* from cumulative sDA curve

There are three possible positions for the *%PDZarea* and *%SDZarea* points on the x-axis in relation to the $\%sDA_{50\%}$ point.

Case 1: (*%PDZarea*) < (*%PDZarea* +*%SDZarea*) < $\%sDA_{50\%}$

Case 2: (*%PDZarea*) < $\%sDA_{50\%}$ < (*%PDZarea* +*%SDZarea*)

Case 3: $\%sDA_{50\%}$ < (*%PDZarea*) < (*%PDZarea* +*%SDZarea*)

In **Case 1**, shown in Figure 19 below, the points on the x-axis representing (*%PDZarea)* and *(%PDZarea + %SDZarea)* are to the left of the $\%sDA_{50\%}$ point.

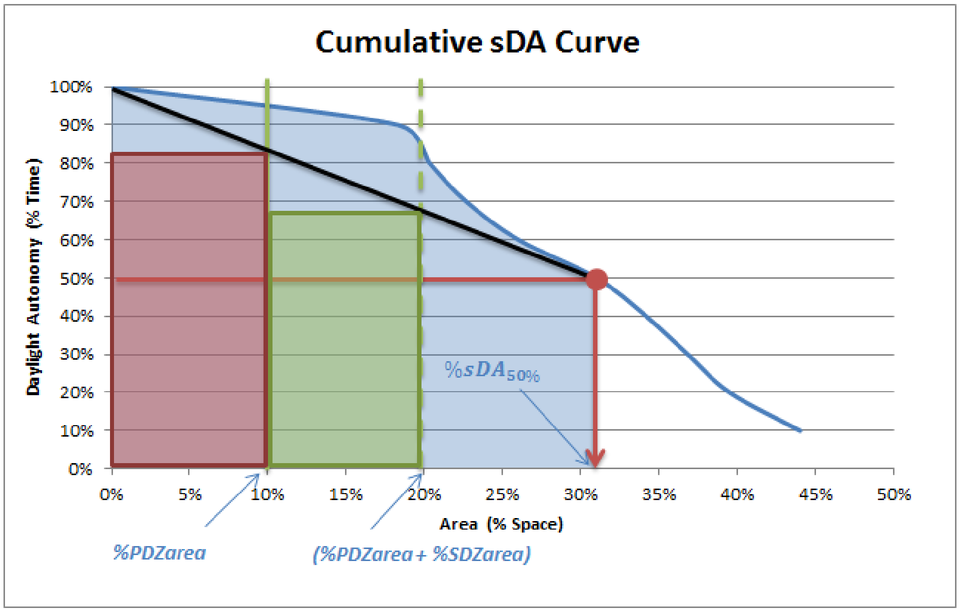


Figure 19: Case 1: (*%PDZarea*) < (*%PDZarea + %SDZarea*) < *%sDA50%*

The energy savings in the Primary Daylit Zone (*PDZsavings*) can be calculated as follows:

$$PDZsavings = \%PDZarea \times -\frac{0.5}{\%sDA_{50\%}} \times \%PDZarea + 1 \times LPD \times Operating\ Hours \times Space\ Area\ /\ 1000$$

Equation 15

The energy savings in the Secondary Daylit Zone (S*DZsavings*) can be calculated as follows:

$$SDZsavings = \%SDZarea \times -\frac{0.5}{\%sDA_{50\%}} \times \%PDZarea + \%SDZarea + 1 \times LPD \times Operating\ Hours \times Space\ Area\ /\ 1000$$

Equation 16

Where:

PDZsavings: Annual energy savings in the primary zone (kWh)

%PDZarea: Percent primary zone daylit area calculated using Equation 10

SDZsavings: Annual energy savings in the secondary zone (kWh)

%SDZarea: Percent secondary zone daylit area calculated using Equation 12

$\%sDA_{50\%}$: is percent area that achieves 50% Daylight Autonomy or more, calculated using Equation 8

OperatingHours: Yearly hours of operation of general lighting in the space (hrs)

LPD: Lighting power density of gernenal lighting in the space (W/sf)

Comparing Figure 18 and Figure 19, it can be seen that the savings estimated by Equation 15 and Equation 16 using the straight line approximation, are a close representation of the savings under the cumulative sDA curve. The straight line approximation results in a slight underestimation of the savings in this case.

In **Case 2**, shown in Figure 20 below, the point on the x-axis representing (*%PDZarea)* is to the left and the point representing *(%PDZarea + %SDZarea)* is to the right of $\%sDA_{50\%}$ point.

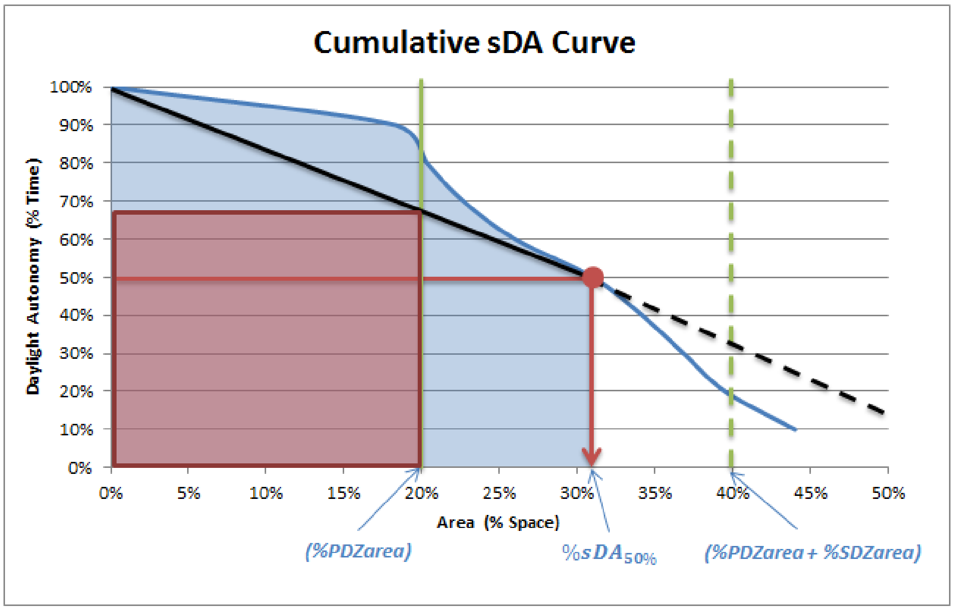


Figure 20: Case 2: (*%PDZarea*) < *%sDA50%* < (*%PDZarea* + *%SDZarea*)

The energy savings in the Primary Daylit Zone (*PDZsavings*) can be calculated as done in Case1:

$$PDZsavings = \%PDZarea \times \; - \frac{0.5}{\%sDA_{50\%}} \times \%PDZarea \; + 1 \; \times LPD \times Operating\ Hours$$
$$\times\, Space\ Area\, /\ 1000$$

Equation 17

Where:

PDZsavings: Annual energy savings in the primary zone (kWh)

%PDZarea: Percent primary zone daylit area calculated using Equation 10

$\%sDA_{50\%}$: is percent area that achieves 50% Daylight Autonomy or more, calculated using Equation 8

OperatingHours: Yearly hours of operation of general lighting in the space (hrs)

LPD: Lighting power density of gernenal lighting in the space (W/sf)

However, as explained earlier, the dotted line equation can only be used as an approximation of the cumulative sDA curve if the x-axis value is close to the $\%sDA_{50\%}$ point. Since that cannot be guaranteed, we cannot use the straight line approximation to estimate savings in the secondary daylit zone. To estimate savings in the secondary daylit zone, we instead developed a formula that predicts the ratio of secondary daylit zone savings to primary daylit zone savings called *'DZ Savings Ratio'*, and using this ratio we determine the secondary daylit zone savings.

$$SDZsavings = DZ\ Savings\ Ratio \times PDZsavings$$

Equation 18

Where:

SDZsavings: Annual energy savings in the secondary zone (kWh)

DZ Savigns Ratio: Ratio of Secondary to Primary DZ Savings calculed using Equation 19

PDZ Savings: Annual primary daylit zone savings calculated using Equation 17 (kWh)

To develop a formula for the DZ Savings Ratio, we used simulation results from the PIER Office Daylighting Potential Study (Saxena, 2011). Using these results, we determined % annual lighting energy savings for various window to wall ratios (Net-WWR's), and visible light transmittances (VLT's) shown in Figure 21. These savings were calculated using a 30 footcandle set point and 5% dimming + off photocontrols for the primary and secondary daylit zones. The model used was that of a template-space described in Section 4.1.2, namely a 60ft x 40ft office space with 60" high furniture and an open office layout shown in Figure 36. Three separate simulations were done with the façade with windows facing North, South, and East. Blinds were operated to block direct sun to represent an occupant operating blinds to avoid glare.

The table in Figure 21 shows the results for North, South and East Façades.

NORTH	Net-WWR 10%		Net-WWR 26%		Net-WWR 40% (interpolated)		Net-WWR 52%	
	Annual Ltg Energy Savings (%)		Annual Ltg Energy Savings (%)		Annual Ltg Energy Savings (%)		Annual Ltg Energy Savings (%)	
VLT	PDZ	SDZ	PDZ	SDZ	PDZ	SDZ	PDZ	SDZ
0	0%	0	0%	0%	0%	0%	0%	0%
0.1	19%	3%	45%	7%	60%	14%	75%	21%
0.2	38%	5%	84%	13%	88%	28%	92%	42%
0.3	59%	8%	92%	20%	93%	42%	94%	64%
0.4	76%	10%	94%	27%	94%	52%	95%	77%
0.5	87%	13%	95%	33%	95%	59%	96%	84%
0.6	90%	16%	95%	41%	96%	65%	96%	88%
0.7	92%	18%	95%	49%	96%	69%	96%	90%

SOUTH	Net-WWR 10%		Net-WWR 26%		Net-WWR 40% (interpolated)		Net-WWR 52%	
	Annual Ltg Energy Savings (%)		Annual Ltg Energy Savings (%)		Annual Ltg Energy Savings (%)		Annual Ltg Energy Savings (%)	
VLT	PDZ	SDZ	PDZ	SDZ	PDZ	SDZ	PDZ	SDZ
0	0%	0	0%	0	0%	0	0%	0
0.1	23%	4%	33%	6%	43%	10%	52%	14%
0.2	48%	7%	58%	12%	70%	20%	81%	28%
0.3	63%	11%	74%	17%	82%	30%	91%	43%
0.4	73%	14%	84%	23%	89%	40%	93%	57%
0.5	80%	18%	90%	29%	92%	49%	95%	68%
0.6	85%	21%	92%	35%	94%	56%	96%	77%
0.7	88%	25%	94%	41%	95%	61%	96%	82%

EAST	Net-WWR 10%		Net-WWR 26%		Net-WWR 40% (interpolated)		Net-WWR 52%	
	Annual Ltg Energy Savings (%)		Annual Ltg Energy Savings (%)		Annual Ltg Energy Savings (%)		Annual Ltg Energy Savings (%)	
VLT	PDZ	SDZ	PDZ	SDZ	PDZ	SDZ	PDZ	SDZ
0	0%	0	0%	0	0%	0	0%	0
0.1	21%	3%	42%	7%	52%	12%	63%	17%
0.2	42%	6%	73%	13%	80%	23%	87%	33%
0.3	61%	9%	87%	20%	90%	35%	93%	50%
0.4	73%	12%	92%	26%	93%	45%	95%	63%
0.5	83%	15%	94%	33%	95%	54%	96%	74%
0.6	88%	18%	95%	41%	95%	60%	96%	80%
0.7	91%	21%	95%	47%	96%	66%	96%	84%

Figure 21: Percent Annual Energy Savings in Primary and Secondary Daylit Zones

We calculated DZ Savings Ratios from this data by dividing the % annual ltg energy savings from the secondary daylit zone with that from the primary daylit zone. We then used multivariate linear regression analysis to determine an equation that would predict the DZ Savings Ratio as a function of VT and WWR. The details of the regression analysis and a study of percent error is described in Appendix C.

$$DZ\ Savings\ Ratio = \ 0.410 \times VLT \ + \ 0.797 \times WWR$$

Equation 19

Where:

DZ Savings Ratio: Ratio of Secondary to Primary DZ Savings

VLT: Visible light transmittance of the glazing

WWR: Net-Window to wall ratio

In **Case 3**, shown in Figure 22 below, the point on the x-axis representing *(%PDZarea)* and the point representing *(%PDZarea + %SDZarea)* are to the right of $\%sDA_{50\%}$ point.

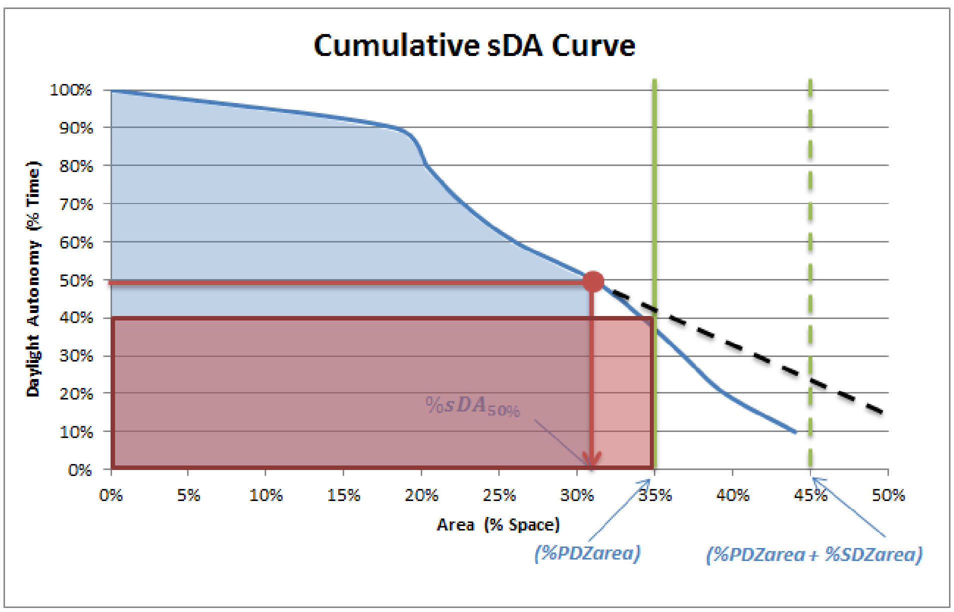


Figure 22: Case 3: *%sDA50%* < (*%PDZarea*) < (*%PDZarea + %SDZarea*)

In this case the primary daylit zone has less than 50% daylight autonomy, and the secondary daylit zone has even lower daylight autonomy. Based on the data shown in Figure 21, it is reasonable to expect the *%PDZarea* point to be close to the $\%sDA_{50\%}$ point. Based on this assumption, the primary daylit zone savings can be calculated as follows:

$$PDZsavings = \%PDZarea \times -\frac{1}{1-\%sDA_{50\%}} \times \%PDZarea + \frac{1+\%sDA_{50\%}}{1-\%sDA_{50\%}} \times 0.5 \times LPD \times Operating\ Hours \times Space\ Area\ /\ 1000$$

Equation 20

Where:

PDZsavings: Annual energy savings in the primary zone (kWh)

%PDZarea: Percent primary zone daylit area calculated using Equation 10

$\%sDA_{50\%}$: is percent area that achieves 50% Daylight Autonomy or more, calculated using Equation 8

OperatingHours: Yearly hours of operation of general lighting in the space (hrs)

LPD: Lighting power density of gernenal lighting in the space (W/sf)

In this case, the secondary daylit zone savings are expected to be quite low, as the primary daylit zone savings are less than 50%. From the study of percent errors of predicted DZ Savings Ratio described in Appendix C, it can be seen that the DZ Savings Ratio formula also tends to overestimate the ratio of *SDZsavings* to *PDZsavings* for low VLTs and low WWRs and would exacerbate the secondary daylit zone savings if applied to the *PDZsavings* calculated using Equation 20. For this reason, the *SDZsavings* are deemed to be zero for this case.

$$SDZsavings = 0$$

Equation 21

Where:

SDZsavings: Annual energy savings in the secondary zone (kWh)

It should be noted that the calculation method described here assumes that area with daylight autonomy equal to and greater than 50% ($sDA_{50\%}$), is located in the primary daylit zone area (*PDZarea*). If the $\%sDA_{50\%}$ is smaller than *%PDZarea* (Case3), then the area falling into the secondary daylit zone has less than 50% daylight autonomy. If $\%sDA_{50\%}$ is greater than *%PDZarea* (Case 2 and Case 1), then the area falling into the secondary daylit zone has more than 50% daylight autonomy.

This is actually an approximation, as the area that has daylight autonomy greater than 50% ($sDA_{50\%}$) doesn't always exactly cover the primary and secondary daylit zones if its depth is smaller than two window head heights. As shown on Figure 23, when $sDA_{50\%}$ is deep enough, it totally covers the primary and the secondary daylit area (left window). The calculation method will report an exact result regarding the daylit area in the secondary daylit area. When the $sDA_{50\%}$ is less than two window head height deep, (right window), the daylit area only partly covers the secondary daylit area, but also covers extra area outside of the primary and secondary daylit area, on the sides of the windows. The calculation method will assume that the area on the side is included in the secondary daylit area. However, the error is usually very small when following the proposed Title 24-2013 method of defining daylit zones.

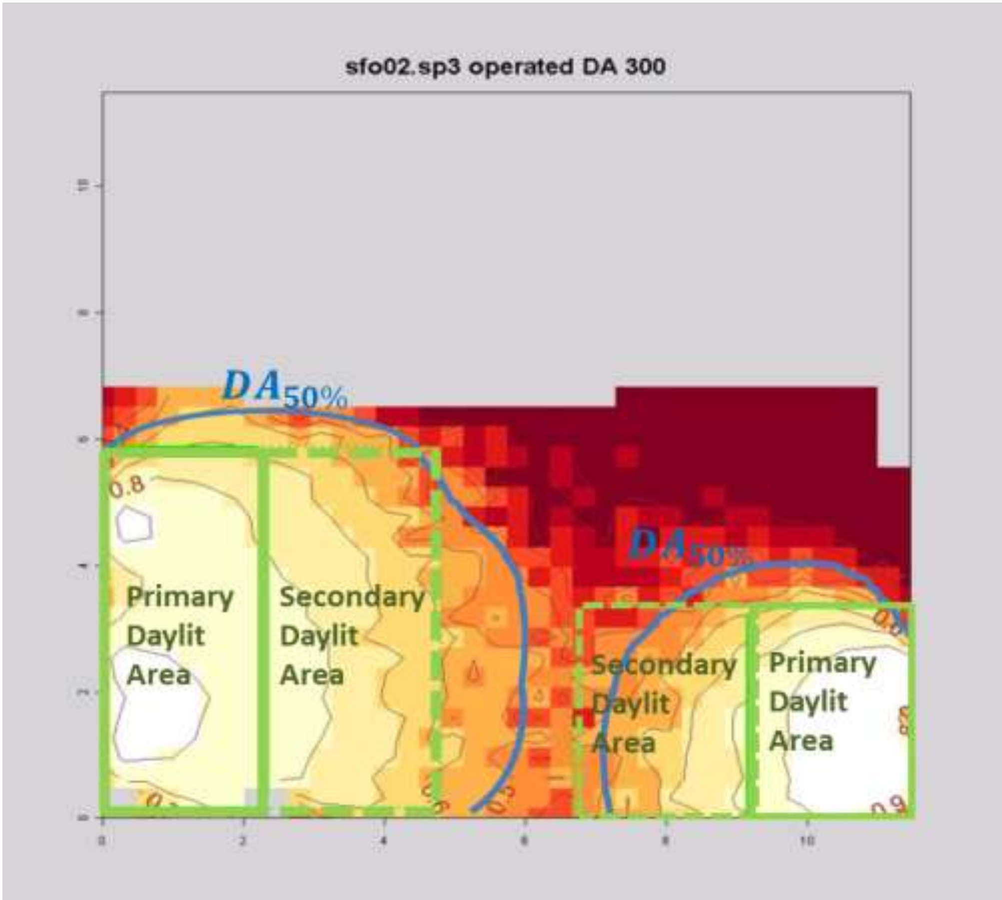


Figure 23 Comparing Primary and Secondary Zones Areas to *sDA50%*

The calculation of $sDA_{50\%}$ is done for each façade. In a space with two facades with windows where the primary/secondary daylit zones overlap, the calculation is done for each façade separately, and added up. This method would overestimate the area in the primary/secondary zone, compared to that in the real space, but at the same time, underestimate the time (number of hours) that the lights in the primary/secondary zone are turned off. We estimate that the effect of these will net the same or very similar result (within error bounds of the methodology).

Watt Calculation Method Calculation Logic

The logic diagram in Figure 24 describes the steps involved in applying the Watt Calculation Method to a space.

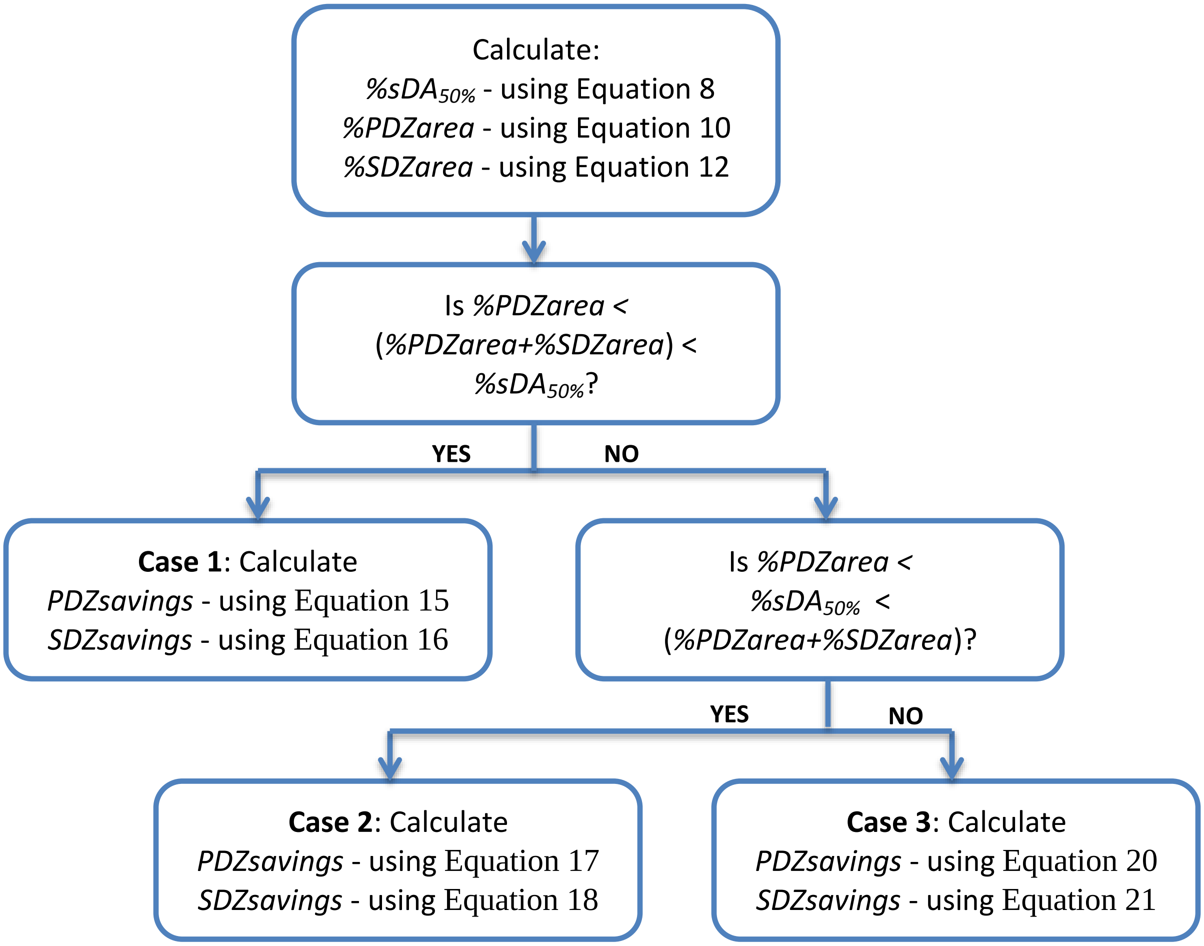


Figure 24: Calculation Logic

5.1.4 Application of Formula for Multiple Façade Orientations

A key assumption in the Watt Calculation Method is that daylight from individual facades can be summed up by space. This includes sidelighting and toplighting as well as adjacent facades that may have daylight overlap.

In the current Title 24 graphical method, the user is expected to deduct overlapping daylit zones. However, in multiples spaces from the 61 examples of real buildings from PIER Daylight Metrics project, we see that when two primary daylit areas from adjacent facades overlap, there are higher daylight autonomy levels in the overlapping area, as well as an increase in area covered by $sDA_{50\%}$. Furthermore, the increase in area is more or less equivalent to the overlapping areas. The result is that $sDA_{50\%}$ for the space with overlapping daylighting from adjacent facades, is close to the same as that calculated individually for each façade and added up per space.

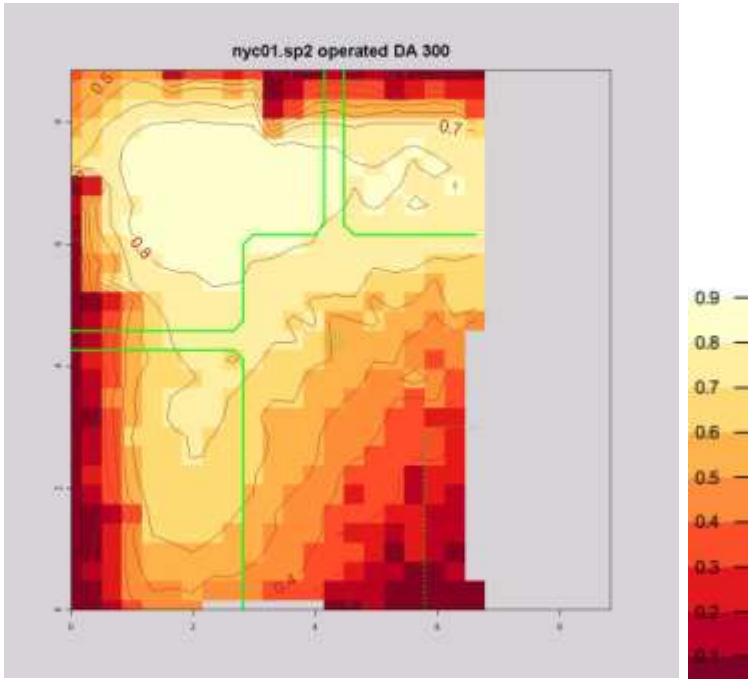
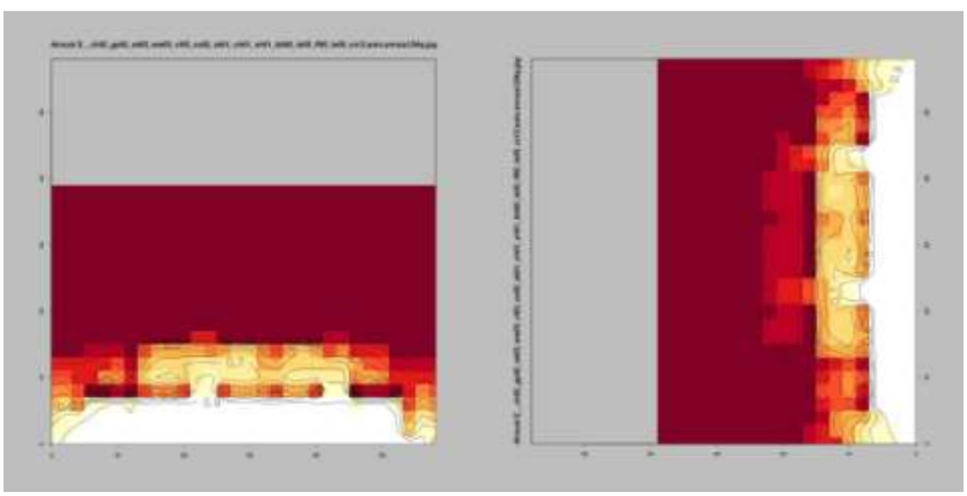


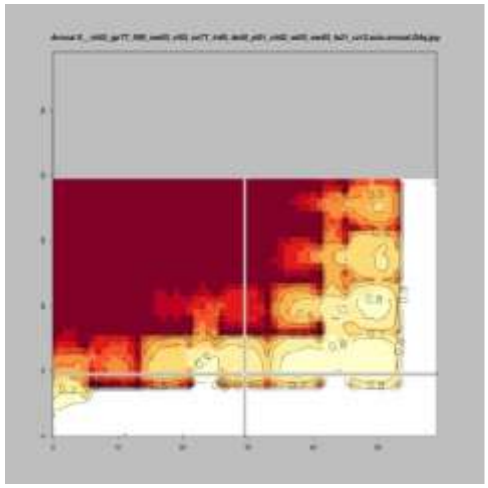
Figure 25: DA Plot for Space E with Sidelighting from Two Adjacent Walls

Figure 25 shows a DA plot for one such space from the set of 61 real spaces, with windows on two adjacent facades (left and top sides of the plot). The solid green line represents net primary daylit area and dotted green line, net secondary daylit areas. The overlap of daylit areas on the top left hand corner of the plot creates additional $sDA_{50\%}$ area in the overlapping secondary daylit areas region.

What we find here is, when two sources of daylight are brought close to each other (as with two adjacent facades), sensors in the secondary daylit area, that had lower illuminance get additional illuminance, causing them to go above the 300 lux threshold, and thus increase the count of sensors with 50% daylight autonomy.



Case A: SOUTH Case B: EAST



Case C: SOUTH & EAST

Figure 26: Individual and Combined Facades

We conducted further investigations to confirm this phenomenon using the template-spaces, and found that when two walls with windows are adjacent to each other, the $sDA_{50\%}$ was about the same as when the two facades were simulated separately, and results added together. Figure 26 shows two simulation runs with individual facades facing South and East (Case A and B), and a third simulation run with a template-space with a south and east façade (Case C).

	$sDA_{50\%}$
Case A, South Facing Façade (60ft façade)	28%
Case B, East Facing Façade (40ft façade)	19%
Case C, South (60ft) and East (40ft) Façade	51%

Figure 27: Table with $sDA_{300,50\%}$ Values for Cases A - C

Figure 27 shows a table with $sDA_{50\%}$ for all three cases. Note here that while the image for Case B shows a 60 ft East facing façade, the value for $sDA_{50\%}$ for Case B in the table is adjusted for a 40ft façade, to make an applicable comparison. What we find here is that the sum of individual facades from Cases A and B (47%) is very close to, in fact slightly lower than, the result from Case C (51%).

5.2 Proposal 2: Photocontrols Requirement Threshold

This section describes the analysis steps used to update the minimum daylit area threshold for a photocontrol requirement in sidelit and toplit spaces as described in Sections 131(c)2B and 131(c)2C, to a more aggressive requirement based on updated costs of photocontrols, and updated energy costs from the 2008 code change proposal. This section also discusses the results from the analysis and their code implications.

5.2.1 Photocontrol System Cost

As discussed in section 0, above, HMG collected cost data for daylighting control equipment from product distributers throughout California, based on two hypothetical projects:

- 800 sf side lit open office area; 250 sf daylit area; 4 fixtures controlled
- 1120 sf top lit warehouse space; 896 sf daylit area; 14 fixtures controlled

Diagrammatic plans of the two scenarios are illustrated below in Figure 28 and Figure 29. Yellow shading in each diagram indicates areas where current code requires luminaires to be controlled by separately for daylighting. For these cost assessments we assumed that luminaires in the daylit zone will be automatically controlled by photocontrols.

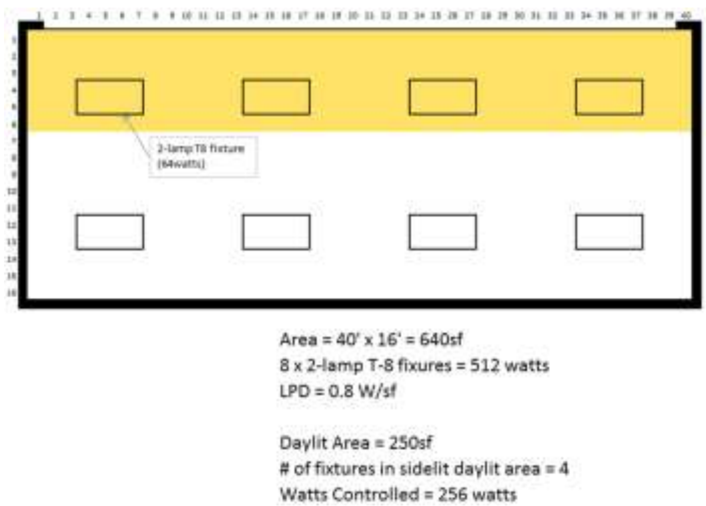


Figure 28: Plan Diagram of Hypothetical Sidelit Space

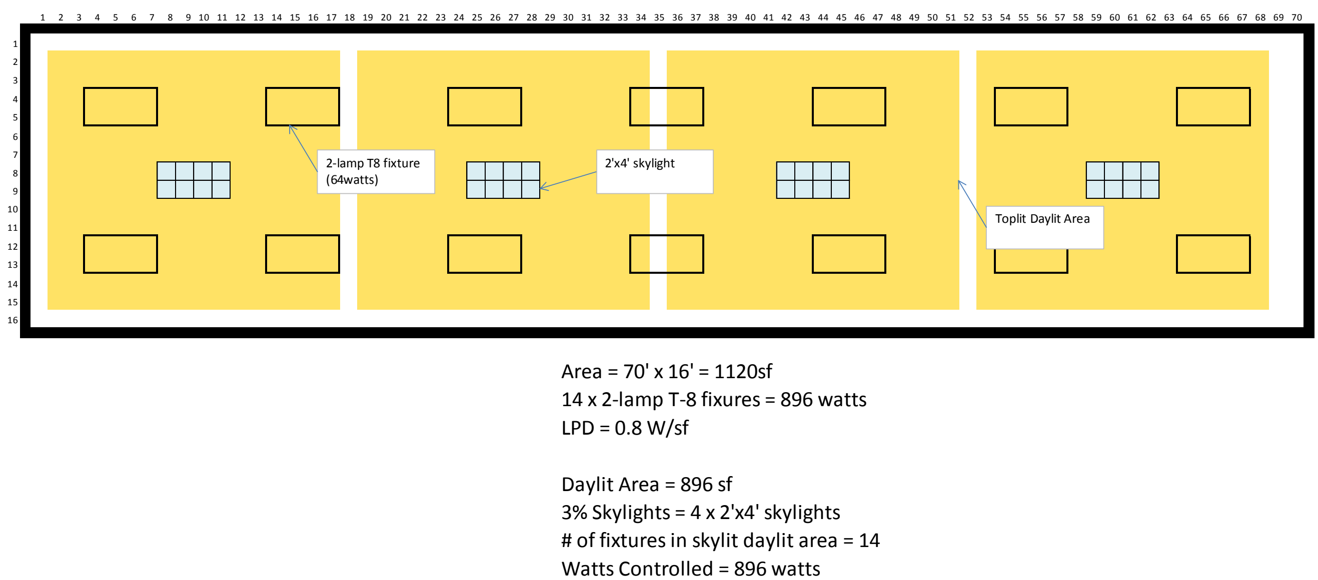


Figure 29: Plan Diagram of Hypothetical Toplit Space

HMG received 40 price quotes of retail prices for 11 different photocontrol products and their required auxiliary components (lens, relay, power pack etc.).

Costs were collected for three different types of photocontrol products:

- Wireless Systems: a photosensor sends a wireless signal to a controller that turns off or dims lights at the pre-determined setpoint(s).
- Wired Stand-Alone Products: a photosensor sends a wired signal (line- or low-voltage) directly to the lighting to be turned off or dimmed.
- Wired Systems: a photosensor sends a wired signal (usually low-voltage) to a controller at the pre-determined setpoint(s); the controller then relays a control signal to the lighting to be turned off or dimmed.

The specific capabilities of each product were taken into account, and any auxiliary equipment such as power packs, controllers, or transformers was included in the cost data for each product. In addition, some of the products would require more than one sensor or controller to meet the current multi-level requirements for Automatic Daylight Control Devices in the current code, section 131(c)2D. The cost of the additional equipment was included. Results of the cost survey for the three product types are summarized below in Figure 30.

	Max Price	Average Price	Min Price
Wireless Photocontrols System (n=3)	**$436.00**	**$320.94**	**$261.00**
Wireless Photosensors	$134.49	$115.16	$100.00
Wireless Reciever	$336.00	$205.78	$131.33
Wired Stand-Alone System (n=4)	**$231.82**	**$129.89**	**$62.00**
Wired Photosensors	$181.82	$99.89	$62.00
Power Pack	$50.00	$30.00	$0.00
Wired Phtocontrols System (n=4	**$662.50**	**$381.22**	**$121.87**
Wired Photosensors	$236.00	$138.72	$84.50
Controller & Aux Equipment	$550.00	$242.50	$0.00

Figure 30: Photocontrols Equipment Price Summary

Initial fixed costs for wireless photocontrol systems are more than wired stand-alone photocontrol systems and wired complete systems (photosensor with controller). However, when the cost of installation and commissioning is included (analysis outlined below), the wireless daylight systems are the least expensive to install, but on balance, not considerably different from the cost of wired photosensor control systems.   The major drawback to wireless daylight systems are in buildings where the wireless signal affects the performance of the building, some examples include:

government buildings where outside access to insecure wireless communication is a security concern and hospitals where wireless signals could reduce equipment performance.

In addition to the fixed equipment costs, we estimated the variable cost of labor to install and commission the system. We obtained estimates of electrical contractor labor hours from a variety of industry stakeholders, ranging from manufacturers, to contractors, to consultants. Estimated installation times ranged from 30 minutes per fixture for wireless systems to 2 hours per fixture for wired systems. In addition to installation, the systems were assumed to require 15-30 minutes per ballast for commissioning of dimming systems, or up to 15 minutes per ballast for switching systems (larger systems are assumed to have a commissioning cap of $2000, based on daily fees for manufacturer support services).

Using the labor estimates obtained from stakeholders, and data sourced from RS Means CostsWorks for electrical contractor labor rates throughout the state (see Figure 31), we estimated the variable cost for installation and commissioning daylight control systems (in Sacramento) to be $350.50 (switching) or $467.75 (dimming) for the sample office sidelit project (shown in Figure 28) and $559.50 (switching) or $886.75 (dimming) for the sample warehouse top lit project (shown in Figure 29). See Figure 32, below, for a detailed summary of labor and commissioning cost estimates.

Labor + O&P ($/hr) from RS Means	City	City Multipliers RS Means (%)	Labor O+P by city
$72.85	Sacramento	115.1	$83.85
	Bay Area	151.6	$110.44
	Los Angeles	122.1	$88.95
	Riverside	110.2	$80.28
	San Diego	103.7	$75.55
	Other (avg)	106.5	$77.59

Figure 31: RS Means CostWorks Hourly Labor Rates for Electrical Contractors

	Sidelighting 4 fixtures controlled			Toplighting 14 fixtures controlled		
	Installation Cost		Comissioning Cost	Installation Cost		Comissioning Cost
	Wireless	Wired		Wireless	Wired	
	0.5 hrs	2hrs	2hrs	0.5 hrs	2hrs	7hrs
Sacramento	$41.93	$167.70	$167.70	$41.93	$167.70	$586.95
Bay Area	$55.22	$220.88	$220.88	$55.22	$220.88	$773.08
Los Angeles	$44.47	$177.90	$177.90	$44.47	$177.90	$622.65
Riverside	$40.14	$160.56	$160.56	$40.14	$160.56	$561.96
San Diego	$37.77	$151.09	$151.09	$37.77	$151.09	$528.82
Other (avg)	$38.79	$155.17	$155.17	$38.79	$155.17	$543.10

Figure 32: RS Means CostWorks Variance in Labor Cost by Region

The total costs, documented below in Figure 33 (switching system) and Figure 34 (dimming system) include photocontrol equipment, installation labor and commissioning labor. The cost differential between a std ballast and a dimmable ballast was not included based on a companion CASE proposal requiring controllable ballasts. Labor costs from the Sacramento area were used to represent an average labor cost for the state. Total costs for wireless and wired jobs were averaged to provide an average total project cost for both dimming and switching systems for both hypothetical spaces.

Example Job		Wireless Job Cost	Wired Job Cost	Average Cost
Sidelit space 800sf - 4 switching fixtures controlled. Daylit Area = 250sf	Purchase Price	$261.00	$62.00	$161.50
	Installation (SAC)	$42.00	$168.00	$105.00
	Commissioning	$84.00	$84.00	$84.00
	Total Cost	**$387.00**	**$314.00**	**$350.50**
Toplit space 1120sf - 14 switching fixtures controlled. Daylit Area = 896sf	Purchase Price	$261.00	$62.00	$161.50
	Installation (SAC)	$42.00	$168.00	$105.00
	Commissioning	$293.00	$293.00	$293.00
	Total Cost	**$596.00**	**$523.00**	**$559.50**

Figure 33: Total Costs for Switching System, Sacramento, CA

Example Job		Wireless Job Cost	Wired Job Cost	Average Cost
Sidelit space 800sf - 4 dimming fixtures controlled. Daylit Area = 250sf	Purchase Price	$261.00	$128.50	$194.75
	Installation (SAC)	$42.00	$168.00	$105.00
	Commissioning	$168.00	$168.00	$168.00
	Total Cost	**$471.00**	**$464.50**	**$467.75**
Toplit space 1120sf - 14 dimming fixtures controlled. Daylit Area = 896sf	Purchase Price	$261.00	$128.50	$194.75
	Installation (SAC)	$42.00	$168.00	$105.00
	Commissioning	$587.00	$587.00	$587.00
	Total Cost	**$890.00**	**$883.50**	**$886.75**

Figure 34: Total Costs for Dimming System, Sacramento, CA

For retrofit projects cost data was collected from one of our stakeholders actively engaged in the retrofit market (Thomas, 2011). We found that to retrofit a space to include photocontrols in the primary daylit zone cost about 10% more than is quoted in the above photocontrols pricing summary. The costs survey also showed that the difference in cost of adding photocontrols to primary daylit zone and that of adding photocontrols to secondary daylit zone was 52%.

	HMG Cost Survey	Stakeholder Cost Data			
	Adding wireless photoctrls to PDZ	Adding wireless photoctrls to PDZ	Difference compared to HMG Cost Survey	Additionally installing photoctrls to SDZ	Difference compared to cost for wireless photoctrls to PDZ
Equipment	$261	$237	-	$16	-
Installation	$42	$98	-	$48	-
Commissioning	$210	$225	-	$225	-
Total	**$513**	**$560**	**9%**	**$289**	**52%**

Figure 35: Total Costs for Photocontrols for New Construction Compared to Retrofit

5.2.2 Photocontrols Requirement Threshold Calculation

In order to determine a threshold for the requirement of photocontrols, energy savings were first estimated for the two hypothetical projects described in Section 5.2.1. However, instead of calculating actual energy savings for these theoretical cases, which depend on multiple factors identified in the watt calculation method in Section 5.1, such as, window to wall ratio, window VLT, sill height, head height, ceiling height, orientation etc., we instead we used a method that calculated savings for different '% full-load equivalent off hours' or %FLE off hours. % FLE off is the fraction of the total time of operation when a number of lights equivalent to the full load is turned off.

So if enough daylight is available in the space to turn off all the electric lights completely in the daylit zone for 1 hour but not for the next hour, the total FLE off hours in the daylit zone is 1. However, if lights are completely off for ½ hour for each of the two hours, or ½ off for each of the two hours, the total FLE off hours would also be 1. Each situation results in exactly the same amount of energy savings when totaled up. When summed up for a full year, %FLE Off hours also represents % annual energy savings from lighting. Equation 22 gives a mathematical representation of % FLE off savings.

$$\%FLE\ off = \frac{Fraction\ of\ full\ load\ off * Duration}{Total\ hours\ of\ operation}$$

Equation 22

Savings in Primary and Secondary Daylit Zone

Using simulation results from the PIER Office Daylighting Potential Study (Saxena, 2011), we determined % annual lighting energy savings for various window to wall ratios (Net-WWR's), and visible light transmittances (VLT's). These savings were calculated using a 30 footcandle set point and 5% dimming + off photocontrols for the primary and secondary daylit zones. The model used was that of a template-space described in Section 4.1.2, namely a 60ft x 40ft office space with 60" high furniture and an open office layout shown in Figure 36. Three separate simulations were done with the façade with windows facing North, South, and East. Blinds were operated to block direct sun to represent an occupant operating blinds to avoid glare.

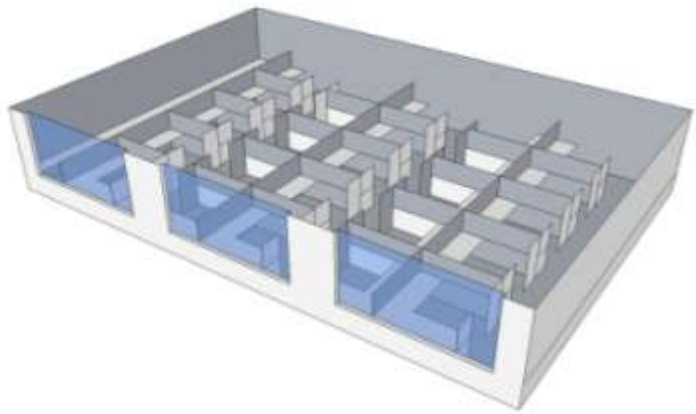


Figure 36: Template Space 60ft x 40ft with 60" Furniture

The results from the analysis are given in Figure 37 below for the South facing template.

SOUTH	Net-WWR 10%		Net-WWR 26%		Net-WWR 40% (interpolated)		Net-WWR 52%	
	Annual Ltg Energy Savings (%)		Annual Ltg Energy Savings (%)		Annual Ltg Energy Savings (%)		Annual Ltg Energy Savings (%)	
VLT	**PDZ**	**SDZ**	**PDZ**	**SDZ**	**PDZ**	**SDZ**	**PDZ**	**SDZ**
0	0%	0	0%	0	0%	0	0%	0
0.1	23%	4%	33%	6%	43%	10%	52%	14%
0.2	48%	7%	58%	12%	70%	20%	81%	28%
0.3	63%	11%	74%	17%	82%	30%	91%	43%
0.4	73%	14%	84%	23%	89%	40%	93%	57%
0.5	80%	18%	90%	29%	92%	49%	95%	68%
0.6	85%	21%	92%	35%	94%	56%	96%	77%
0.7	88%	25%	94%	41%	95%	61%	96%	82%

% values are FLE Off hours, 5% dimming + off controls

Figure 37: Annual Lighting Energy Savings for South Facing Template-Space

The results show that across all Net-WWR's savings are about 50% for most VLTs in the primary daylit zone. Figure 37 gives savings for the South façade, savings tables for the other orientations, given in Figure 21. The savings remain mostly unchanged by orientation as blinds operation make the daylighting more or less equivalent, with South having slightly lower savings than the rest.

Threshold for New Construction

To determine a threshold for the requirement of photocontrols in new construction, energy savings were estimated for the two hypothetical projects described in Section 5.2.1 using the following parameters:

- 15 year analysis period
- LPD of 0.8 W/sf
- 2600 annual hours of operation
- Energy costs of $0.16/kWh
- Simple on-off photocontrols system applied to luminaires one head height from the windows, and 0.7*Ceiling Height from the skylights

The FLE off hours were calculated for the installed lighting wattage identified as being in one head height of the windows (primary daylit zone), and 0.7*Ceiling Height from the skylights (skylit zone) for the two theoretical cases described in Section 5.2.1. In the sidelit space this results in a total of 256 Watts of installed lighting, and 896 Watts of installed lighting in the toplit case. In order to determine the threshold for savings, we calculated a range of FLE off hours and savings as percentages ranging from 20% to 70% at 10% intervals. Figure 38 below shows the savings calculated for various % FLE Off hours (y-axis) for 256 and 896 controlled watts respectively (x-axis).

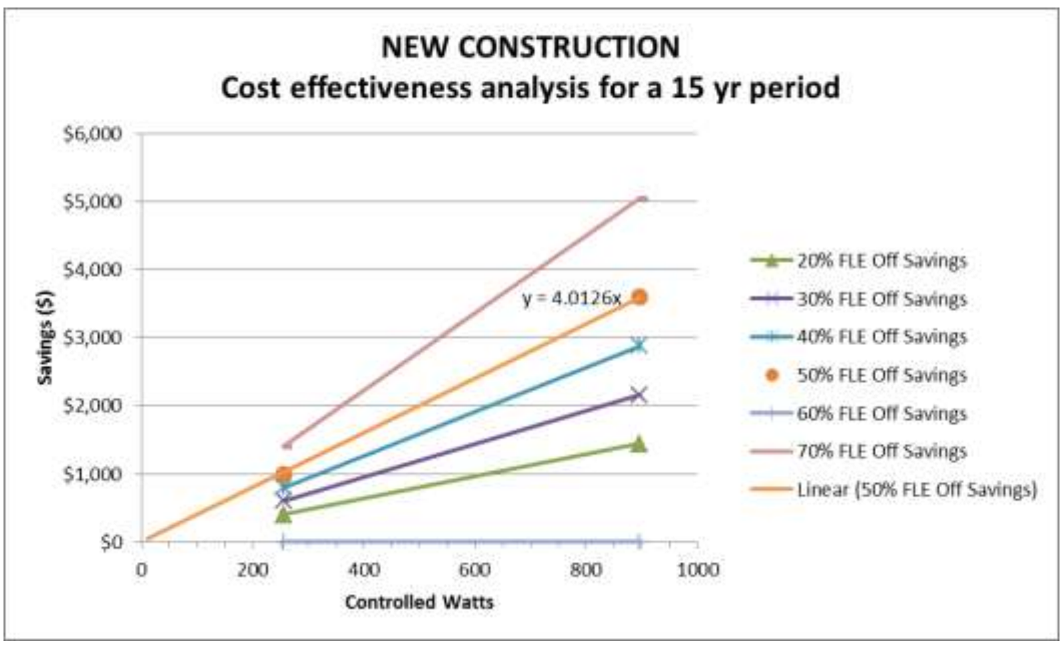


Figure 38: %FLE Off Savings vs Controlled Watts (New Const.)

Simulation results from the template-space runs described in the section on “Savings in Primary and Secondary Daylit Zone” above, as well as analysis of various sidelit and toplit spaces in the PIER Office Daylighting Potential Study (Saxena, 2011) and PIER Daylit Metrics Study (Heschong, 2011), shows that 50% FLE Off savings in the primary daylit zone and skylit zone regions is easily achievable in most cases with 0.4 VLT glazing. We hence extend the 50% FLE off savings line (Orange) in Figure 38.

To determine the threshold where savings over a 15 year period equals the cost of photocontrols, we plot an additional line (black) to represent photocontrols costs as shown in Figure 39. The point of intersection of the photocontrols cost line and the 50% FLE Off Savings line represents the threshold Watts of controlled lighting in the primary daylit zone or skylit zone.

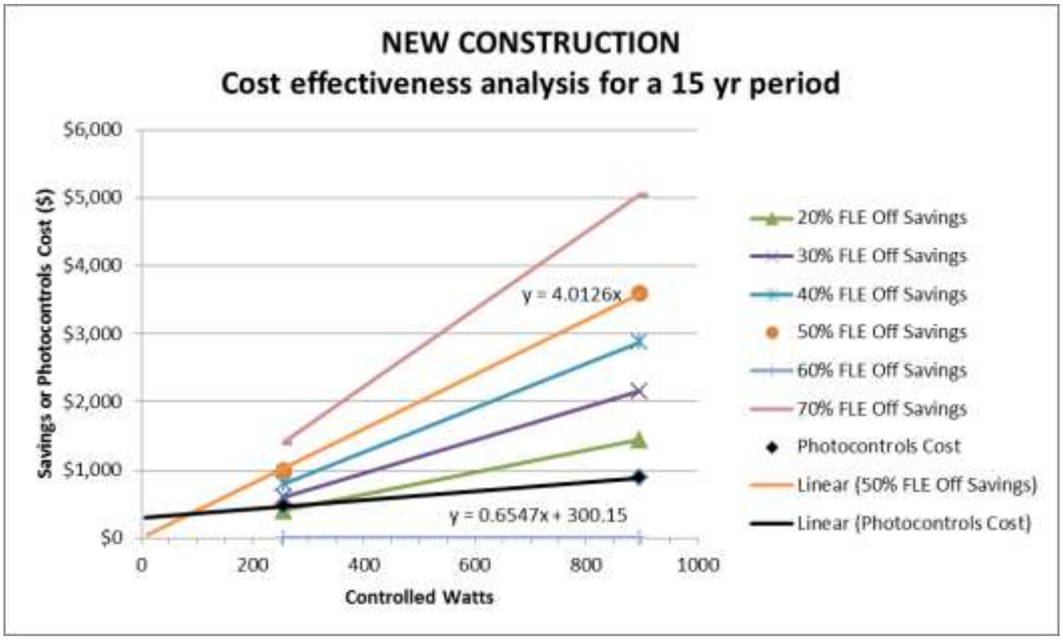


Figure 39: %FLE Off Savings vs Controlled Watts with Photocontrols Cost (New Const.)

From Figure 39, it can be seen that the two lines intersect at 120 Watts. Thus 120 Watts is the recommended threshold for requiring photocontrols in primary daylit and skylit zones.

In our analysis, we used several layers of conservatism. First, we used a conservative energy costs of \$0.12/kWh for the full 15 year assessment. Second, the analysis was based on 50% FLE Off hours which is roughly equivalent to 50% daylight autonomy at 30 footcandles in the primary daylit zone or skylit zone with on/off photocontrols. A basic on/off control requires a higher daylight illuminance level threshold to turn off the electric lighting, than the code-required multi-level daylight control. Third, the analysis did not take into account TDV savings. An hourly calculation with TDV energy savings will likely produce higher savings, as TDV multipliers are higher for peak hours and thus favor technologies like daylighting at provide energy savings during peak periods.

Threshold for Retrofits

Similar to the method used to determine threshold for new construction, we developed a threshold for retrofit (additions and alterations). However, compared to new construction, retrofits have two key differences:

(a) Cost of adding photocontrols is slightly higher than that of new construction. From Section 5.2.1 we know that the cost of photocontrols in retrofits is about 10% higher than that of photocontrols in new construction.

(b) A Min VT of 0.4 cannot be assumed as a Min VT requirement is being proposed only for new construction.

The challenge in developing a recommendation for retrofits was that we wanted to develop simple code language that will not burden the user with steps like figuring out VT of a glazing in an existing building, and calculating effective aperture; yet provide the correct guidance for when to require photocontrols.

To find controlled wattage threshold for which photocontrols in retrofit projects are cost effective, we needed to determine which %FLE off savings line was appropriate to use to intersect with the line that represents photocontrol costs for retrofits.

SOUTH	Net-WWR 10%		Net-WWR 26%		Net-WWR 40% (interpolated)		Net-WWR 52%	
	Annual Ltg Energy Savings (%)		Annual Ltg Energy Savings (%)		Annual Ltg Energy Savings (%)		Annual Ltg Energy Savings (%)	
VLT	PDZ	SDZ	PDZ	SDZ	PDZ	SDZ	PDZ	SDZ
0	0%	0	0%	0	0%	0	0%	0
0.1	23%	4%	33%	6%	43%	10%	52%	14%
0.2	48%	7%	58%	12%	70%	20%	81%	28%
0.3	63%	11%	74%	17%	82%	30%	91%	43%
0.4	73%	14%	84%	23%	89%	40%	93%	57%
0.5	80%	18%	90%	29%	92%	49%	95%	68%
0.6	85%	21%	92%	35%	94%	56%	96%	77%
0.7	88%	25%	94%	41%	95%	61%	96%	82%

% values are FLE Off hours, 5% dimming + off controls

Figure 40: Annual Lighting Savings for Photocontrols in the Primary and Secondary Daylit Zone

Figure 40 shows the same table of annual lighting energy savings as a function of the VT's and Net-WWR's as in Figure 37 with different cell shadings. Assuming that at windows in retrofits have a VLT of at least 0.2, from the table in Figure 40, we can see that savings of about 26%-27% (~30%) are possible in the primary daylit zone with 0.2 VLT.

Next, similar to new construction, we develop a % FLE off savings vs controlled watts graph for Retrofit savings in primary daylit zone as shown in Figure 41. The photocontrols cost line here is 10% higher than that in Figure 39. Here we extend the 30% %FLE off savings line to find where it intersects with the photocontrols cost line. We find that the lines intersect at about 210 Watts. To be conservative, we recommend 300 Watts as our recommended threshold for cost effective photocontrols in the primary daylit zone for Retrofits.

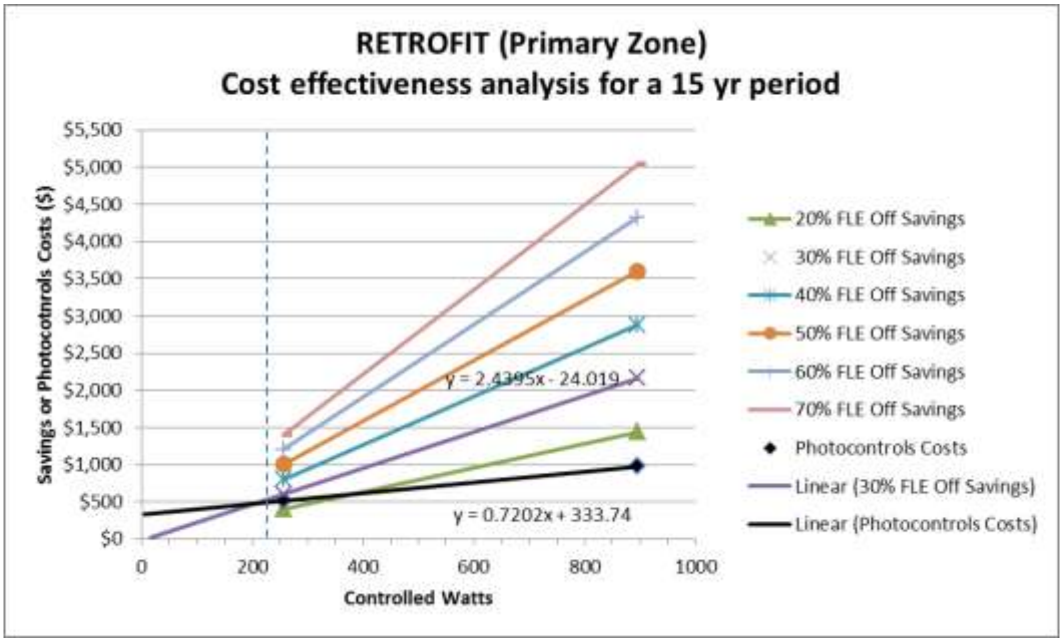


Figure 41: %FLE Off Savings in Primary Zone vs Controlled Watts (Retrofit)

To keep the code simple and memorable, we recommend a 300 Watt threshold for the secondary zone as well. This makes it very simple for the user who has already determined if they have 300 controlled watts of lighting in the primary daylit zone to check if the same wattage (ie. same number of luminaires) are included in the secondary daylit zone.

To determine % FLE off hours required to make controlling the 300 Watts in secondary daylit zone cost effective, we plot the graph shown in Figure 42. The photocontrols cost plotted in this figure are 52% of the cost of photocontrols in Figure 41 per our findings in Section 5.2.1 about cost of adding wireless photocontrols in secondary daylit zones (see Figure 35).

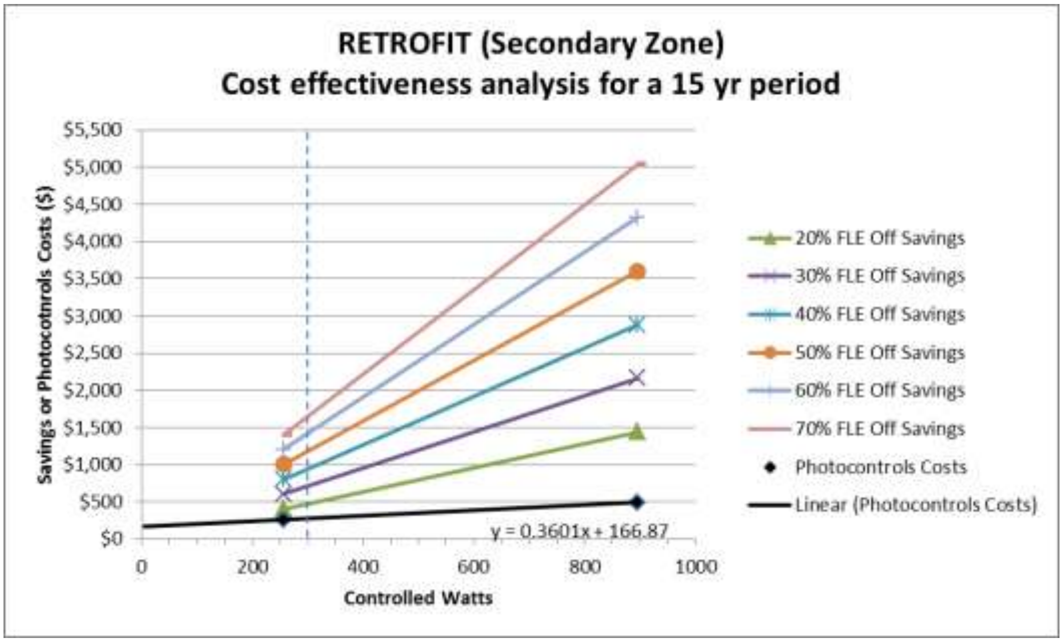


Figure 42: %FLE Off Savings Secondary Zone vs Controlled Watts (Retrofit)

At 300 Watts, the savings line that comes closes to the photocontrols cost is slightly lower than 20% FLE off savings (green line), i.e. 15%. In other words, to cost effectively add photocontrols to the secondary daylit zone, the lights in the secondary daylit zone need to be off 15 % of the time or the secondary daylit zone should have at least 15% annual lighting energy savings.

Looking at the savings table in Figure 40, we shade (dark pink) the cells in the secondary daylit zone columns that have savings less than 15%. Looking at the table it is clear that 15% FLE off savings are possible with Net-WWR > 25% and VLT > 0.2. Continuing with the assumption that most spaces will have windows with VLT > 0.2, we recommend that photocontrols be required in secondary daylit zones for all spaces except those with Net WWR < 25%.

To simplify the calculation steps further, the exception for Net WWR < 25% for requiring photocontrols in secondary daylit zones can be reinterpreted as spaces where the length of a window is ½ the length of the wall. Assuming that the window height (sill height to head height) in most cases is ½ the floor to ceiling height, a wall with window width ½ the wall width will result in a 25% Net-WWR.

5.2.3 Recommendations

The following are the recommendations for changes to the code language. Draft code language has been proposed in Section 6.

New Construction

As described in the analysis above, automatic daylight photocontrols are cost effective in all primary daylit zones and skylit zones that include at least 120 Watts of controlled lighting. Based on this we recommend a mandatory requirement for photocontrols in primary daylit zones and skylit zones that include at least 120 Watts of controlled lighting in Section 131. Adding photocontrols to the secondary daylight zone can be done with very little cost, as the majority of the cost, that of purchasing a photocontrol has already be justified by the savings in the primary daylit zone. Adding photocontrols to the secondary daylit zone only requires a small additional cost of labor to wire and commission the secondary daylit zone. Based on this we recommend a prescriptive requirement for photocontrols in the secondary daylit zone in Section 146.

However, a small window placed high up on a wall is likely to produce a large daylit zone, which may not have enough daylight to be cost effective. To account for such conditions, we recommend an exception to the requirement for spaces with windows less than 24 square feet. This will exclude windows small enough to not bring in enough daylight that may be placed high enough on a wall to include more than 120 Watts of installed lighting.

Retrofit

As described in the analysis, automatic daylight photocontrols are cost effective in all primary daylit zones and skylit zones that include at least 300 Watts of controlled lighting. Based on this we recommend a requirement in Section 149 for automatic photocontrols in the primary daylit zones if they include installed wattage of more than or equal to 300 Watts. Moreover, if the secondary daylit zone also includes at least 300 Watts of controlled lighting, adding photocontrols to the secondary daylit zone is cost effective for spaces where Net-WWR is more than or equal to 25%. Based on this we recommend a requirement for photocontrols in secondary daylit zones if they include installed wattage of more than or equal to 300 Watts and if the total width of windows is at least ½ the width of the wall.

5.2.4 Energy Savings

To develop energy savings estimates from the proposed code changes, we developed two prototype buildings described in Section 4.7.1.

(a) Office Building Prototype: This building represents a typical office building layout (see Figure 5) with a mix of open, private and core office spaces. All spaces adjacent to the exterior façade with windows will be required to have photocontrols per the new recommended code change proposal.

(b) Small Retail Building Prototype: This building represents a small retail store that is not large enough (less than 8,000 sf) to qualify for the prescriptive requirement for skylights, and has skylights that produce a skylit daylit area of 2,400 sf. (see Figure 6). This is less than the Title 24-2008 requirement of 2,500 sf to require photocontrols. The luminaires in the skylit zone will be required to have photocontrols per the new recommended code change proposal.

Office Building Prototype

To estimate energy savings, we used the results from the extensive simulations done for the PIER Office Daylighting Potential Study (Saxena, 2011) for office buildings in California. This study gave us the opportunity to select average savings from office buildings in California, thus not limiting the results to one particular window layout or orientation or window VLT in the prototype building. The savings values are provided as “Lighting + HVAC Savings” per sf of primary daylit zone and per sf of building area, for four representative CA climate zones. Results from the four climate zones were applied to the remaining 12 climate zones based on similarity of solar and daylighting conditions. Hourly annual simulation results were also used to determine TDV savings.

Climate Zones in PIER Study	Mapped Climate Zones
2 (North coastal - Heating dominated)	1,3,4,16
6 (South coastal - Mild)	5,7,8,9,10
12 (Central valley - Intermediate)	11
13 (Sunny inland - Cooling dominated)	14,15

Figure 43: Climate Zone Mapping from PIER Study

However the results of energy savings from daylighting from the PIER study had to first be adjusted to account for the fact the PIER study savings represented existing office buildings, whereas the energy saving required for the CASE report were for new construction built to Title 24-2008 standards. We developed scalars for two key differences between existing office building (PIER study results) and new construction (CASE Estimate for Savings).

(a) Lighting Power Density (LPD): The average LPD of the dataset in the PIER study was 1.28 W/sf. The average LPD for office spaces, private and open per Title 24-2008 is 1.0 W/sf. The results were adjusted by a scalar of 0.781 to account for this difference.

(b) Occupancy Sensors in Spaces < 250sf: Spaces in the prototype building plan that were less than 250sf were required to have occupancy sensors per Title 24-2008 standards. From the TDV Lighting Controls Schedules Report (PG&E, 2008a), we estimated a scalar for occupancy sensors by dividing the average hourly lighting schedule for a weekday with occupancy sensors to the average hourly lighting schedule for a weekday without occupancy sensors. This scalar was determined to be 0.835. Note: the scale was only applied to the savings estimates for those spaces that were less than 250sf and daylit.

Figure 44 below provides the energy savings calculated for the office sidelit building prototype for each climate zone. Note that the savings per sf of primary daylit zone are total savings (primary and secondary daylit zone) savings per primary daylit zone area.

Office Sidelit Building Prototype		Electricity Savings (kWh/yr)	Demand Savings (kW)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings (kBtu)	TDV Gas Savings (kBtu)
CZ 1 Savings	Per sf of Primary Daylit Zone*	2.43	1.17	-0.0005	76.13	-0.49
	Per Prototype Building	32,442	14,086	-4.91	553,521	-2,454
	Per Building sf	0.95	0.41	-0.0001	16.28	-0.07
CZ 2 Savings	Per sf of Primary Daylit Zone*	2.43	1.17	-0.0005	75.82	-0.49
	Per Prototype Building	32,442	14,086	-4.91	551,380	-2,445
	Per Building sf	0.95	0.41	-0.0001	16.22	-0.07
CZ 3 Savings	Per sf of Primary Daylit Zone*	2.43	1.17	-0.0005	75.87	-0.49
	Per Prototype Building	32,442	14,086	-4.91	551,747	-2,446
	Per Building sf	0.95	0.41	-0.0001	16.23	-0.07
CZ 4 Savings	Per sf of Primary Daylit Zone*	2.43	1.17	-0.0005	76.02	-0.49
	Per Prototype Building	32,442	14,086	-4.91	552,665	-2,450
	Per Building sf	0.95	0.41	-0.0001	16.25	-0.07
CZ 5 Savings	Per sf of Primary Daylit Zone*	2.99	1.12	-0.0018	71.43	-1.25
	Per Prototype Building	18,392	7,427	-12.44	522,235	-10,352
	Per Building sf	0.54	0.22	-0.0004	15.36	-0.30
CZ 6 Savings	Per sf of Primary Daylit Zone*	2.99	1.12	-0.0018	69.24	-1.21
	Per Prototype Building	18,392	7,427	-12.44	506,587	-10,042
	Per Building sf	0.54	0.22	-0.0004	14.90	-0.30
CZ 7 Savings	Per sf of Primary Daylit Zone*	2.99	1.12	-0.0018	70.00	-1.23
	Per Prototype Building	18,392	7,427	-12.44	512,274	-10,155
	Per Building sf	0.54	0.22	-0.0004	15.07	-0.30
CZ 8 Savings	Per sf of Primary Daylit Zone*	2.99	1.12	-0.0018	69.44	-1.22
	Per Prototype Building	18,392	7,427	-12.44	508,112	-10,073
	Per Building sf	0.54	0.22	-0.0004	14.94	-0.30
CZ 9 Savings	Per sf of Primary Daylit Zone*	2.99	1.12	-0.0018	68.79	-1.21
	Per Prototype Building	18,392	7,427	-12.44	503,123	-9,974
	Per Building sf	0.54	0.22	-0.0004	14.80	-0.29
CZ 10 Savings	Per sf of Primary Daylit Zone*	2.99	1.12	-0.0018	69.32	-1.22
	Per Prototype Building	18,392	7,427	-12.44	506,660	-10,044
	Per Building sf	0.54	0.22	-0.0004	14.90	-0.30
CZ 11 Savings	Per sf of Primary Daylit Zone*	2.16	0.84	-0.0056	52.79	-3.99
	Per Prototype Building	15,199	6,275	-41.58	390,278	-31,285
	Per Building sf	0.45	0.18	-0.0012	11.48	-0.92
CZ 12 Savings	Per sf of Primary Daylit Zone*	2.16	0.84	-0.0056	52.48	-3.96
	Per Prototype Building	15,199	6,275	-41.58	388,064	-31,108
	Per Building sf	0.45	0.18	-0.0012	11.41	-0.91
CZ 13 Savings	Per sf of Primary Daylit Zone*	1.87	0.77	-0.0006	38.77	-0.36
	Per Prototype Building	16,859	7,683	-3.72	287,830	-1,859
	Per Building sf	0.50	0.23	-0.0001	8.47	-0.05
CZ 14 Savings	Per sf of Primary Daylit Zone*	1.87	0.77	-0.0006	38.99	-0.36
	Per Prototype Building	16,859	7,683	-3.72	289,308	-1,869
	Per Building sf	0.50	0.23	-0.0001	8.51	-0.05
CZ 15 Savings	Per sf of Primary Daylit Zone*	1.87	0.77	-0.0006	38.49	-0.35
	Per Prototype Building	16,859	7,683	-3.72	285,672	-1,845
	Per Building sf	0.50	0.23	-0.0001	8.40	-0.05
CZ 16 Savings	Per sf of Primary Daylit Zone*	2.43	1.17	-0.0005	76.15	-0.49
	Per Prototype Building	32,442	14,086	-4.91	553,562	-2,454
	Per Building sf	0.95	0.41	-0.0001	16.28	-0.07

* Total Saving in Primary and Seconday Daylit Zones per Primary Daylit Zone Area

Figure 44: Energy Savings for Office Sidelit Building Prototype

Small Retail Building Prototype

To estimate energy savings, we ran simulations in SkyCalc™ 3.0 for the above described prototype model for all 16 California climate zones. To determine TDV savings, we used hourly simulation results from one of the "template" spaces used in the PIER Office Daylighting Potential study with skylights and no windows. The hourly profile of savings was scaled to match the results of energy savings from SkyCalc™, and the resulting hourly profile of savings used to determine TDV savings.

Figure 45 below gives energy savings calculated for the small retail building prototype for each climate zone.

Small Retail Toplit Building Prototype		Electricity Savings (kWh/yr)	Demand Savings (W/sf)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings (kBtu)	TDV Gas Savings (kBtu)
CZ 1 Savings	Per sf of Skylit Zone	1.89	0.89	0.000	62.66	-0.01
	Per Prototype Building	4,547	2,148	-0.022	150,376	-21.46
	Per Building sf	0.79	0.37	0.000	26.11	0.00
CZ 2 Savings	Per sf of Skylit Zone	2.54	0.89	0.000	61.74	-0.01
	Per Prototype Building	6,107	2,148	-0.040	148,186	-28.52
	Per Building sf	1.06	0.37	0.000	25.73	0.00
CZ 3 Savings	Per sf of Skylit Zone	2.53	0.89	0.000	62.95	-0.01
	Per Prototype Building	6,071	2,148	-0.017	151,089	-12.08
	Per Building sf	1.05	0.37	0.000	26.23	0.00
CZ 4 Savings	Per sf of Skylit Zone	2.78	0.89	0.000	61.61	0.00
	Per Prototype Building	6,668	2,148	-0.018	147,861	-11.73
	Per Building sf	1.16	0.37	0.000	25.67	0.00
CZ 5 Savings	Per sf of Skylit Zone	2.72	1.05	0.000	68.65	0.00
	Per Prototype Building	6,530	2,522	-0.011	164,759	-8.10
	Per Building sf	1.13	0.44	0.000	28.60	0.00
CZ 6 Savings	Per sf of Skylit Zone	2.78	1.05	0.000	67.44	0.00
	Per Prototype Building	6,662	2,522	-0.009	161,853	-6.12
	Per Building sf	1.16	0.44	0.000	28.10	0.00
CZ 7 Savings	Per sf of Skylit Zone	2.85	1.05	0.000	66.59	0.00
	Per Prototype Building	6,837	2,522	-0.009	159,823	-6.18
	Per Building sf	1.19	0.44	0.000	27.75	0.00
CZ 8 Savings	Per sf of Skylit Zone	2.88	1.05	0.000	66.57	0.00
	Per Prototype Building	6,920	2,522	-0.013	159,772	-8.95
	Per Building sf	1.20	0.44	0.000	27.74	0.00
CZ 9 Savings	Per sf of Skylit Zone	2.79	1.05	0.000	65.96	-0.01
	Per Prototype Building	6,700	2,522	-0.035	158,293	-24.38
	Per Building sf	1.16	0.44	0.000	27.48	0.00
CZ 10 Savings	Per sf of Skylit Zone	2.82	1.05	0.000	67.39	-0.01
	Per Prototype Building	6,766	2,522	-0.025	161,738	-17.46
	Per Building sf	1.17	0.44	0.000	28.08	0.00
CZ 11 Savings	Per sf of Skylit Zone	2.64	1.14	0.000	66.85	-0.01
	Per Prototype Building	6,341	2,733	-0.033	160,438	-24.31
	Per Building sf	1.10	0.47	0.000	27.85	0.00
CZ 12 Savings	Per sf of Skylit Zone	2.78	1.14	0.000	65.81	-0.01
	Per Prototype Building	6,673	2,733	-0.035	157,932	-24.52
	Per Building sf	1.16	0.47	0.000	27.42	0.00
CZ 13 Savings	Per sf of Skylit Zone	2.92	1.14	0.000	68.94	-0.01
	Per Prototype Building	7,016	2,727	-0.028	165,462	-19.48
	Per Building sf	1.22	0.47	0.000	28.73	0.00
CZ 14 Savings	Per sf of Skylit Zone	2.91	1.14	0.000	70.42	-0.08
	Per Prototype Building	6,978	2,727	-0.286	169,010	-202.66
	Per Building sf	1.21	0.47	0.000	29.34	-0.04
CZ 15 Savings	Per sf of Skylit Zone	3.04	1.14	0.000	69.78	0.00
	Per Prototype Building	7,292	2,727	-0.016	167,476	-10.92
	Per Building sf	1.27	0.47	0.000	29.08	0.00
CZ 16 Savings	Per sf of Skylit Zone	2.41	0.89	0.000	61.98	-0.28
	Per Prototype Building	5,791	2,148	-0.886	148,757	-666.73
	Per Building sf	1.01	0.37	0.000	25.83	-0.12

Figure 45: Energy Savings for Small Retail Toplit Building Prototype

5.2.5 Measure Cost

For the office building prototype, accounting for different orientations and space use (as open office or private office), we identified that 8 photocontrols will be required. These are identified by red dots on Figure 5. Each photocontrols will have 2 sensors - one for the primary daylit zone and one for the secondary daylit zone. In total 111 luminaires will be controlled by the 8 photocontrol. We calculated the cost of photocontrols, installation of sensors, and commissioning of ballasts using the cost survey of photocontrols described in Section 5.2.1. As shown in Figure 46, the average cost was $7,889

DIMMING SYSTEM

Measure 1 Prototype Office Sidelit Building		Wireless Job Cost	Wired Job Cost	Average Cost
Measure 1 - 8 photocontrols with 111 dimming fixtures controlled.	Purchase Price	$2,088.00	$1,028.00	$1,558.00
	Installation (SAC)	$671.00	$2,683.00	$1,677.00
	Commissioning	$4,654.00	$4,654.00	$4,654.00
	Total Cost	**$7,413.00**	**$8,365.00**	**$7,889.00**

Figure 46: Prototype Office Sidelit Building - Photocontrols Costs

For the small retail building prototype, we calculated the cost of photocontrols, installation of sensors, and commissioning of ballasts using the cost survey of photocontrols described in Section 5.2.1. As shown in Figure 47, the average cost was $1,808.75

DIMMING SYSTEM

Measure 2 Prototype Small Retail Toplit Bldg		Wireless Job Cost	Wired Job Cost	Average Cost
Measure 2 - 1 photocontrol with 36 dimming fixtures controlled.	Purchase Price	$261.00	$128.50	$194.75
	Installation (SAC)	$42.00	$168.00	$105.00
	Commissioning	$1,509.00	$1,509.00	$1,509.00
	Total Cost	**$1,812.00**	**$1,805.50**	**$1,808.75**

Figure 47: Prototype Small Retail Toplit Building - Photocontrols Costs

5.2.6 Cost Effectiveness Analysis

Figure 48 below provides the cost effectiveness analysis for the proposed measure of requiring photocontrols in primary and secondary daylit zones.

Measure 1: Photocontrols in Sidelit Spaces

		Measure Life (Years)	Additional Costs- Current Measure Costs (Relative to Basecase) (Dollars)		Additional Cost - Post-Adoption Measure Costs (Relative to Basecase) (Dollars)		PV of Additional Maintenance Costs (Savings) (Relative to Basecase) (PV Dollars)		PV of Energy Cost Savings (PV Dollars)	Δ LCC Per Prototype Building (Dollars)	
	Measure Name		Per Unit	Per Proto Building	Per Unit	Per Proto Building	Per Unit	Per Proto Building	Per Proto Building	Based on Current Costs	Based on Post-Adoption Costs
CZ 1	Measure 1	15	-	$7,889	-	$7,889	-	$0	$49,043	-$41,154	-$41,154
CZ 2	Measure 1	15	-	$7,889	-	$7,889	-	$0	$48,853	-$40,964	-$40,964
CZ 3	Measure 1	15	-	$7,889	-	$7,889	-	$0	$48,886	-$40,997	-$40,997
CZ 4	Measure 1	15	-	$7,889	-	$7,889	-	$0	$48,967	-$41,078	-$41,078
CZ 5	Measure 1	15	-	$7,889	-	$7,889	-	$0	$45,556	-$37,667	-$37,667
CZ 6	Measure 1	15	-	$7,889	-	$7,889	-	$0	$44,191	-$36,302	-$36,302
CZ 7	Measure 1	15	-	$7,889	-	$7,889	-	$0	$44,687	-$36,798	-$36,798
CZ 8	Measure 1	15	-	$7,889	-	$7,889	-	$0	$44,324	-$36,435	-$36,435
CZ 9	Measure 1	15	-	$7,889	-	$7,889	-	$0	$43,889	-$36,000	-$36,000
CZ 10	Measure 1	15	-	$7,889	-	$7,889	-	$0	$44,197	-$36,308	-$36,308
CZ 11	Measure 1	15	-	$7,889	-	$7,889	-	$0	$31,949	-$24,060	-$24,060
CZ 12	Measure 1	15	-	$7,889	-	$7,889	-	$0	$31,768	-$23,879	-$23,879
CZ 13	Measure 1	15	-	$7,889	-	$7,889	-	$0	$25,450	-$17,561	-$17,561
CZ 14	Measure 1	15	-	$7,889	-	$7,889	-	$0	$25,581	-$17,692	-$17,692
CZ 15	Measure 1	15	-	$7,889	-	$7,889	-	$0	$25,260	-$17,371	-$17,371
CZ 16	Measure 1	15	-	$7,889	-	$7,889	-	$0	$49,047	-$41,158	-$41,158

Figure 48: Cost Effectiveness Table: Measure 1 - Photocontrols in Sidelit Spaces

Figure 49 below provides the cost effectiveness analysis for the proposed measure of requiring photocontrols in skylit zones.

Measure 2: Photocontrols in Skylit Spaces

		Measure Life (Years)	Additional Costs- Current Measure Costs (Relative to Basecase) (Dollars)		Additional Cost - Post-Adoption Measure Costs (Relative to Basecase) (Dollars)		PV of Additional Maintenance Costs (Savings) (Relative to Basecase) (PV Dollars)		PV of Energy Cost Savings (PV Dollars)	Δ LCC Per Prototype Building (Dollars)	
	Measure Name		Per Unit	Per Proto Building	Per Unit	Per Proto Building	Per Unit	Per Proto Building	Per Proto Building	Based on Current Costs	Based on Post-Adoption Costs
CZ 1	Measure 2	15	-	$1,809	-	$1,809	-	$0	$13,381	-$11,572	-$11,572
CZ 2	Measure 2	15	-	$1,809	-	$1,809	-	$0	$13,186	-$11,377	-$11,377
CZ 3	Measure 2	15	-	$1,809	-	$1,809	-	$0	$13,445	-$11,637	-$11,637
CZ 4	Measure 2	15	-	$1,809	-	$1,809	-	$0	$13,158	-$11,349	-$11,349
CZ 5	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,662	-$12,854	-$12,854
CZ 6	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,404	-$12,595	-$12,595
CZ 7	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,223	-$12,414	-$12,414
CZ 8	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,218	-$12,410	-$12,410
CZ 9	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,085	-$12,277	-$12,277
CZ 10	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,393	-$12,584	-$12,584
CZ 11	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,276	-$12,468	-$12,468
CZ 12	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,053	-$12,245	-$12,245
CZ 13	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,724	-$12,915	-$12,915
CZ 14	Measure 2	15	-	$1,809	-	$1,809	-	$0	$15,023	-$13,215	-$13,215
CZ 15	Measure 2	15	-	$1,809	-	$1,809	-	$0	$14,904	-$13,095	-$13,095
CZ 16	Measure 2	15	-	$1,809	-	$1,809	-	$0	$13,180	-$11,371	-$11,371

Figure 49: Cost Effectiveness Table: Measure 2 - Photocontrols in Skylit Spaces

5.3 Proposal 3: Minimum Skylight Area Requirement

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

5.3.1 Rooftop Survey

As discussed in section 4.3.1, above, HMG surveyed a sample of 70 commercial and industrial buildings in climate zone 12 for rooftop obstructions using satellite imagery from Bing maps. Using tools available in Bing maps, the survey estimated the area of the roof, and the area of any obstructions such as packaged HVAC units. Figure 50 and Figure 51, below, show examples of the survey process, illustrating the polygon tool used to estimate roof and obstruction area (in square feet) using the polygon tool in Bing maps (polygons are shown with blue outline and green transparent overlay).

Figure 50: Screen capture of Bing maps showing polygon tool to estimate total roof area.

Figure 51: Screen capture of Bing maps showing polygon tool to estimate rooftop obstructions.

As summarized in Figure 52, below, of the 70 buildings surveyed, the maximum obstructed area was 11%. However, most buildings had much lower amounts of rooftop obstructions. The average was

2% roof obstruction, though 18 of the 70 buildings (26%) had no obstructions at all, and 50 of the 70 buildings (71%) had 2% or less obstructed area. These findings suggest that there is ample room for skylights and an increase in the skylit area requirement would not create interference with other rooftop systems in typical conditions.

	Maximum	Average	Minimum
Percent Obstructed Area	11%	2%	0%

Figure 52: Summary of Rooftop Survey Findings

In addition to identifying rooftop obstructions, the survey recorded estimates of the skylit area for buildings where skylights were present. Eleven of the 70 buildings surveyed had skylights. Of those eleven, ten buildings were estimated to have more than 50% daylit area through skylights, including five where 100% of the floor area seemed to be daylit using skylights. This finding shows that there are situations where builders or building owners choose to voluntary include more skylighting that required by code. Based on this evidence, an increase in the code requirement from the current minimum skylight daylit area of 50% to a higher value should be achievable by most buildings. We recommend that the minimum skylit area be increase to 75%, as it leaves a large margin of 25%, for areas that may not be amenable to having skylights, for privacy, or any other reason.

Detailed results of the rooftop surveys can be found in Appendix A.

5.3.2 Analysis and Recommendation

Based on the findings discussed above, on average, only 2% of a building's roof area is taken up by mechanical equipment or other obstructions. In addition, of the buildings surveyed that had existing skylights, all but one exceeded the current minimum skylit area requirement of 50%. As a result of these findings, we recommend increasing the minimum skylit are requirement from 50% to 75%.

5.3.3 Energy Savings

To develop energy savings estimates from the proposed code changes, we used two prototype buildings described in the 2008 CASE proposal for Skylighting (PG&E, 2008b).

(a) Large Retail Store: This building represents a typical retail store building that will trigger the prescriptive requirement for skylights in ½ the floor area per Title 24 -2008. Per proposed code change, it would not trigger the prescriptive requirement for skylights in 3/4th the floor area.

(b) Large Warehouse: This building represents a typical warehouse building that will trigger the prescriptive requirement for skylights in ½ the floor area per Title 24 -2008. Per proposed code change, it would not trigger the prescriptive requirement for skylights in 3/4th the floor area.

Since this prototype described above is the same used in the 2008 CASE proposal for Skylighting (PG&E, 2008b), the energy savings per sf of daylit area for the proposed 2013 code change, were obtained from the CASE report for the 2008 proposal. The savings were then applied to the prototype building with the assumption that ½ the floor are already had skylights, and that an additional 1/4th the floor area now has skylights.

Figure 53 and Figure 54 below provides the energy savings calculated for the large retail and large sidelit building prototype for each climate zone.

	Large Retail Toplit Building Prototype	Electricity Savings (kWh/yr)	Demand Savings (kW)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings (kBtu)	TDV Gas Savings (kBtu)
	Per sf of Skylit Zone	2.00	0.79	-0.012	52.46	-9.39
CZ 1	Per Prototype Building	7,493	2,975	-45.751	196,734	-35,195.99
Savings	Per Building sf	1.50	0.60	-0.009	39.35	-7.04
	Per sf of Skylit Zone	2.00	0.79	-0.012	52.43	-9.38
CZ 2	Per Prototype Building	7,493	2,975	-45.751	196,625	-35,176.63
Savings	Per Building sf	1.50	0.60	-0.009	39.33	-7.04
	Per sf of Skylit Zone	2.00	0.79	-0.012	53.34	-9.54
CZ 3	Per Prototype Building	7,493	2,975	-45.751	200,044	-35,788.20
Savings	Per Building sf	1.50	0.60	-0.009	40.01	-7.16
	Per sf of Skylit Zone	2.00	0.79	-0.012	52.44	-9.38
CZ 4	Per Prototype Building	7,493	2,975	-45.751	196,636	-35,178.62
Savings	Per Building sf	1.50	0.60	-0.009	39.33	-7.04
	Per sf of Skylit Zone	2.25	1.05	-0.002	59.94	-1.28
CZ 5	Per Prototype Building	8,437	3,922	-6.135	224,760	-4,788.66
Savings	Per Building sf	1.69	0.78	-0.001	44.95	-0.96
	Per sf of Skylit Zone	2.25	1.05	-0.002	59.38	-1.27
CZ 6	Per Prototype Building	8,437	3,922	-6.135	222,662	-4,743.96
Savings	Per Building sf	1.69	0.78	-0.001	44.53	-0.95
	Per sf of Skylit Zone	2.25	1.05	-0.002	58.31	-1.24
CZ 7	Per Prototype Building	8,437	3,922	-6.135	218,666	-4,658.83
Savings	Per Building sf	1.69	0.78	-0.001	43.73	-0.93
	Per sf of Skylit Zone	2.25	1.05	-0.002	58.64	-1.25
CZ 8	Per Prototype Building	8,437	3,922	-6.135	219,893	-4,684.97
Savings	Per Building sf	1.69	0.78	-0.001	43.98	-0.94
	Per sf of Skylit Zone	2.25	1.05	-0.002	58.57	-1.25
CZ 9	Per Prototype Building	8,437	3,922	-6.135	219,621	-4,679.16
Savings	Per Building sf	1.69	0.78	-0.001	43.92	-0.94
	Per sf of Skylit Zone	2.02	1.05	-0.008	59.90	-7.15
CZ 10	Per Prototype Building	7,560	3,922	-30.784	224,607	-26,798.25
Savings	Per Building sf	1.51	0.78	-0.006	44.92	-5.36
	Per sf of Skylit Zone	1.85	0.99	-0.014	48.48	-10.57
CZ 11	Per Prototype Building	6,951	3,721	-51.726	181,792	-39,639.69
Savings	Per Building sf	1.39	0.74	-0.010	36.36	-7.93
	Per sf of Skylit Zone	1.85	0.99	-0.014	47.57	-10.37
CZ 12	Per Prototype Building	6,951	3,721	-51.726	178,390	-38,897.96
Savings	Per Building sf	1.39	0.74	-0.010	35.68	-7.78
	Per sf of Skylit Zone	2.01	1.03	-0.011	51.08	-8.37
CZ 13	Per Prototype Building	7,522	3,858	-42.054	191,543	-31,378.77
Savings	Per Building sf	1.50	0.77	-0.008	38.31	-6.28
	Per sf of Skylit Zone	2.01	1.03	-0.011	52.64	-8.62
CZ 14	Per Prototype Building	7,522	3,858	-42.054	197,395	-32,337.49
Savings	Per Building sf	1.50	0.77	-0.008	39.48	-6.47
	Per sf of Skylit Zone	2.01	1.03	-0.011	51.94	-8.51
CZ 15	Per Prototype Building	7,522	3,858	-42.054	194,790	-31,910.70
Savings	Per Building sf	1.50	0.77	-0.008	38.96	-6.38
	Per sf of Skylit Zone	2.00	0.79	-0.012	52.62	-9.41
CZ 16	Per Prototype Building	7,493	2,975	-45.751	197,325	-35,301.77
Savings	Per Building sf	1.50	0.60	-0.009	39.46	-7.06

Figure 53: Energy Savings for Large Retail Building Prototype

Large Warehouse Toplit Building Prototype		Electricity Savings (kWh/yr)	Demand Savings (kW)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings (kBtu)	TDV Gas Savings (kBtu)
CZ 1 Savings	Per sf of Skylit Zone	1.03	0.43	0.000	28.69	0.00
	Per Prototype Building	6,153	2,569	0.000	172,125	0.00
	Per Building sf	0.77	0.32	0.000	21.52	0.00
CZ 2 Savings	Per sf of Skylit Zone	1.03	0.43	0.000	28.64	0.00
	Per Prototype Building	6,153	2,569	0.000	171,832	0.00
	Per Building sf	0.77	0.32	0.000	21.48	0.00
CZ 3 Savings	Per sf of Skylit Zone	1.03	0.43	0.000	29.09	0.00
	Per Prototype Building	6,153	2,569	0.000	174,516	0.00
	Per Building sf	0.77	0.32	0.000	21.81	0.00
CZ 4 Savings	Per sf of Skylit Zone	1.03	0.43	0.000	28.62	0.00
	Per Prototype Building	6,153	2,569	0.000	171,715	0.00
	Per Building sf	0.77	0.32	0.000	21.46	0.00
CZ 5 Savings	Per sf of Skylit Zone	1.12	0.52	0.000	30.05	0.00
	Per Prototype Building	6,719	3,134	0.000	180,305	0.00
	Per Building sf	0.84	0.39	0.000	22.54	0.00
CZ 6 Savings	Per sf of Skylit Zone	1.12	0.52	0.000	29.79	0.00
	Per Prototype Building	6,719	3,134	0.000	178,720	0.00
	Per Building sf	0.84	0.39	0.000	22.34	0.00
CZ 7 Savings	Per sf of Skylit Zone	1.12	0.52	0.000	29.29	0.00
	Per Prototype Building	6,719	3,134	0.000	175,744	0.00
	Per Building sf	0.84	0.39	0.000	21.97	0.00
CZ 8 Savings	Per sf of Skylit Zone	1.12	0.52	0.000	29.41	0.00
	Per Prototype Building	6,719	3,134	0.000	176,478	0.00
	Per Building sf	0.84	0.39	0.000	22.06	0.00
CZ 9 Savings	Per sf of Skylit Zone	1.12	0.52	0.000	29.37	0.00
	Per Prototype Building	6,719	3,134	0.000	176,207	0.00
	Per Building sf	0.84	0.39	0.000	22.03	0.00
CZ 10 Savings	Per sf of Skylit Zone	1.08	0.52	0.000	30.03	0.00
	Per Prototype Building	6,508	3,134	0.000	180,161	0.00
	Per Building sf	0.81	0.39	0.000	22.52	0.00
CZ 11 Savings	Per sf of Skylit Zone	1.04	0.56	0.000	28.28	0.00
	Per Prototype Building	6,233	3,373	0.000	169,692	0.00
	Per Building sf	0.78	0.42	0.000	21.21	0.00
CZ 12 Savings	Per sf of Skylit Zone	1.04	0.56	0.000	27.80	0.00
	Per Prototype Building	6,233	3,373	0.000	166,824	0.00
	Per Building sf	0.78	0.42	0.000	20.85	0.00
CZ 13 Savings	Per sf of Skylit Zone	1.18	0.59	0.000	30.11	0.00
	Per Prototype Building	7,068	3,530	0.000	180,679	0.00
	Per Building sf	0.88	0.44	0.000	22.58	0.00
CZ 14 Savings	Per sf of Skylit Zone	1.18	0.59	0.000	30.96	0.00
	Per Prototype Building	7,068	3,530	0.000	185,764	0.00
	Per Building sf	0.88	0.44	0.000	23.22	0.00
CZ 15 Savings	Per sf of Skylit Zone	1.18	0.59	0.000	30.57	0.00
	Per Prototype Building	7,068	3,530	0.000	183,401	0.00
	Per Building sf	0.88	0.44	0.000	22.93	0.00
CZ 16 Savings	Per sf of Skylit Zone	1.03	0.43	0.000	28.79	0.00
	Per Prototype Building	6,153	2,569	0.000	172,734	0.00
	Per Building sf	0.77	0.32	0.000	21.59	0.00

Figure 54: Energy Savings for Large Warehouse Building Prototype

5.3.4 Measure Cost

The incremental costs for this measure are:

(a) Cost of skylights in the additional 1/4th the space area

(b) Additional cost to wire and commission luminaires that is in the additional 1/4th the space area.

In the prototype building 1/4th the space area is 2,000sf. For an 8 x 10 conservative luminaire spacing, this results in a maximum luminaire count of 16, Commissioning costs for 16 luminaires was calculated the cost survey of photocontrols described in Section 5.2.1. The purchase price of photocontrols is zero, because it is assumed that the photocontrol and sensor have already been bought to control lighting in the ½ of the space area per Title 24-2008.

The cost of a single 15 sf skylight (installed) was obtained from the 2008 Title 24 CASE report on Skylighting (PG&E, 2008b - Table 3) as $379. In our prototype, to daylight the additional 1/4th the space needs four (4) skylights (See Figure 10).

DIMMING SYSTEM

Measure 3 Prototype Large Toplit Bldg		**Wireless Job Cost**	**Wired Job Cost**	**Average Cost**
Measure 3 - existing photocontrols with 16 dimming fixutures controlled	Purchase Price	$0.00	$0.00	$0.00
	Installation (SAC)	$0.00	$0.00	$0.00
	Commissioning	$670.67	$670.67	$670.67
	Skylights (installed)	$1,516.00	$1,516.00	$1,516.00
	Total Cost	**$2,186.67**	**$2,186.67**	**$2,186.67**

Figure 55: Prototype Large Toplit Building - Photocontrols Costs

5.3.5 Cost Effectiveness

Figure 56 provides the cost effectiveness analysis for the proposed measure of requiring photocontrols in primary and secondary daylit zones.

Measure 3&4 : Increase Minimum Skylit Area and Reduce Space Area Trigger

	Measure Name	Measure Life (Years)	Additional Costs- Current Measure Costs (Relative to Basecase) (Dollars)		Additional Cost - Post-Adoption Measure Costs (Relative to Basecase) (Dollars)		PV of Additional Maintenance Costs (Savings) (Relative to Basecase) (PV Dollars)		PV of Energy Cost Savings (PV Dollars)	Δ LCC Per Prototype Building (Dollars)	
			Per Unit	Per Proto Building	Per Unit	Per Proto Building	Per Unit	Per Proto Building	Per Proto Building	Based on Current Costs	Based on Post-Adoption Costs
CZ 1	Measure 3&4	15	-	$2,187	-	$2,187	-	$0	$19,160	-$16,974	-$16,974
CZ 2	Measure 3&4	15	-	$2,187	-	$2,187	-	$0	$19,141	-$16,954	-$16,954
CZ 3	Measure 3&4	15	-	$2,187	-	$2,187	-	$0	$19,460	-$17,274	-$17,274
CZ 4	Measure 3&4	15	-	$2,187	-	$2,187	-	$0	$19,136	-$16,950	-$16,950
CZ 5	Measure 3&4	15	-	$2,187	-	$2,187	-	$0	$23,685	-$21,498	-$21,498
CZ 6	Measure 3&4	15	-	$2,187	-	$2,187	-	$0	$23,468	-$21,281	-$21,281
CZ 7	Measure 3&4	15	-	$2,187	-	$2,187	-	$0	$23,057	-$20,870	-$20,870
CZ 8	Measure 3&4	15	-	$2,187	-	$2,187	-	$0	$23,175	-$20,989	-$20,989
CZ 9	Measure 3&4	15	-	$2,187	-	$2,187	-	$0	$23,144	-$20,958	-$20,958
CZ 10	Measure 3&4	15	-	$2,187	-	$2,187	-	$0	$22,100	-$19,914	-$19,914
CZ 11	Measure 3&4	15	-	$2,187	-	$2,187	-	$0	$17,672	-$15,485	-$15,485
CZ 12	Measure 3&4	15	-	$2,187	-	$2,187	-	$0	$17,355	-$15,168	-$15,168
CZ 13	Measure 3&4	15	-	$2,187	-	$2,187	-	$0	$19,443	-$17,257	-$17,257
CZ 14	Measure 3&4	15	-	$2,187	-	$2,187	-	$0	$20,018	-$17,831	-$17,831
CZ 15	Measure 3&4	15	-	$2,187	-	$2,187	-	$0	$19,758	-$17,571	-$17,571
CZ 16	Measure 3&4	15	-	$2,187	-	$2,187	-	$0	$19,222	-$17,035	-$17,035

Figure 56: Cost Effectiveness Table: Measure 3 - Increase Minimum Skylit Area

5.4 Proposal 4: Space Area Threshold for Requiring Skylights

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

5.4.1 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 58 through Figure 60 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 57, 3C covers most of central and coastal California, 4C and 5B cover northern California, and 2B covers a small region in southern California.

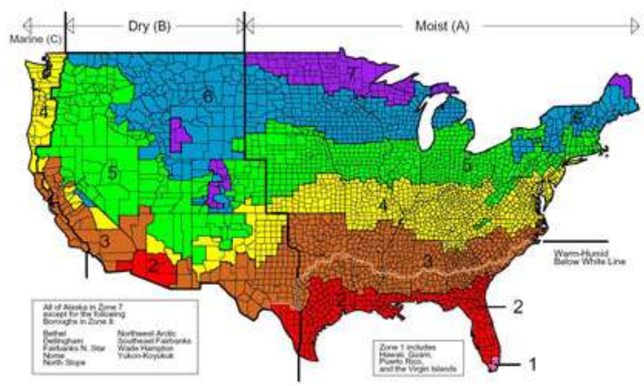


Figure 57: ASHRAE Climate Zones

Figure 58 through Figure 60 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 BC ratio will be at least 1.0. Calculated per Equation 1

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 58: 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 59: 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 60: Breakpoint Area Analysis - Warehouse Low Ceiling Building

5.4.2 Recommendation

As seen in the tables above, the highest breakpoint area for all four climate zones and all three building types ranges was 2,038sf, which means requiring skylights will be cost effective at 2,038sf or more. However, to be conservative, we propose that the minimum area be 5,000sf. This requirement matches the space area threshold for skylights in ASHRAE 90.1.

5.4.3 Energy Savings and Cost Effectiveness

Energy savings and cost effectiveness for this measure were calculated for the same two prototypes used to calculate energy savings for Measure 3 and are hence included in the tables in Figure 53 and Figure 54.

5.5 Proposal 5: Ceiling Height Threshold for Skylight Area Requirement

To determine if the ceiling height that triggers the requirement for skylights in Section 143 can be lowered, we first conducted a cost survey to collect updated costs for light wells. The implicit assumption here is that when ceiling heights are lowered, this necessitates a light well in the skylight design. A light well is either a constructed or assembled "well" connecting the skylight on the roof to an opening at the ceiling. It spans across a plenum spaces to bring light from the skylight to the conditioned space below the plenum.

5.5.1 Light Well Cost Survey Results

As described above, in section 4.5.1, the project team conducted a cost survey to determine the material and labor costs associated with installing a skylight with a 4' deep light well in spaces with dropped or finished ceilings. Based on input from a range of contractors, we found that costs have not changed substantially from the previous code revision. Figure 61 outlines cost information gathered from six contractors. Based on this data, the average cost of a 4' x 4' skylight with a light well was determined to be $1,373, compared to $561 for the skylight without a light well. Using the difference between the two average values, it was estimated that the average cost of a 4' deep light well is $812.

	4x4 Skylight w/o light well	4x4 Skylight w/ light well
Contact A		$1,100
Contact B	$347	$741
Contact C	$550	$1,100
Contact D	$1,150	$2,550
Contact E	$426	
Contact F	$332	
Average	**$561**	**$1,373**

Figure 61: Installation costs of skylights, with and without light wells

Comparing this to the cost of light well collected for the 2008 Title 24 CASE report on Updates to Skylighting Requirements (PG&E, 2008b), it was concluded that the average cost of light well has not changed.

5.5.2 Updated Cost Effectiveness Analysis

In the 2008 Title 24 CASE report on Updates to Skylighting Requirements (PG&E, 2008b), the CASE team determined cost effectiveness of buildings with skylights with ceiling heights lower than 15 ft. For this proposal, we leveraged the savings calculated for those building prototypes. Details of energy savings and prototype models used can be obtained from the 2008 CASE report.

Three typical buildings with dropped ceilings described in Figure 62, were modeled in SkyCalc™ to determine energy savings, and compared to costs of adding skylights and photocontrols. For all three buildings, a 4' deep light well as assumed.

Building Type	Ceiling Height	Lighting Power Density (W/sf)
Retail	12'	1.6 W/sf
Retail	10'	1.6 W/sf
Office	10'	1.1 W/sf

Figure 62: Model building scenarios for cost effectiveness analysis

The SkyCalc™, a modeling program that determines impacts on lighting, cooling and heating energy use from various skylighting strategies and the tool made it possible to simulate a range of skylight to floor area ratios for multiple climate zones throughout the state.

The cost effectiveness analysis from the 2008 study was redone with the following changes:

(a) Updated TDV Energy costs

(b) Updated costs for photocontrols

The table in Figure 63 below gives the comparison of values used in the 2008 and 2013 analyses.

	2008 analysis	2013 analysis
Cost of Photocontrols		
Per Unit	$2,500	$560
Cost of Energy		
Electric Ave. TDV $/kWh	$1.63	$1.86
Gas Ave. TDV $/Therm	$12.72	$14.59

Figure 63: Comparison of 2008 and 2013 Analyses

Because SkyCalc™ produces only annual energy savings, it was necessary to use an average TDV value to determine cost effectiveness. The average TDV value of $1.86/kWh used in the analysis represents a conservative assumption because energy savings from skylighting tend to be highest at peak demand times that have higher TDV values.

Cost effectiveness of skylights in spaces with lower ceiling heights for the three models was this recalculated. The analysis assessed two different skylight types (single and double glazed), as well as two different control scenarios (two levels plus off, and on/off only for 2/3 of the lamps). The analysis also considered a range of quantity of skylights, determined by skylight to floor area ratios (SFR) ranging from 0 to 12%. Cost effectiveness was determined for a broad range of climate zones. However, only results for climate zones 3 (San Francisco Bay Area coastal-northern California) and 7 (San Diego coastal southern California) are shown here, as illustrations.

The benefit to cost ratio (BC Ratio) tables shown below illustrate where skylighting was found to be cost effective for each model building type. Figure 64, below, shows the BC Ratios for a range of scenarios for retail buildings with 1.6 W/sf LPD, 12' ceilings and 4' lightwells. BC Ratios of 1 or higher are considered to be cost effective, and are highlighted below in grey. As shown, only a handful of conditions for this scenario are cost effective.

		Single Glazed Acrylic		**Double Glazed Acrylic**	
Climate Zone	**SFR**	two level plus off	on/off for 2/3 of lamps	two level plus off	on/off for 2/3 of lamps
CZ 3	0%	0.00	0.00	0.00	0.00
	1%	0.23	0.49	0.18	0.45
	2%	0.70	0.87	0.64	0.82
	3%	0.84	0.95	0.82	0.93
	4%	0.86	0.91	0.87	0.93
	5%	0.80	0.84	0.84	0.89
	6%	0.74	0.76	0.80	0.83
	8%	0.59	0.60	0.70	0.71
	10%	0.46	0.45	0.60	0.60
	12%	0.34	0.33	0.51	0.50
CZ 7	0%	0.00	0.00	0.00	0.00
	1%	0.29	0.60	0.23	0.53
	2%	0.88	**1.05**	0.76	0.95
	3%	**1.06**	**1.13**	0.97	**1.05**
	4%	**1.04**	**1.08**	0.97	**1.02**
	5%	0.98	1.00	0.94	0.96
	6%	0.90	0.90	0.86	0.88
	8%	0.73	0.73	0.72	0.72
	10%	0.58	0.57	0.59	0.58
	12%	0.45	0.44	0.47	0.46

Figure 64: BC Ratios (Base Code) - Retail, 12' Ceiling, 1.6 W/sf LPD, 4' lightwells

Cost effectiveness is even less likely for lower ceiling heights, as shown in Figure 65 below, illustrating a retail building with 10' ceilings. In this case, none of the scenarios shown were found to be cost effective.

Climate Zone	SFR	Single Glazed Acrylic two level plus off	Single Glazed Acrylic on/off for 2/3 of lamps	Double Glazed Acrylic two level plus off	Double Glazed Acrylic on/off for 2/3 of lamps
CZ 3	0%	0.00	0.00	0.00	0.00
	1%	0.19	0.39	0.15	0.35
	2%	0.58	0.70	0.53	0.66
	3%	0.69	0.77	0.68	0.76
	4%	0.72	0.75	0.73	0.77
	5%	0.68	0.70	0.72	0.75
	6%	0.63	0.64	0.68	0.70
	8%	0.52	0.52	0.61	0.62
	10%	0.40	0.40	0.53	0.53
	12%	0.30	0.29	0.45	0.45
CZ 7	0%	0.00	0.00	0.00	0.00
	1%	0.24	0.47	0.18	0.41
	2%	0.71	0.84	0.62	0.76
	3%	0.87	0.92	0.81	0.86
	4%	0.87	0.89	0.81	0.85
	5%	0.83	0.83	0.79	0.80
	6%	0.76	0.77	0.74	0.75
	8%	0.64	0.63	0.63	0.62
	10%	0.51	0.50	0.52	0.51
	12%	0.40	0.39	0.42	0.41

Figure 65: BC Ratios (Base Code) - Retail, 10’ Ceiling, 1.6 W/sf LPD, 4’ lightwells

Similarly, as shown below in Figure 66, traditional skylight products are even less cost effective for spaces with lower LPDs such as offices.

Climate Zone	SFR	Single Glazed Acrylic two level plus off	Single Glazed Acrylic on/off for 2/3 of lamps	Double Glazed Acrylic two level plus off	Double Glazed Acrylic on/off for 2/3 of lamps
CZ 3	0%	0.00	0.00	0.00	0.00
	1%	0.14	0.25	0.12	0.24
	2%	0.32	0.37	0.32	0.38
	3%	0.34	0.36	0.37	0.40
	4%	0.31	0.32	0.36	0.38
	5%	0.26	0.27	0.34	0.35
	6%	0.21	0.21	0.31	0.31
	8%	0.11	0.11	0.24	0.24
	10%	0.02	0.02	0.18	0.18
	12%	(0.06)	(0.06)	0.12	0.12
CZ 7	0%	0.00	0.00	0.00	0.00
	1%	0.22	0.33	0.16	0.29
	2%	0.42	0.46	0.39	0.44
	3%	0.43	0.45	0.41	0.43
	4%	0.40	0.40	0.38	0.39
	5%	0.34	0.34	0.34	0.34
	6%	0.29	0.29	0.29	0.29
	8%	0.18	0.18	0.20	0.20
	10%	0.09	0.09	0.12	0.11
	12%	0.01	0.01	0.05	0.04

Figure 66: BC Ratios (Base Code) - Office, 10’ Ceiling, 1.1 W/sf LPD, 4’ lightwells

Results shown in the above tables are similar to cost effectiveness conditions for other climate zones. Based on these findings, traditional skylights with finished light wells are not considered cost effective at this time.

Implications for Reach Code Proposal.

In developing reach codes for cities that want to make use of advanced energy codes to meet their Greenhouse Gas reduction objectives, the California Energy Commissions has developed Reach TDV energy costs values that are 25% higher than those used for evaluating the Title 24, part 6 building energy efficiency standards. We updated the BC ratios in the tables in Figure 64 through Figure 66 with 25% higher energy cost values. The revised BC Ratios for Reach Code are given in Figure 67 through Figure 69.

For the Retail model with 12’ high ceilings, skylights were found to be cost effective at 3% SFR for all climate zones considered except CZ1. The results for CZ 3 and CZ 7 are given in Figure 67.

Climate Zone	SFR	Single Glazed Acrylic: two level plus off	Single Glazed Acrylic: on/off for 2/3 of lamps	Double Glazed Acrylic: two level plus off	Double Glazed Acrylic: on/off for 2/3 of lamps
CZ 3	0%	0.00	0.00	0.00	0.00
	1%	0.28	0.62	0.23	0.56
	2%	0.88	**1.09**	0.80	**1.02**
	3%	**1.05**	**1.18**	**1.02**	**1.16**
	4%	**1.08**	**1.14**	**1.08**	**1.16**
	5%	**1.01**	**1.05**	**1.05**	**1.11**
	6%	0.92	0.95	1.00	**1.04**
	8%	0.74	0.75	0.88	0.89
	10%	0.57	0.57	0.75	0.75
	12%	0.42	0.41	0.63	0.63
CZ 7	0%	0.00	0.00	0.00	0.00
	1%	0.36	0.75	0.28	0.66
	2%	**1.10**	**1.31**	0.95	**1.18**
	3%	**1.32**	**1.41**	**1.22**	**1.32**
	4%	**1.30**	**1.35**	**1.22**	**1.28**
	5%	**1.22**	**1.24**	**1.17**	**1.20**
	6%	**1.12**	**1.13**	**1.08**	**1.10**
	8%	0.92	0.91	0.90	0.90
	10%	0.73	0.71	0.73	0.72
	12%	0.56	0.55	0.59	0.58

Figure 67: BC Ratios (Reach Code) - Retail, 12’ Ceiling, 1.6 W/sf LPD, 4’ lightwells

The same was not found to be true for ceiling heights lower than 12’, as seen in the results in Figure 68. All climate zones except CZ 7 had BC ratios less than 1 for this case.

		Single Glazed Acrylic		Double Glazed Acrylic	
Climate Zone	**SFR**	two level plus off	on/off for 2/3 of lamps	two level plus off	on/off for 2/3 of lamps
CZ 3	0%	0.00	0.00	0.00	0.00
	1%	0.24	0.49	0.19	0.44
	2%	0.72	0.87	0.66	0.82
	3%	0.87	0.96	0.85	0.95
	4%	0.89	0.94	0.91	0.97
	5%	0.85	0.88	0.89	0.93
	6%	0.78	0.80	0.85	0.88
	8%	0.64	0.65	0.76	0.77
	10%	0.50	0.50	0.66	0.66
	12%	0.37	0.37	0.57	0.56
CZ 7	0%	0.00	0.00	0.00	0.00
	1%	0.30	0.59	0.22	0.52
	2%	0.89	**1.05**	0.78	0.95
	3%	**1.08**	**1.15**	**1.01**	**1.08**
	4%	**1.08**	**1.11**	**1.02**	**1.06**
	5%	**1.03**	**1.04**	0.99	**1.01**
	6%	0.95	0.96	0.93	0.93
	8%	0.79	0.78	0.79	0.78
	10%	0.64	0.63	0.65	0.64
	12%	0.50	0.49	0.53	0.51

Figure 68: BC Ratios (Reach Code) - Retail, 10' Ceiling, 1.6 W/sf LPD, 4' lightwells

The same was also true for lower LPD cases such as the Office model with less than 12' ceiling height as shown in Figure 69.

Climate Zone	SFR	Single Glazed Acrylic: two level plus off	Single Glazed Acrylic: on/off for 2/3 of lamps	Double Glazed Acrylic: two level plus off	Double Glazed Acrylic: on/off for 2/3 of lamps
CZ 3	0%	0.00	0.00	0.00	0.00
	1%	0.18	0.32	0.16	0.30
	2%	0.40	0.46	0.40	0.48
	3%	0.42	0.45	0.46	0.50
	4%	0.38	0.40	0.45	0.47
	5%	0.33	0.34	0.42	0.43
	6%	0.27	0.27	0.39	0.39
	8%	0.14	0.14	0.30	0.30
	10%	0.03	0.02	0.22	0.22
	12%	-0.07	-0.08	0.15	0.15
CZ 7	0%	0.00	0.00	0.00	0.00
	1%	0.27	0.41	0.19	0.36
	2%	0.53	0.58	0.48	0.55
	3%	0.54	0.56	0.51	0.54
	4%	0.49	0.50	0.48	0.49
	5%	0.43	0.43	0.42	0.43
	6%	0.36	0.36	0.37	0.37
	8%	0.23	0.22	0.25	0.24
	10%	0.12	0.11	0.15	0.14
	12%	0.02	0.01	0.06	0.05

Figure 69: BC Ratios (Reach Code) - Office, 10' Ceiling, 1.1 W/sf LPD, 4' lightwells

Thus, when considering skylighting for reach codes with a higher projected energy valuation, we did find that skylights with light wells were cost-effective for ceiling heights greater than 12 feet.

5.5.3 Tubular Daylighting Devices (TDDs)

HMG also collected and analyzed cost data from two manufacturers of tubular daylighting devices (TDDs) and hybrid TDD products that have integrated pre-assembled specular light wells. Because of their highly specular light wells, and the used of diffusing lenses to distribute daylight more evenly throughout the space, these TDD products are expected to be more effective at delivering daylight than traditional skylight products with finished drywall light wells.

However, there is currently no independent methodology for determining annual daylighting potential and energy savings for these products (manufacturers use proprietary product-specific simulation methods to estimate daylight potential and energy savings). Without an accepted simulation methodology that can accommodate a range of such products, we found that it was not possible to account for the higher performance potential of TDDs. We looked at the cost effectiveness of these products, by using the same energy savings as described above for 'traditional' skylight with light well products, and the cost collected from the TDD and hybrid TDD manufacturers, and found that without correctly accounting for the additional energy savings we did not achieve B/C ratios greater than 1 for most climate zones.

Finally, it was determined that there is a need to develop a daylighting energy simulation method that accounts for the enhanced daylighting performance for the TTDs and hybrid TDDs. Without these, it was not possible to determine their cost effectiveness appropriately.

5.5.4 Recommendations

Based on updated cost of traditional light wells, lower cost of photocontrols, and higher cost of energy, compared to the same analysis done in 2008, reducing the ceiling height threshold was not found to be cost effective at this time, and is therefore not recommended. We recommend that a daylighting energy simulation method be developed that accounts for the enhanced daylighting performance for the TTDs and hybrid TDDs.

In developing reach codes for cities that want to make use of advanced energy codes to meet their Greenhouse Gas reduction objectives, the California Energy Commissions has developed Reach TDV energy costs values that are 25% higher than those used for evaluating the Title 24, part 6 building energy efficiency standards. When considering skylighting for reach codes with a higher projected energy valuation, we did find that skylights with light wells were cost-effective for ceiling heights greater than 12 feet in the retail prototype.

Current plans for the Reach code (Title 24, part 11 also known as CALGreen) include voluntary tiers that are 15% and 30% beyond the proposed base building energy efficiency code (Title 24, part 6). As such no added code language is required as skylighting is a prescriptive requirements that would be a method to achieve the higher energy efficiency targets. For those cities that do adopt either Tier 1 or Tier 2 Reach codes, adding skylighting to retail spaces with ceiling heights as low as 12 feet is one cost-effective method to comply with these advanced energy codes.

5.6 Statewide Energy Savings Estimation

To estimate the statewide energy savings for each measure in their first year in effect HMG applied the unit savings per square foot estimates to the estimated square footage of new construction that would trigger each measure.

Based on non-residential new construction forecast, described in Appendix D, the applicable construction forecast for 2014 was estimated for each measure. A different mix of new construction building types was selected from the forecast data, based on applicability of the measure and similarity with the prototype building. Where possible, estimates were generated from the Non-Residential New Construction (NRNC) Database or estimated based on the CASE team's best judgment. The table in Figure 71 gives the percentages applied, for each measure and the reasoning used.

Since Daylighting is a climate dependent measure, the total energy and energy cost savings potential for each of the three measures, are given in tables in Figure 44, Figure 45, Figure 53 and Figure 54. Applying these unit estimates to the statewide estimate of new construction, based on the mix of building types described in Figure 71, results in first year statewide energy savings given in Figure 70.

	Total Electric Energy Savings (GWh)	Total Gas Energy Savings (MMtherms)	Total TDV Savings (Mil. $)
Measure 1	45.57	-0.03	$93.52
Measure 2	2.89	0.00	$6.11
Measure 3	46.74	-0.06	110.30
TOTAL Statewide	95.19	-0.09	209.93

Figure 70: Statewide Energy Savings Estimates

Space Type	Measure 1	Reasoning	Measure 2	Reasoning	Measure 3	Reasoning
OFF-SMALL	100%	Same as prototype	3.66%	From NRNC database - percent 'Office' space area with skylights	0%	Not expected to have 5,000sf of contiguous space and 15' ceiling
OFF-LRG	100%	Same as prototype	3.66%	From NRNC database - percent 'Office' space area with skylights	0%	Not expected to have 5,000sf of contiguous space and 15' ceiling
REST	50%	Has sidelighting, but layout different from prototype	0%	No or very little toplighting	0%	Not expected to have 5,000sf of contiguous space and 15' ceiling
RETAIL	0%	No or very little sidelighting	0%	Expected to have more than 2,500 of skylit area	26.92%	From NRNC database - percent 'Single Storey Large Retail' from total 'Retail' space
FOOD	0%	No or very little sidelighting	0%	Expected to have more than 2,500 of skylit area	26.92%	From NRNC database - percent 'Single Storey Large Retail' from total 'Retail' space
NWHSE	0%	No or very little sidelighting	0%	Expected to have more than 2,500 of skylit area	100%	Most spaces expected to trigger requirement
RWHSE	0%	No or very little sidelighting	0%	Expected to have more than 2,500 of skylit area	100%	Most spaces expected to trigger requirement
SCHOOL	100%	Similar to prototype	8.30%	From NRNC database - percent 'Small School' space area with skylights	5.83%	From NRNC database - percent 'Gymnasium' area from total 'School' area
COLLEGE	100%	Similar to prototype	1.25%	From NRNC database - percent 'Community College' space area with skylights	5.83%	From NRNC database - percent 'Gymnasium' area from total 'School' area
HOSP	0%	Not required to follow Title-24	0%	Not required to follow Title-24	0%	Not required to follow Title-24
HOTEL	25%	Conference rooms and lobbly similar to prototype, guest rooms don’t have general lighting	0%	No or very little toplighting	0%	No or very little toplighting
MISC	50%	Community center, assembly spaces, laboratories etc. have sidelighting, but layout different from prototype	0.76%	From NRNC database - percent 'Other' space area with skylights	0%	Not expected to have 5,000sf of contiguous space and 15' ceiling

Figure 71: Percent of Construction of Each Building Type Applicable to Measures 1, 2 and 3

6. Recommended Language for the Standards Document, ACM Manuals, and the Reference Appendices

SECTION 131 – INDOOR LIGHTING CONTROLS THAT SHALL BE INSTALLED

(a) **Area Controls.**

(unchanged)

(b) **Multi-Level Lighting Controls**.

(unchanged)

~~(c) **Daylight Areas.**~~ (d) **Automatic Daylighting Controls**

~~1. Daylight areas shall be defined as follows:~~

1. Daylit Zones shall be defined as follows:

   A. SKYLIT DAYLIT ZONE is the area on plan within a space, under each skylight, 0.7 times average ceiling height, in each direction from the edge of the rough opening of the skylight, minus any area on plan beyond a permanent obstruction that is taller than one-half the distance from the floor to the ceiling.

   B. PRIMARY SIDELIT DAYLIT ZONE is the area on plan within a space, directly adjacent to each vertical glazing, one window head height deep into the space, 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 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 plan within a space, directly adjacent to each vertical glazing, two window head heights deep into the space, 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 plan beyond a permanent obstruction that is 6 feet or taller as measured from the floor.

   ~~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.~~

2. Luminaires providing general lighting in a space with more than 24 square feet of vertical glazing, that are in or partially in the skylit daylit zones and/or the primary sidelit daylit zones, shall be controlled independently by an automatic daylighting control device that meets the applicable requirements of Section 119 and is installed in accordance with Section 131(c) 2D

A. All skylit daylit zones and primary sidelit daylit zones shall be shown on plan

B. Luminaires in the skylit daylit zone shall be controlled separately from those in the primary sidelit daylit zones

C. Luminaires that fall in a skylit and primary sidelit daylit zone shall be controlled as part of the skylit daylit zone

EXCEPTION 1 to Section 131(c) 2: Total wattage of general lighting that is in, or partially in, a skylit daylit zone and/or primary sidelit daylight zone is less than 120 Watts

EXCEPTION 2 to Section 131(c) 2: Parking garages complying with Section ___.

~~2. Luminaires providing general lighting that are in or are partially in the skylit daylight area and/or the primary sidelit daylight area, shall be controlled as follows:~~

~~A. Primary sidelit and skylit daylight areas shall have at least one lighting control that:~~

~~i. Controls at least 50 percent of the general lighting power in the primary sidelit and skylit daylight areas separately from other lighting in the enclosed space.~~

~~ii. Controls luminaires in primary sidelit areas separately from skylit areas.~~

~~**EXCEPTION to Section 131(c) 2A**: Primary sidelit and skylit daylight areas that have a combined area totaling less than or equal to 250 square feet within any enclosed space.~~

~~B. For all skylit daylight areas:~~

~~i. The skylit daylight area shall be shown on the plans.~~

~~ii. All of the general lighting in the skylit area shall be controlled independently by an automatic daylighting control device that meets the applicable requirements of Section 119.~~

~~iii. The automatic daylighting control shall be installed in accordance with Section 131(c)2D.~~

~~**EXCEPTION 1 to Section 131(c)2B**: Where the total skylit daylight area in any enclosed space is less than or equal to 2,500 square feet.~~

~~**EXCEPTION 2 to Section 131(c)2B**: Skylit daylight areas where existing adjacent structures obstruct direct beam sunlight for at least 6 hours per day during the equinox as calculated using computer or graphical methods.~~

~~**EXCEPTION 3 to Section 131(c)2B**: When the skylight effective aperture is greater than 4.0 percent, and all general lighting in the skylit area is controlled by a multi-level astronomical time switch that meets the requirements of Section 119(h) and that has an override switch that meets the requirements of Section 131(d)2.~~

~~**EXCEPTION 4 to Section 131(c)2B**: Skylit daylight areas where the effective aperture is less than 0.006. The effective aperture for skylit daylight areas is specified in Section 146(a)2E.~~

~~C. The primary sidelit area(s) shall be shown on the plans, and the general lighting in the primary sidelit areas shall be controlled independently by an automatic daylighting control device that meets the applicable requirements of Section 119 and is installed in accordance with Section 131(c) 2D.~~

~~**EXCEPTION 1 to Section 131(c) 2C**: Where the total primary sidelit daylight area in any enclosed space has an area less than or equal to 2,500 square feet.~~

~~**EXCEPTION 2 to Section 131(c) 2C**: Primary sidelit daylight areas where the effective aperture is less than 0.1. The effective aperture for primary sidelit daylight areas is specified in Section 146(a)2E.~~

~~**EXCEPTION 3 to Section 131(c) 2C**: Primary sidelit daylight areas where existing adjacent structures are twice as tall as their distance away from the windows.~~

~~**EXCEPTION 4 to Section 131(c) 2C**: Parking garages.~~

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

i. Automatic daylighting control devices shall have photosensors that are located so that they are not readily accessible in accordance with the designer's or manufacturer's instructions.

ii. The location where calibration adjustments are made to the automatic daylighting control device shall be readily accessible to authorized personnel, or located within 2 feet of a ceiling access panel that is no higher than 11 feet above floor level.

iii Under all daylight conditions in all areas served by the controlled lighting, the combined illuminance from the controlled lighting and daylight is not less than the illuminance from controlled lighting when no daylight is available.

iv. When all areas served by the controlled lighting are receiving daylight illuminance levels greater than 150 percent of the illuminance from controlled lighting when no daylight is available, the controlled lighting power consumption shall be no greater than 35 percent of the rated power of the controlled lighting.

v. Automatic daylighting controls shall be multi-level, including continuous dimming, and have at least ~~one control step that is between 50 to 70 percent of rated power of the controlled lighting~~ <u>the number of control steps specified in Table 131-A</u>

EXCEPTION 1 to Section 131(c) 2Dv:

Controlled lighting having a lighting power density less than 0.3 W/ft^2.

EXCEPTION 2 to Section 131(c)2Dv: When skylights are replaced or added to on an existing building with an existing general lighting system.

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

(unchanged)

SECTION 141 – PERFORMANCE APPROACH: ENERGY BUDGETS.

In order to meet the energy budget, a proposed building's use of TDV energy calculated under Subsection (b) must be no greater than the TDV energy budget calculated under Subsection (a).

(a) **Energy Budget**. The energy budget for a proposed building is the sum of the space-conditioning, lighting, and service water-heating budgets in Subdivisions 1, 2, and 3 of this subsection, expressed in Btu per square foot of conditioned floor area per year.

1. **Space-conditioning budget**.

(unchanged)

2. **Lighting budget.** The lighting budget is the TDV energy used for lighting in a standard building calculated with a method approved by the Commission (expressed in Btu per square foot of conditioned floor area per year), and assuming that:

A. The lighting power density of the standard building, for areas where no lighting plans or specifications are submitted for permit and the occupancy of the building is known, is the maximum allowed lighting power density calculated according to Section 146(c)1; and

B. The lighting power density of the standard building, for areas where no lighting plans or specifications are submitted for permit, and the occupancy of the building is not known, is 1.2 watts per square foot; and

C. The lighting power density of the standard building, for areas where lighting plans and specifications are being submitted for permit, is the maximum allowed lighting power density calculated according to Section 146(c) 1, 2, or 3; and

D. The lighting power density of the standard building is adjusted as described in the Nonresidential ACM Manual ~~for an astronomical timeclock when required by Section 131(c)2.~~ for the presence of automatic daylighting controls in skylit and primary sidelit zones as required by Section 131(d) and the secondary sidelit zones as required by Section 146(d) in conjunction with fenestration having a visible light transmittance (VT) as required by Section 143(a).

3. **Service water-heating budget**.

(unchanged)

(b) **TDV Energy Use of Proposed Building**. The TDV energy use of a proposed building is the sum of the space-conditioning, lighting, and service water-heating TDV energy use calculated in Subdivisions 1, 2, and 3 of this subsection, using the same Compliance software used to calculate the budget under Subsection (a), and expressed in Btu per square foot of conditioned floor area per year. If any feature of the proposed building, including, but not limited to, the envelope or the space-conditioning, lighting, or service water-heating system, is not included in the building permit application, the energy performance of the feature shall be assumed to be that of the corresponding feature calculated in Subsection (a).

1. **Space-conditioning TDV energy use**.

(unchanged)

2. **Lighting TDV energy use**. The lighting TDV energy use shall be calculated using a method approved by the Commission, and using the actual lighting power density calculated under Section 146(c), including reduction of wattage by the applicable lighting power adjustment factors specified in Section 146(a)2. The lighting power density shall also be adjusted as described in the Nonresidential ACM Manual for ~~an astronomical timeclock when required by Section 131(c)2.~~ for the presence of automatic daylighting controls in the secondary sidelit zones as required by Section 146(d).

3. **Service water-heating TDV energy use**.

(unchanged)

(c) **Calculation of Budget and Energy Use**.

(unchanged)

.

(d) **Relocatable Public School Buildings.**

(unchanged)

SECTION 143 – PRESCRIPTIVE REQUIREMENTS FOR BUILDING ENVELOPES

(a) **Envelope Component Approach.**

(unchanged)

(b) **Overall Envelope TDV Energy Approach.**

(unchanged)

(c) **Minimum ~~Skylight Area~~ Daylighting Requirements 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~~ 5,000 ft^2 directly under a roof with ceiling heights greater than 15 feet shall meet Sections 143(c)1-4 below.

1. At least 75% of the floor area will 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

2. All skylit daylit zones and the primary sidelit daylit zones shall be shown on plan

3. General lighting in daylit zones shall be controlled in accordance with Section 131(c)

~~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~~ 4. ~~**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, barns 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~~ 5,000 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

A building complies with this section if the actual lighting power density calculated under Subsection (a) is no greater than the allowed indoor lighting power calculated under Subsection (c), lighting power trade-offs comply with Subsection (b) and general lighting in secondary sidelit zones comply with the lighting controls requirements in Subsection (d).

(a) **Calculation of Actual Indoor Lighting Power Density.** The actual indoor lighting power of the proposed building area is the total watts of all planned permanent and portable lighting systems; subject to the following specific requirements and adjustments under Subsections 1 through 4.

EXCEPTION to Section 146(a) Up to 0.2 watts per square foot of portable lighting for office areas shall not be required to be included in the calculation of actual indoor lighting power density.

1. **Multiple interlocked lighting systems serving a space.** When multiple interlocked lighting systems serve an auditorium, convention center, conference room, multipurpose room, or theater, the watts of all systems except the system with the highest wattage may be excluded if the lighting systems are interlocked with a non-programmable double throw switch to prevent simultaneous operation.

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:

   A. The control complies with the applicable requirements of Section 119; and

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

   C. Except as noted in TABLE 146-C, only one PAF is used for the luminaire; and

   D. Multi-level occupant sensors used to qualify for the PAF in any space less than or equal to 250 square feet enclosed by floor-to-ceiling partitions, or any size classroom, corridor, conference or waiting room, shall meet the applicable requirements of Section 119. The multi-level occupancy sensor shall be installed to meet all the multi-level and uniformity requirements of Section 131(b) for the controlled lighting. The first stage shall activate between 30-70 percent of the lighting power in a room either through an automatic or manual action, and may be a switching or dimming system. After that event occurs any of the following actions shall be assigned to occur when manually called to do so by the occupant:

      i. Activating the alternate set of lights.

      ii. Activating 100 percent of the lighting power.

      iii. Deactivating all lights.

   ~~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.~~

      ~~i. **Power Adjustment Factor for controlling Primary Sidelit Daylight Areas**:~~

      ~~The PAF for the primary sidelit daylight area shall be used only if the daylighting control is separately controlling lighting within the primary sidelit daylight area. If lighting in the primary sidelit area is controlled together with lighting in the secondary sidelit area, the PAF for the secondary sidelit area in accordance with Section 146(a) 2Eii shall be used. The PAF is a function of the effective aperture of the primary sidelit daylight area in accordance with Equation 146-A.~~

~~*EQUATION 146-A EFFECTIVE APERTURE OF THE PRIMARY SIDELIT AREA*~~

~~Where:~~

~~Window Area = rough opening of windows adjacent to the sidelit area, ft²~~

~~Window VT = visible light transmittance of window, no units~~

~~Primary Sidelit Daylight Area = see Section 131(c)1 daylight area, primary sidelit~~

~~ii. **Power Adjustment Factor for controlling secondary sidelit areas**:~~

~~To qualify for the secondary sidelit daylight area PAF, the lighting in the secondary sidelit daylight area, or the lighting in the combined primary and secondary sidelit areas shall be controlled separately from lighting outside of these sidelit areas. The PAF is a function of the effective aperture of the secondary sidelit area in accordance with Equation 146-B.~~

~~*EQUATION 146-B EFFECTIVE APERTURE OF THE SECONDARY SIDELIT AREA*~~

~~Where:~~

~~Window Area = rough opening of windows adjacent to the sidelit area, ft²~~

~~Window VT = visible light transmittance of window, no units~~

~~Primary Sidelit Daylight Area = see Section 131(c)1B daylight area, primary sidelit~~

~~Secondary Sidelit Daylight Area = see Section 131(c)1C daylight area, secondary sidelit.~~

~~iii. **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*~~

~~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*~~

~~**; or**~~

~~*EQUATION 146-E WELL CAVITY RATIO FOR NON-RECTANGULAR-SHAPED WELLS:*~~

~~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:*~~

~~Where:~~

~~ρ = specular reflectance of interior light well wall~~

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

~~F. PAFs shall not be available for demand responsive lighting controls required by Section 131(g).~~

3. **Lighting wattage excluded**.

(unchanged)

4. **Luminaire Power.**

(unchanged)

(b) **Indoor Lighting Power Trade-offs.**

(unchanged)

(c) **Calculation of Allowed Indoor Lighting Power Density.**

(unchanged)

(d) **Automatic Daylighting Controls in Secondary Daylit Zones.** Luminaires providing general lighting in a space with more than 24 square feet of vertical glazing, that are in, or partially in, the secondary sidelit daylit zones, and not included in the primary sidelit daylit zones shall be controlled independently by an automatic daylighting control device that meets the applicable requirements of Section 119 and is installed in accordance with Section 131(c) 2C

1. All secondary sidelit daylit zones shall be shown on plan.

2. Luminaires in the secondary sidelit daylit zones shall be controlled separately from those in the primary sidelit daylit zones and skylit daylit zones.

3. Luminaires that fall in a skylit and secondary sidelit daylit zone shall be controlled as part of the skylit daylit zone

EXCEPTION 1 to Section 146(d): Total wattage of general lighting that is in or partially in a secondary sidelit daylight zone(s) is less than 120 Watts

EXCEPTION 2 to Section 146(d): Parking garages complying with Section ____.

~~*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~~

TABLE 146-C LIGHTING POWER ADJUSTMENT FACTORS

TYPE OF CONTROL		TYPE OF SPACE	FACTOR
Multi-level occupant sensor (see Note 2) combined with multi-level circuitry and switching in accordance with Section 146(a)2D		Any space ≤ 250 square feet enclosed by floor-to-ceiling partitions; any size classroom, corridor, conference or waiting room.	0.20
Multi-level occupant sensor (see Note 2) that reduces lighting power at least 50% when no persons are present. May be a switching or dimming (see Note 3) system.		Hallways of hotels/motels , multi-family, dormitory, and senior housing	0.25
		Commercial and Industrial Storage stack areas (max. 2 aisles per sensor)	0.15
		Library Stacks (maximum 2 aisles per sensor)	0.15
Dimming system	Manual	Hotels/motels, restaurants, auditoriums, theaters	0.10
	Multiscene programmable	Hotels/motels, restaurants, auditoriums, theaters	0.20
Demand responsive lighting control that reduces lighting power consumption in response to a demand response signal. (See Note 1)		All building types	0.05
Manual dimming of dimmable electronic ballasts. (see Note 3)		All building types	0.10
Demand responsive lighting control that reduces lighting power consumption in response to a demand response signal when used in combination with manual dimming of dimmable electronic ballasts (see Note 1 and 3).		All building types	0.15
Combined controls	Multi-level occupant sensor (see Note 2) combined with multi-level circuitry and switching in accordance with Section 146(a)2D combined with automatic multi-level daylighting controls	Any space ≤ 250 square feet within a daylit area and enclosed by floor-to-ceiling partitions, any size classroom, corridor, conference or waiting room. The PAF may be added to the daylighting control credit	0.10
	Manual dimming of dimmable electronic ballasts (see Note 3) when used in combination with a multi-level occupant sensor (see Note 2) combined with multi-level circuitry and switching in accordance with Section 146(a)2D.	Any space ≤ 250 square feet enclosed by floor-to-ceiling partitions; any size classroom, corridor, conference or waiting room	0.25

~~Automatic multi-level daylighting controls (See Note 1)~~	~~Total primary sidelit daylight areas less than 2,500 ft² in an enclosed space and all secondary sidelit areas. (see Note 4)~~		~~Effective Aperture~~			
		~~General Lighting Power Density (W/ft²)~~	~~>10% and ≤20%~~	~~>20% and ≤35%~~	~~>35% and ≤65%~~	~~> 65%~~
		~~All~~	~~0.12~~	~~0.20~~	~~0.25~~	~~0.30~~
	~~Total skylit daylight areas in an enclosed space less than 2,500 square feet, and where glazing material or diffuser has ASTM D1003 haze measurement greater than 90%~~		~~Effective Aperture~~			
		~~General Lighting Power Density (W/ft²)~~	~~0.6% ≤ EA < 1%~~	~~1% ≤ EA < 1.4%~~	~~1.4% ≤ EA < 1.8%~~	~~1.8% ≤ EA~~
		~~LPD < 0.7~~	~~0.24~~	~~0.30~~	~~0.32~~	~~0.34~~
		~~0.7 ≤ LPD< 1.0~~	~~0.18~~	~~0.26~~	~~0.30~~	~~0.32~~
		~~1.0 ≤ LPD < 1.4~~	~~0.12~~	~~0.22~~	~~0.26~~	~~0.28~~
		~~1.4 ≤ LPD~~	~~0.08~~	~~0.20~~	~~0.24~~	~~0.28~~

NOTES FOR TABLE 146-C:

1. PAFs shall not be available for lighting controls required by Title 24, Part 6.
2. To qualify for the PAF the multi-level occupant sensor shall comply with the applicable requirements of Section 119.
3. To qualify for the PAF all dimming ballasts for T5 and T8 linear fluorescent lamps shall be electronic and shall be certified to the Commission with a minimum RSE in accordance with Table 146-D.
4. ~~If the primary sidelit daylight area and the secondary sidelit daylight area are controlled together, the PAF is determined based on the secondary sidelit effective aperture for both the primary sidelit daylight area and the secondary sidelit daylight area.~~

SECTION 149 – ADDITIONS, ALTERATIONS, AND REPAIRS TO EXISTING BUILDINGS THAT WILL BE NONRESIDENTIAL, HIGH-RISE RESIDENTIAL, AND HOTEL/MOTEL OCCUPANCIES AND TO EXISTING OUTDOOR LIGHTING FOR THESE OCCUPANCIES AND TO INTERNALLY AND EXTERNALLY ILLUMINATED SIGNS

(a) **Additions.**

(unchanged)

(b) **Alterations.**

1. Prescriptive approach.

I. Alterations to existing indoor lighting systems shall meet the following requirements:

(vi) Lighting Alterations in daylit areas of enclosed spaces other than parking garages, ~~where the resulting installed lighting power density is greater than 0.7 watts per square foot,~~ shall meet the following requirements, as applicable:

a. When the total combined wattage of altered luminaires in the skylit daylit zone and primary sidelit daylight zone is greater than 300 watts, the altered luminaires shall comply with Sections 131(d) and 134.

b. When the total wattage of altered luminaires in the primary sidelit daylight zone is greater than 300 watts, and the total wattage of altered luminaire in the secondary sidelit daylight zone is greater than 300 watts, shall comply with Section 146(d)

Exception 1 to Section 149(b)1I(vi)(b) Spaces where total width of window is less than one-half of the total length of exterior walls

Exception 2 to Section 149(b)1I(vi)(b) When the total lighting power density in the space is less than 0.7 watts per square foot and the automatic daylighting control system and controlled lighting has a control step between 30-70 percent of full rated power in addition to off, the controlled lighting need not comply with Section 131(d)2Diii

(vii) Lighting Alterations in daylit areas of parking garages, when the total combined wattage of altered luminaires in both primary and secondary sidelit daylight zone is greater than 300 watts, the altered luminaires shall comply with Sections 131(d) and 134

7. Bibliography and Other Research

Heschong, Lisa. (Heschong Mahone Group). 2011. Daylit Metrics. California Energy Commission, Public Interest Energy Research. Publication number: To be published

> This CEC PIER study developed the core methodology for the Radiance simulations that formed the bases of the code change proposal and the Watt Calculation Method.

Saxena, Mudit et al. 2010. Dynamic Radiance – Predicting Annual Daylighting with Variable Fenestration Optics Using BSDFs. SimBuild 2010 New York, NY, Conference Proceedings

> This paper describes the "Dynamic Radiance" approach used for the simulation runs to develop the Watt Calculation Method.

Saxena, Mudit. (Heschong Mahone Group). 2011. Office Daylighting Potential. California Energy Commission, Public Interest Energy Research. Publication number: To be published

> This CEC PIER study estimated the demand and energy savings potential from adding photocontrols to existing daylit office spaces in California. It described existing office buildings in California using the California Commercial End-Use Survey (CEUS) database, and used a Radiance-based annual daylighting simulation to estimate the savings.
>
> The Daylighting CASE also leveraged the information provided by this study on physical characteristics of existing office buildings to develop the Office Sidelit Building prototype. The CASE study also estimated energy savings for the code change proposal for mandatory requirement for photocontrols in primary daylit zones and prescriptive requirement for photocontrols in secondary daylit zones, from the detailed energy savings estimated in the PIER study. TDV energy savings were calculated from hourly savings estimated from the Radiance simulation runs from this study.

PG&E Codes & Standards Program. 2008a. Final CASE Report - TDV (Time Dependent Valuation) Lighting Controls Schedules. CEC Title 24 Building Energy Efficiency Standards. Prepared by the Heschong Mahone Group.

> This report provided the occupancy schedule for spaces without occupancy sensors and spaces with occupancy sensors used in the energy savings estimate

PG&E Codes & Standards Program. 2008b. Final CASE Report - Updates to Skylighting Requirements. CEC Title 24 Building Energy Efficiency Standards. Prepared by the Heschong Mahone Group.

> This report provided the description of the prototype buildings used in estimating energy savings from the measure to increase minimum skylit area in large enclosed spaces. It was also used to determine energy savings per square foot area of skylit daylit zone for the large warehouse and large retail store prototypes.

Thomas, Gene. 2011. Email communication - Subject: Updated Title 24 Cost Analysis. 7/25/2011.

> Gene Thomas from Ecology Action provided cost estimation for photocontrols in retrofit spaces.

PNNL. 2008. 90.1 Final Report on Skylighting Requirements Code Change Proposal. Code Change Proposal prepared by Heschong Mahone Group on behalf Pacific Northwest National Laboratory

This report provides the analysis for reducing skylight minimum area requirement used leveraged this CASE report.

List of experts involved in the development of the code change proposals:

- Jon McHugh, McHugh Energy
- Jim Benya, Benya Lighting Design
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8. Appendix A: Detailed Results from Rooftop Surveys

Detailed results for each of the properties surveyed in the rooftop survey are presented below in Figure 72, Figure 73 and Figure 74.

Survey #	Roof Area (sf)	Duct Area (sf)	Other Obstruction Area (sf)	Total Obstruction Area (sf)	% Obstructed	Approximate Skylit Area
1	78475	0	6225	6225	8%	NA
2	7904	0	0	0	0%	NA
3	46609	0	942	942	2%	NA
4	17000	0	163	163	1%	NA
5	5379	335	0	335	6%	NA
6	26420	0	1360	1360	5%	NA
7	29249	0	857	857	3%	60%
8	5932	0	503	503	8%	NA
9	3893	0	380	380	10%	NA
10	7588	0	0	0	0%	NA
11	9054	0	0	0	0%	NA
12	12459	0	700	700	6%	NA
13	5475	0	119	119	2%	NA
14	7463	0	400	400	5%	NA
15	1591	0	48	48	3%	NA
16	9774	0	0	0	0%	NA
17	17887	0	140	140	1%	NA
18	2053	0	34	34	2%	NA
19	2150	0	30	30	1%	NA
20	20274	120	80	200	1%	NA
21	5040	0	50	50	1%	NA
22	24014	0	337	337	1%	NA
23	6422	0	50	50	1%	NA
24	10198	0	24	24	0%	NA
25	4600	0	50	50	1%	NA

Figure 72: Detailed Rooftop Survey Results (part 1 of 3)

Survey #	Roof Area (sf)	Duct Area (sf)	Other Obstruction Area (sf)	Total Obstruction Area (sf)	% Obstructed	Approximate Skylit Area
26	22403	0	65	65	0%	NA
27	6099	0	86	86	1%	NA
28	20630	0	48	48	0%	NA
29	6024	0	0	0	0%	NA
30	6705	0	100	100	1%	NA
31	50267	0	250	250	0%	NA
32	145125	0	0	0	0%	NA
33	46087	0	520	520	1%	NA
34	3352	0	100	100	3%	NA
35	3960	0	0	0	0%	NA
36	2353	0	40	40	2%	NA
37	7441	0	490	490	7%	NA
38	23935	0	1343	1343	6%	NA
39	110089	100	1200	1300	1%	NA
40	5818	0	160	160	3%	NA
41	50052	0	220	220	0%	NA
42	18727	0	365	365	2%	NA
43	11073	0	600	600	5%	NA
44	25238	0	525	525	2%	NA
45	108178	0	2140	2140	2%	100%
46	5109	0	45	45	1%	NA
47	6999	751	0	751	11%	NA
48	39919	0	625	625	2%	NA
49	31705	0	1279	1279	4%	NA
50	38193	236	1518	1754	5%	NA

Figure 73: Detailed Rooftop Survey Results (part 2 of 3)

Survey #	Roof Area (sf)	Duct Area (sf)	Other Obstruction Area (sf)	Total Obstruction Area (sf)	% Obstructed	Approximate Skylit Area
51	17151	0	0	0	0%	100%
52	67176	0	0	0	0%	NA
53	12419	0	216	216	2%	NA
54	51472	0	340	340	1%	60%
55	49733	0	467	467	1%	NA
56	24615	0	0	0	0%	NA
57	20922	0	390	390	2%	NA
58	26630	0	0	0	0%	NA
59	20600	0	0	0	0%	40%
60	11734	0	40	40	0%	100%
61	14940	0	780	780	5%	NA
62	40015	0	2080	2080	5%	100%
63	16628	0	100	100	1%	NA
64	145421	0	2700	2700	2%	NA
65	154807	0	1080	1080	1%	100%
66	12477	0	80	80	1%	NA
67	20777	0	132	132	1%	80%
68	72392	0	520	520	1%	60%
69	68533	0	1300	1300	2%	60%
70	125181	0	3419	3419	3%	NA

Figure 74: Detailed Rooftop Survey Results (part 3 of 3)

9. Appendix B: Regression Equation Error Check

To test the regression equation developed for the Watt Calculation Method we applied the regression equation to calculate $\%sDA_{50\%}$ to 104 different spaces. These spaces included a mix of different space dimensions, single and multiple orientations, non-rectilinear spaces, asymmetrical window layouts, different window to wall ratios and all four cardinal directions (North, South, East and West). This exercise was conducted to test if the regression equation worked for spaces that were sufficiency different from the façade-template used to develop the regression equation.

$\%sDA_{50\%}$ was first calculated using Equation 7 for all 104 spaces. This was then compared to $\%sDA_{50\%}$ results from annual Radiance daylighting simulations of each of these spaces and a percent error was calculated.

The average percent error was -12%. The negative sign indicates that on average, the regression equation under-predicted the results by 12% as compared to the simulations. The maximum percent error was 13% for a shallow space (60' wide by 10' deep). The minimum error -51% for a non-rectilinear space shaped as an 'L'. Overall, we found that the equation was doing a sufficiently accurate job of predicting $\%sDA_{50\%}$ for a vast majority of spaces expected to be encountered, and equation error's on the side of being conservative by under-predicting the result. The table in Figure 75 gives the average percent error for each of space type in the dataset. The reported error value is an average for all four orientations of each space type.

Space Description	Average % Error
60'x40' space, Windows in 1 orientation, 28% Net-WWR, 28% Net-WWR	3%
60'x40' space, Windows in 1 orientation, 52% Net-WWR, 52% Net-WWR	-8%
60'x30' space, Windows in 1 orientation, 28% Net-WWR	-3%
60'x30' space, Windows in 1 orientation, 52% Net-WWR	-1%
60'x20' space, Windows in 1 orientation, 28% Net-WWR	-2%
60'x20' space, Windows in 1 orientation, 52% Net-WWR	-8%
60'x10' space, Windows in 1 orientation, 28% Net-WWR	12%
60'x10' space, Windows in 1 orientation, 52% Net-WWR	8%
60'x60' space, Windows in 1 orientation, 28% Net-WWR	-8%
60'x60' space, Windows in 1 orientation, 52% Net-WWR	-7%
60'x40' space, Windows in 2 orientations (Adj.), 28% Net-WWR	-18%
60'x40' space, Windows in 2 orientations (Adj.), 52% Net-WWR	-6%
60'x40' space, Windows in 2 orientations (Opp.), 28% Net-WWR	-19%
60'x40' space, Windows in 2 orientations (Opp.), 52% Net-WWR	-28%
60'x40' space, Windows in 3 orientations, 28% Net-WWR	-28%
60'x40' space, Windows in 3 orientations, 52% Net-WWR	-9%
60'x40' space, Windows in 4 orientations, 28% Net-WWR	-42%
60'x40' space, Windows in 4 orientations, 52% Net-WWR	-3%
L shape space, one short- one long leg, Windows in 1 orientation, 28% Net-WWR	-16%
L shape space, one short- one long leg, Windows in 1 orientation, 52% Net-WWR	-18%
L shape space, Windows on 4 facades, entrant and exitat coreners, 28% Net-WWR	-50%
L shape space, Windows on 4 facades, entrant and exitat coreners, 52% Net-WWR	-41%
Asymetrical Window Layout 1, 28% Net-WWR	-22%
Asymetrical Window Layout 2, 52% Net-WWR	6%
Asymetrical Window Layout 2, 28% Net-WWR	-20%
Asymetrical Window Layout 3, 52% Net-WWR	1%

Figure 75: Average Percent Error for All Space Types in Study

We also plotted the simulated and predicted value of $\%sDA_{50\%}$, for each of the 104 spaces in the study as shown in Figure 76. Most values, as seen in Figure 76 are on, or very close to the 45deg line shown in dotted green line. The cases where the results deviate from the line are mostly under-predictions of the $\%sDA_{50\%}$ value and are limited to specific cases such as L-shaped spaces and spaces with windows in 4 orientations noted in the table in Figure 75. A linear straight trend line with a 0 constant across the data had a slope of 0.84 and an r^2 of 0.851.

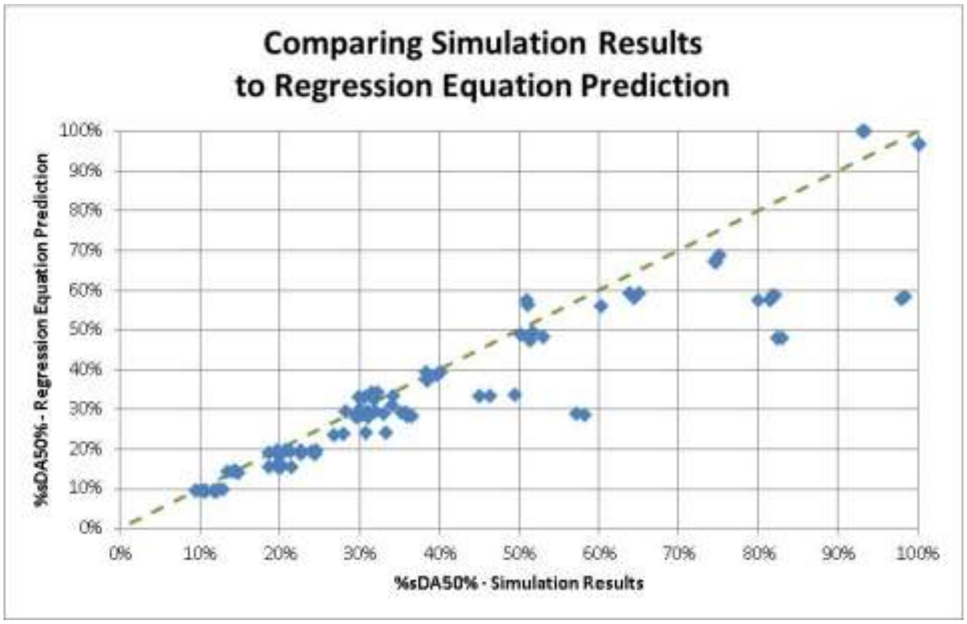

Figure 76: Comparing Simulation Results to Regression Equation Predictions

Our conclusion from this exercise was that the regression based equation used in the Watt Calculation Method to predict $\%sDA_{50\%}$ was estimating its value fairly closely to the simulation results in most space and façade geometries. The error was typically on the side of underestimation, and was within acceptable range.

10. Appendix C: DZ Savings Ratio Regression and Percent Error

This section provides the details of the regression analysis used to develop the DZ Savings Ratio equation. Figure 77 gives the DZ Savings Ratios calculated for the North, South and East orientation models.

NORTH DZ Savings Ratios		WWR			
		0.1	0.26	0.4	0.52
VLT	0.1	0.138	0.149	0.229	0.276
	0.2	0.138	0.159	0.312	0.452
	0.3	0.133	0.216	0.450	0.679
	0.4	0.138	0.284	0.549	0.810
	0.5	0.151	0.352	0.618	0.881
	0.6	0.173	0.432	0.676	0.917
	0.7	0.198	0.509	0.724	0.937

SOUTH DZ Savings Ratios		WWR			
		0.1	0.26	0.4	0.52
VLT	0.1	0.153	0.174	0.232	0.269
	0.2	0.149	0.199	0.285	0.347
	0.3	0.170	0.233	0.366	0.474
	0.4	0.194	0.274	0.451	0.610
	0.5	0.223	0.322	0.527	0.719
	0.6	0.251	0.379	0.594	0.801
	0.7	0.283	0.438	0.647	0.851

EAST DZ Savings Ratios		WWR			
		0.1	0.26	0.4	0.52
VLT	0.1	0.146	0.158	0.223	0.266
	0.2	0.144	0.179	0.290	0.383
	0.3	0.149	0.227	0.390	0.541
	0.4	0.166	0.287	0.478	0.662
	0.5	0.184	0.353	0.565	0.772
	0.6	0.207	0.428	0.632	0.833
	0.7	0.235	0.489	0.684	0.877

Figure 77: DZ Savings Ratios for North, South and East

Summary output of the regression analysis is given below:

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.971122
R Square	0.943077
Adjusted R Square	0.930188
Standard Error	0.110641
Observations	84

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	16.63059	8.315293	679.2764	2.43E-51
Residual	82	1.003795	0.012241		
Total	84	17.63438			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
VLT	0.410041	0.045308	9.050173	5.72E-14	0.31991	0.500173	0.31991	0.500173
WWR	0.797076	0.056857	14.01896	1.75E-23	0.683969	0.910182	0.683969	0.910182

Figure 78: Summary Output from Regression

Line fit plots for VLT and WWR are given below:

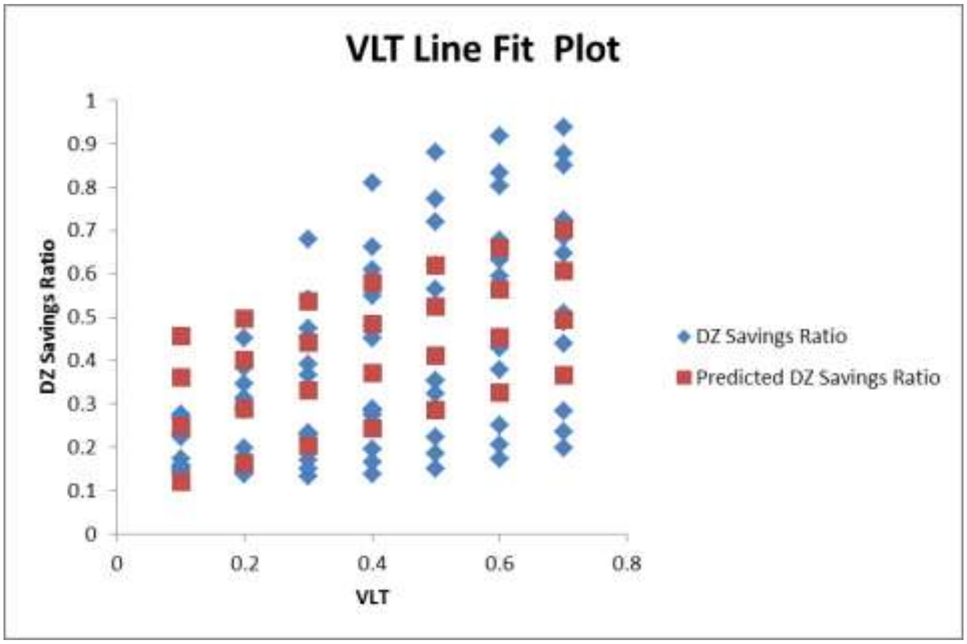

Figure 79: VLT Line Fit Plot

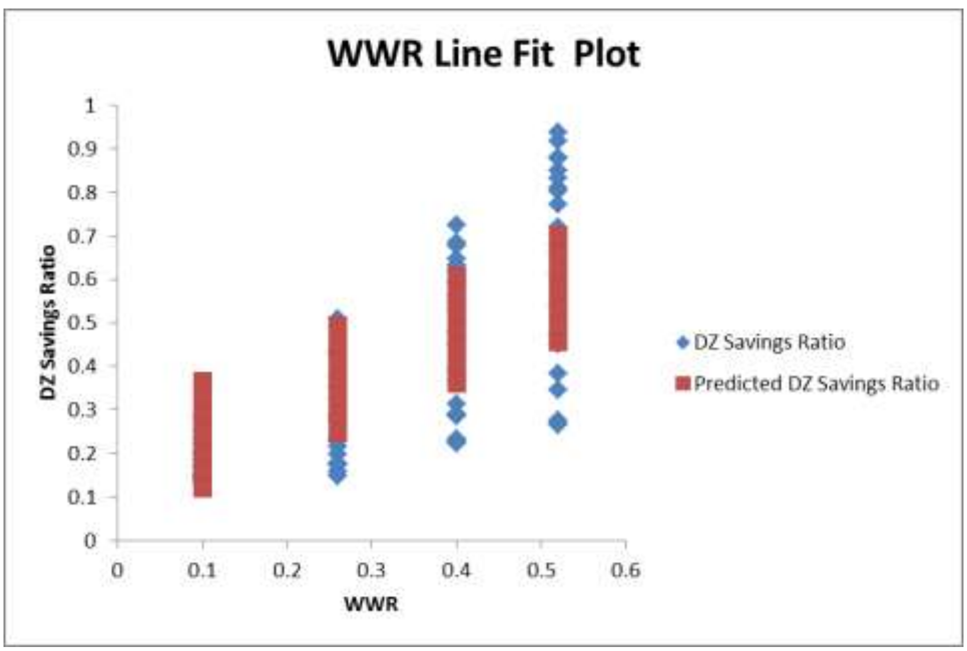

Figure 80: WWR Line Fit Plot

We calculated the error from the formula to predict DZ Savings Ratio, and that error is represented as percentage value in the figure below. Negative value means the formula under predicts the DZ Savings Ratio, and positive means it over predicts the DZ Savings Ratio.

NORTH DZ Savings Ratios Errors		WWR			
		0.1	0.26	0.4	0.52
VLT	0.1	-12%	67%	57%	65%
	0.2	17%	82%	28%	10%
	0.3	53%	53%	-2%	-21%
	0.4	77%	31%	-12%	-29%
	0.5	89%	17%	-15%	-30%
	0.6	88%	5%	-16%	-28%
	0.7	85%	-3%	-16%	-25%

SOUTH DZ Savings Ratios Errors		WWR			
		0.1	0.26	0.4	0.52
VLT	0.1	-21%	43%	55%	69%
	0.2	8%	46%	41%	43%
	0.3	20%	42%	21%	13%
	0.4	25%	36%	7%	-5%
	0.5	28%	28%	-1%	-14%
	0.6	30%	20%	-5%	-18%
	0.7	30%	13%	-6%	-18%

EAST DZ Savings Ratios Errors		WWR			
		0.1	0.26	0.4	0.52
VLT	0.1	-18%	57%	61%	71%
	0.2	12%	62%	38%	30%
	0.3	36%	45%	13%	-1%
	0.4	47%	29%	1%	-13%
	0.5	54%	17%	-7%	-20%
	0.6	58%	6%	-11%	-21%
	0.7	56%	1%	-11%	-20%

Figure 81: DZ Savings Ratio Prediction Percent Error

11. Appendix D: Non-Residential Construction Forecast details

11.1 Summary

The Non-Residential construction forecast dataset is data that is published by the California Energy Commission's (CEC) demand forecast office. This demand forecast office is charged with calculating the required electricity and natural gas supply centers that need to be built in order to meet the new construction utility loads. Data is sourced from Dodge construction database, the demand forecast office future generation facility planning data, and building permit office data.

All CASE reports should use the statewide construction forecast for 2014. The TDV savings analysis is calculated on a 15 or 30 year net present value, so it is correct to use the 2014 construction forecast as the basis for CASE savings.

11.2 Additional Details

The demand generation office publishes this dataset and categorizes the data by demand forecast climate zones (FCZ) as well as building type (based on NAICS codes). The 16 climate zones are organized by the generation facility locations throughout California, and differ from the Title 24 building climate zones (BCZ). HMG has reorganized the demand forecast office data using 2000 Census data (population weighted by zip code) and mapped FCZ and BCZ to a given zip code. The construction forecast data is provided to CASE authors in BCZ in order to calculate Title 24 statewide energy savings impacts. Though the individual climate zone categories differ between the demand forecast published by the CEC and the construction forecast, the total construction estimates are consistent; in other words, HMG has not added to or subtracted from total construction area.

The demand forecast office provides two (2) independent data sets: total construction and additional construction. Total construction is the sum of all existing floor space in a given category (Small office, large office, restaurant, etc.). Additional construction is floor space area constructed in a given year (new construction); this data is derived from the sources mentioned above (Dodge, Demand forecast office, building permits).

Additional construction is an independent dataset from total construction. The difference between two consecutive years of total construction is not necessarily the additional construction for the year because this difference does not take into consideration floor space that was renovated, or repurposed.

In order to further specify the construction forecast for the purpose of statewide energy savings calculation for Title 24 compliance, HMG has provided CASE authors with the ability to aggregate across multiple building types. This tool is useful for measures that apply to a portion of various building types' floor space (e.g. skylight requirements might apply to 20% of offices, 50% of warehouses and 25% of college floor space).

The main purpose of the CEC demand forecast is to estimate electricity and natural gas needs in 2022 (or 10-12 years in the future), and this dataset is much less concerned about the inaccuracy at 12 or 24 month timeframe.

It is appropriate to use the CEC demand forecast construction data as an estimate of future years construction (over the life of the measure). The CEC non-residential construction forecast is the best publicly available data to estimate statewide energy savings.

11.3 Citation

“NonRes Construction Forecast by BCZ v7”; Developed by Heschong Mahone Group with data sourced August, 2010 from Abrishami, Moshen at the California Energy Commission (CEC)

12. Appendix E: Environmental Impact Assessment

To determine the environmental impact of the proposed measure, we first estimated the mercury, lead, copper, steel and plastic content of a single photosensor and a 20’ long Cat 5 control wire, as shown in Figure 82.

For measure 1, a primary daylit zone, was assumed to have 1 photosensor and 20’ long control wiring. The prototype building of an office space with sidelighting (as described in Section 4.7.1) has 8 photosensors and 100’ control wiring.

For Measure 2, a skylit daylit zone, was assumed to have 1 photosensor and 50’ long control wiring. The prototype building of a retail store (as described in Section 4.7.1) has 1 photosensor and 50’ control wiring.

For Measures 3 and 4, a skylit daylit zone, was assumed to have 1 photosensor and 100’ long control wiring. The prototype building of a retail store (as described in Section 4.7.1) has 1 photosensor and 100’ control wiring.

	Mercury	Lead	Copper	Steel	Plastic	Others (Identify)
Photosensor	0.0005	0	0.15	0.1	0.25	0
Cat 5 control wire, 20'	0	0	0.188	0	0	0
Measure 1: Photocontrols Requirement Threshold for Sidelighting						
Per Primary Daylit Zone (1 photosensor and 20' control wire)	0.0005	0	0.338	0.1	0.25	0
Per Prototype Building (8 photosensors and 100' control wire)	0.004	0	2.14	0.8	2	0
Measure 2: Photocontrols Requirement Threshold for Toplighting						
Per Skylit Daylit Zone (1 photosensor and 50' control wire)	0.0005	0	0.62	0.1	0.25	0
Per Prototype Building (1 photosensors and 50' control wire)	0.0005	0	0.62	0.1	0.25	0
Measure 3b & 4: Increase Min Skylight Area Requirement and Decrease Minimum Area Threshold						
Per Primary Daylit Zone (1 photosensor and 100' control wire)	0.0005	0	0.62	0.1	0.25	0
Per Prototype Building (1 photosensors and 100' control wire)	0.0025	0	3.1	0.5	1.25	0

Figure 82: Environmental impact assessment of adding photocontrols