SIZING SKYLIGHTS FOR DAYLIGHTING LANDSCAPING IN AN ATRIUM

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ABSTRACT

A major interior landscaping project is a central component of a proposed corporate headquarters. While interior landscaping is a significant part of many such projects, typical plant losses of 20-40 percent each year are not acceptable for this installation. The client is confident of their ability to control important factors to sustain plant growth such as soil, irrigation, and plant compatibility. Daylighting for plants remains as the element most difficult to predict and control in an integrated manner in the interior environment. The architect proposed two different skylight designs. The study provides a methodology based on physical model testing and computer simulation using California Energy Commission (CEC) climate data that resulted in the required illumination level data for the architect during the early phases of project development.

1. PROJECT SCOPE

The subject project is a proposed three-story office building to serve as a corporate headquarters. The project is located between Los Angeles and Ventura in Calabasas, California. The building will be about 65,000 gross square feet when completed. The building's interior open office plan is penetrated by an approximately 3,600 square foot atrium at the center of the building. This study looks at sizing a skylight intended to provide daylight for mature planting in the atrium floor.

2. APPROACHES TO DAYLIGHTING FOR PLANTING IN A TOPLIT ATRIUM

Considerations of lighting for interior planting ideally include plant types and their photoperiods, and light sources, intensity, distribution. Others have studied these factors in some detail [(1)]. The client has expertise in the requirements for maintaining planting in indoor atria and provided specific performance targets for the design team. The client provided guidance based on their understanding of desired plant types and their light intensity and photoperiod requirements. The client established a minimum target average daylight level of 250 foot candles horizontal at 60" above the atrium floor be provided across an 11 to 12 hour period during a "typical" summer day. This figure could be achieved gross – without considering the likely shading from plant canopies at higher levels in the space. This study is concerned with comparing daylight factors available at the site with two different skylight designs in order to provide skylight area parameters for the architect that would allow the client's target light levels to be achieved.

3. BASIS OF DESIGN AND TESTING METHODOLOGY

Schematic Design documents provided by the architect showed an irregular shaped atrium with a long axis running north-south. We first calculated the gross area available for skylighting suggested by compliance with applicable energy code. The California Energy Commission (CEC) Code prescriptive package requires that office buildings in all Climate Zones have 5% or less of the total roof area in skylights**.** A total net roof area of 29,500 SF would give us a total skylight area of no more than 1500 gross SF to allow conformance. If the performance option for code compliance is chosen this restriction need not apply, however it is a useful starting place.

We ran preliminary calculations using Skycalc [(2)] to provide a "ballpark" recommendation for skylight area to serve as a basis for constructing physical models for more detailed study. The building sections showed open railings at the atrium edges with open offices (no walls and low partitions beyond the circulation perimeter). For reasons of economy, there was also direction that the skylight profile be relatively close to the roof surface. Initial analysis was done with assumptions of basically "dark" walls (little contribution from atrium sides) and openings close to the roof (shallow wells).

Initial rough calculations showed areas of the skylight that would yield the minimum target 250 fc average across 12 hours (summer day) at the base of the atrium. Calculations were run to compare a group of evenly distributed smaller skylights having equal net area (Table 1) to a single large skylight (Table 2). Calculations were then run on those configurations with and without diffusers located at the bottoms of the skylight wells. These preliminary estimates indicated that there would be a benefit to using one relatively large opening (or a few mid-sized) as opposed to many smaller openings. This suggests that beam contribution through wider light wells is a contributor to the calculated levels. The benefit of using a net area greater than 1,500 square feet to achieve the target levels would be outweighed by the problems of managing peak levels due to increased beam radiation.

TABLE 1: FC (TARGET & PEAK) FOR ALTERNATIVE SKYLIGHT CONFIGURATIONS (NET AREA 1250SF)

Skylights	250 fc: Jun	250 fc: Dec	Peak fc	Diffuser
(1) 100’x12.5’	8:00 - 17:00	10:30 - 14:00	731	No
(100) 2.5’x5.0’	8:30 - 16:40	11:00 - 13:20	613	No
(1) 100’x12.5’	8:30 - 16:40	11:00 - 13:00	585	Bot. of well
(100) 2.5’x5.0’	8:50 - 16:20	never	490	Bot. of well

TABLE 2: FC (TARGET & PEAK) FOR SINGLE LARGE SKYLIGHT (VARIOUS AREAS)

Skylights	250 fc: Jun	250 fc: Dec	Peak fc	Diffuser
(1) 100’x20’=2000sf	7:20 - 17:30	9:30 - 15:00	>1000	No
(1) 100’x15’=1500sf	7:40 - 17:20	10:00 - 14:30	881	No
(1) 100’x10’=1000sf	8:30 - 16:40	11:00 - 13:00	581	No

The initial calculation shows greatest efficiency using skylights without diffusers. Eliminating diffusers would probably mean beam sunlight hitting the sides of the atrium, but would make daylight available to the atrium that would otherwise be absorbed by the diffuser. Another option is to fabricate large directional egg crates or vertical fins to cut off misdirected beam sunlight and direct daylight downward. This approach would absorb much less daylight than a diffusing plane. These data were tentative at this point; however this exercise allowed us to give direction to the architect for the initial skylight design and for the construction of the model.

4. THE PHYSICAL MODEL

We recommended that the model include two roof alternatives – one with a large continuous skylight and one with six mid-sized skylights. Ideally, they would have the same area net of structural obstructions. An eggcrate or vertical fin type louver would be provided for the single large skylight. The diffuser would use a five foot by ten foot grid, five feet deep, oriented along the long axis of the skylight with the “fins” as thin and as white as possible. The baffle was mounted to the interior ceiling of the model. The skylight curb was to be constructed as low to the roof as practical. We also recommended that the skylights be centered over the atrium to improve the light distribution across the planted area. The model would include vertical structural elements (side walls, core, stairs, etc.) that were within 15’ of the atrium.

The six skylight model provided by the architect represented a net skylight area of about 1,000 square feet (Fig. 1). The continuous skylight model provided a net area of about 890 square feet (Fig. 2).

Fig. 1: Six well skylight model interior view looking north on a simulated June morning (note sunpatch on upper left). The skylights are evenly disposed somewhat to the east of the long axis (north-south) of the atrium

Fig. 2: Louvered skylight model interior view looking south at simulated June midday

Interior floor surfaces were painted a light neutral gray to approximate anticipated surface reflectance values. The ground floor was painted to about 20% reflectance to simulate the planting area and dark plant materials. The upper two floors were painted to about 35% reflectance to represent floor coverings and furnishings. The interior wall and ceiling surfaces provided approximately 80% reflectance. The model was constructed of foamcore made opaque by the application of gesso to exterior and interior surfaces.

5. MODEL TESTING

Illumination levels were measured at 12 spots around the perimeter and interior of the planting area using a Lutron LX-101 lux meter with a remote sensor. The model was tilted and rotated to simulate beam radiation throughout the day on June 21 and December 21 using the model testing sundial printed out from Climate Consultant [(3)]. Sky conditions were clear with a slight haze, typical of southern California conditions at the site. Before and after each hourly set of twelve readings, horizontal diffuse sky illumination was measured on the roof (with beam radiation blocked).

The Daylight Factor method has been used to predict the relative indoor illuminance in the atrium. The average Daylight Factor (DF) is the ratio of the average indoor illuminance (measured at the target plane) to the outdoor horizontal illuminance. Determining the DF allows us to predict illumination using actual climate data collected at the nearest station.

Because the Daylight Factor method was originally developed for a diffuse daylight from the sky, excluding direct sunlight, we gathered data at the base of the atrium model in areas that avoided beam sunlight. Our use of this method relies on assumptions that the skylight glazing is clear and essentially horizontal.

We believe this is a conservative strategy that guarantees that our final illumination results will be valid for most diffuse sky conditions, and for times when no beam radiation falls on the atrium floor. During any midday hours when there is beam sunlight on the atrium floor, the actual illumination levels will be greater than the minimum levels predicted.

6. CALCULATION METHOD

We ran calculations using Pasadena CZ09 weather data file because the building will be located in this climate zone, and checked it against the Los Angeles TMY2 data (Airport station)[(4)]. The Los Angeles data file contains both solar radiation and illumination data, but the Pasadena CZ09 file does not contain illumination data. To crosscheck against the Pasadena file, we applied an accepted efficacy equation to the solar radiation data to get illumination values [(5)]. Because the monthly average hourly values were very close, we elected to stay with the TMY2 published illumination data.

The resulting Pasadena data is a little more conservative than the LA data so our recommended skylight net areas are somewhat larger (up to about 5%) than they would be using the Los Angeles data. We believe it is advisable to use the conservative data.

A spreadsheet was developed that first tabulated (for each skylight type and every month) illumination data recorded at the 12 spots and at the roof (for each of eleven hours). Next it speculated the daylight factor (DF) at the 12 points for each hour as the ratio of interior to exterior illumination. Then for each hour, DF was multiplied by the mean global horizontal illumination level directly from the TMY2 data. Finally these data were modified by the glazing transmissivity (see Tables 3 and 4). Once the actual glass type and geometry of the final skylight is known (tilt and bearing), the Fresnel correction should be applied. This will have its greatest effect at angles greater than 45 degrees, especially important at early morning hours. The angle is a function of the glass type and number of layers. Some studies indicate that any kind of dome might perform slightly better than flat glass (up facing).

7. GLAZING CONSIDERATIONS

Final glazing specifications for the project were under review at the time of this study. Transmissivity of 0.79 was used to develop these findings, based on a Pilkington Glass specification for clear double-glazing. Other glazing choices are available and the simulations can be easily rerun. We do not typically recommend using glazing with a low-e coating for planting, as this changes the spectral transmission in the infrared range – affecting the plants. Spectral balance issues should be reviewed with the landscape consultant for the project.

The goal for this project is to achieve maximum daylight with minimum initial cost (associated with the area of constructed skylight) and heat gain, so we recommended using clear glazing. This approach will also allow for the best possible placement of the skylight in respect to the delivery of daylight to the planting. A larger area of skylight would result in potential inefficiencies, as increased admitted daylight would be broadcast to non-atrium areas. Increasing the area of the skylight also increases the amount of direct beam sunlight that would need to be controlled for glare and would unnecessarily increase loads on the heating and cooling systems.

8. FINDINGS

Using the six skylight scheme would require an area net of obstructions of about 1,400 square feet to achieve the target level of 250 FC average across 11 hours of a typical summer day (see Table 3). Using the single continuous skylight scheme with diffusing fins would require an area net of obstructions of about 1,320 square feet to achieve the target level of 250 FC average across 11 hours of a typical summer day (see Table 4). We believe that the relative efficiency of the latter scheme is due to the better placement of the skylight as well as its use of fins to redirect beam sunlight down into the atrium (some light admitted through the six skylight scheme is intercepted by the second and third floor plates and is therefore unavailable to the atrium at the points of measurement).

Note that these calculations do not take into account two very important factors: Depreciation due to dirt accumulation on the exterior of the skylights – seasonal cleaning of the skylights will be necessary to maintain the performance of the design, and second the effect of angle of incidence on the glass (Fresnel correction).

We also plotted the hourly light levels for the two skylight schemes at each of the data collection points. These plots (fig. 3) show a slightly more even light distribution for the scheme with the diffusers. Such plots show the potential for mapping light "profiles" for portions of the atrium, allowing the designer to closely match individual plant requirements to locations in the interior landscape.

9. FURTHER AREAS OF INTEREST

Daylight is the best light source for planting. In a top lit atrium such as this subject project, daylight is admitted entirely from above. In nature, daylight is broadcast vertically as well as from above. The tall planting proposed for this project means that significant area of the planting is disposed vertically.

The target light levels of 250 fc needed to support the interior landscape design are about five times the level necessary for general area ambient lighting. Providing this target foot-candle level for a large portion of the interior of the building significantly increases the cooling load that must be addressed by the building mechanical system design [(6)]. "Right-sizing" of the skylight design to deliver only the light that is determined to be necessary for plant health is an important part of meeting this need in an energy efficient manner. Care needs to be taken when selecting glazing for the skylights. Our calculations are based on using clear insulated glazing units without coatings, tinting, heat mirror, etc.

Predicting daylight availability in spaces like this is difficult due to the complexity of both atrium forms and skylight shapes. Existing computational models are either expensive to run or have limited predictive value [(7)]. This deters many architects from attempting to resolve their designs with adequate precision. The procedure outlined in this paper provided the basis for a dialogue that occurred during the initial phases of this project and allowed the architect and client to come to an understanding of how to best balance proposed designs with program needs.

It would be appropriate to integrate the skylight design area with broader project considerations including daylighting and lighting controls, mechanical cooling design, landscape lighting design for aesthetic goals, and energy efficiency strategies. It would be especially worthwhile to study the effect of integrating this skylight and atrium design with a low velocity displacement ventilation scheme supplying conditioned air to the open offices surrounding the atrium.

10. REFERENCES

(1) Navvab, M. "Lighting Design for Plant Growth", paper presented at the International Lighting Congress, CIE – Division Meeting, Istanbul 2001. This describes in greater detail issues beyond light intensity and duration in designing successful interior landscapes.
(2) Skycalc, www.energydesignresources.com.
(3) Climate Consultant, www.aud.ucla.edu/energy-design-tools.
(4) Climate data is published in TMY and TMY2 by the National Renewable Energy Lab (available at http://rredc.nrel.gov/solar/old_data/nsrdb/tmy2/), and in CZ01 to CZ16 format (available at the EnergyPlus site http://www.energyplus.gov).
(5) This equation develops an efficacy factor that multiplies Total Global Radiation by 107.0 lumens/watt to get Total Global Illumination. This is a value published by Gilette and Treado (1984), and recommended by Steve Selkowitz at LBL. Other authors have published values up to 114 lumens/watt, so this value is conservative. Most of the TMY climate data stations do not record illumination data, and so NREL had to use an equation of this type to get the illumination values published in the new TMY2 format (it was not published in the older TMY data).
(6) Energy analysis was produced by the latest version of SOLAR-5, www.aud.ucla.edu/energy-design-tools.
(7) Laouadi, A.; Atif, M.R. "Daylight availability in top-lit atria: prediction of skylight transmittance and daylight factor", International Journal of Lighting Research and

Technology, v. 32, no. 4, 2000, pp. 175-186. This is a detailed discussion of alternative calculation methods.

TABLE 3: ROOF A (SIX SEPARATE LIGHT WELLS - 1,000GSF) CALCULATED FOOT-CANDLE (F.C.) LEVELS FOR DIFFUSE LIGHT FROM THE SKY FOR JUNE 6

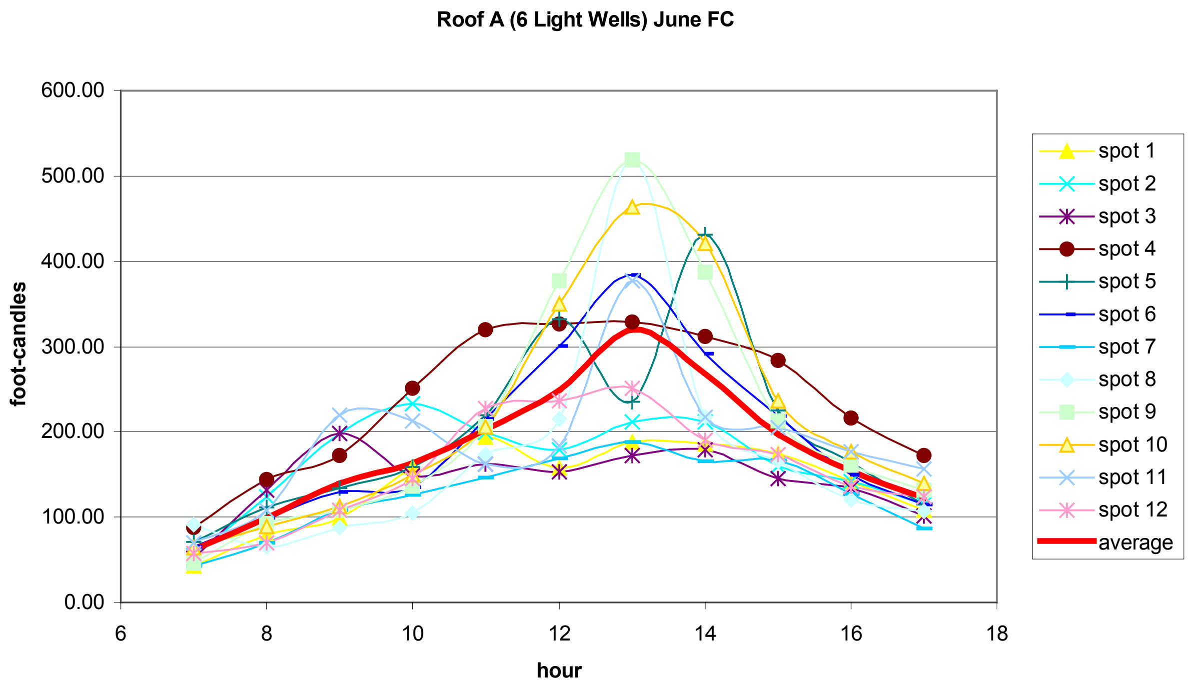
Hour	7	8	9	10	11	12	13	14	15	16	17
0.79 : Transmissivity											
Spot 1	42.24	78.38	99.00	158.38	193.68	158.04	188.05	185.65	174.36	141.92	107.97
2	55.23	123.76	198.00	232.91	198.92	179.12	211.56	212.17	159.83	141.92	115.16
3	51.98	132.01	198.00	149.06	162.28	152.78	172.38	179.02	145.30	134.45	100.77
4	87.72	144.38	172.18	251.54	319.32	326.62	329.09	311.62	283.33	216.61	172.75
5	71.47	111.38	133.44	158.38	219.86	331.89	235.07	430.97	225.21	164.33	115.16
6	64.98	99.01	129.13	135.09	214.62	300.28	383.94	291.73	217.94	149.39	115.16
7	42.24	70.13	107.61	125.77	146.57	168.58	188.05	165.76	167.09	126.98	86.37
8	91.33	65.78	88.02	104.32	173.49	215.23	518.47	217.28	165.39	120.37	106.88
9	45.66	92.86	108.03	136.07	206.02	376.66	518.47	387.03	212.65	160.50	131.55
10	63.93	88.99	112.03	149.67	206.02	349.76	463.48	420.98	236.28	176.55	139.77
11	70.02	108.34	220.06	213.17	162.64	182.95	377.07	217.28	204.77	176.55	156.21
12	57.84	69.65	108.03	145.14	227.70	236.76	251.38	190.12	173.27	136.42	123.33
Average:	62.05	98.72	139.46	163.29	202.59	248.22	319.75	267.47	197.12	153.83	122.59

F.C. calculations are based on using clear double-glazed skylights with transmissivity = 0.79. The average F.C. level for diffuse light from the sky for 11 hours (7 to 17) is 179.55. The target of 250 average F.C. is achieved for 4 hours (11 to 15). The skylight would need to be increased in size by a factor of 1.39 (to about 1,390 square feet) to produce the desired 250 FC Average for 11 hours. These values for diffuse sky light are conservative because patches of beam sunlight will raise averages on sunny days.

TABLE 4: ROOF B (SLOT WITH LOUVERS - 890GSF) CALCULATED FOOT-CANDLE (F.C.) LEVELS FOR DIFFUSE LIGHT FROM THE SKY FOR JUNE 6

Hour	7	8	9	10	11	12	13	14	15	16	17
0.79: Transmissivity											
Spot 1	41.37	63.11	76.18	103.18	184.51	195.20	206.87	187.26	197.75	168.56	125.90
2	51.71	92.56	160.83	192.28	206.87	201.12	199.48	232.46	220.56	229.85	170.33
3	55.16	96.76	190.46	140.70	167.74	189.29	192.09	213.09	197.75	191.54	133.30
4	89.63	143.04	190.46	211.04	341.06	366.75	310.30	303.49	296.62	222.19	177.74
5	72.40	109.38	126.97	145.39	162.14	201.12	369.41	426.18	235.78	183.88	125.90
6	55.16	88.35	110.04	131.32	145.37	242.53	310.30	335.77	228.17	176.22	118.49
7	34.47	54.69	80.41	84.42	106.23	130.14	177.32	180.80	182.54	137.91	81.46
8	35.16	50.81	68.32	76.68	102.10	138.56	182.19	179.51	112.26	120.28	94.53
9	57.53	82.08	104.49	157.88	136.13	250.73	291.50	398.91	161.37	154.65	120.31
10	63.92	97.71	116.55	135.33	153.15	277.13	378.95	452.10	189.43	189.02	137.49
11	54.34	97.71	208.98	225.54	192.85	224.34	371.66	239.35	217.50	249.16	189.05
12	51.14	62.54	84.40	103.75	221.21	164.96	189.47	159.56	140.32	154.65	120.31
Average:	55.17	86.56	126.51	142.29	176.61	215.16	264.96	275.71	198.34	181.49	132.90

F.C. calculations are based on using clear double-glazed skylights with transmissivity = 0.79. The average F.C. level for diffuse light from the sky for 11 hours (7 to 17) is 168.7. The target of 250 average F.C. is achieved for 2 hours (12 to 14). The skylight would need to be increased in size by a factor of 1.48 (to about 1,320 square feet) to produce the desired 250 FC Average for 11 hours. These values for diffuse sky light are conservative because patches of beam sunlight will raise averages on sunny days.



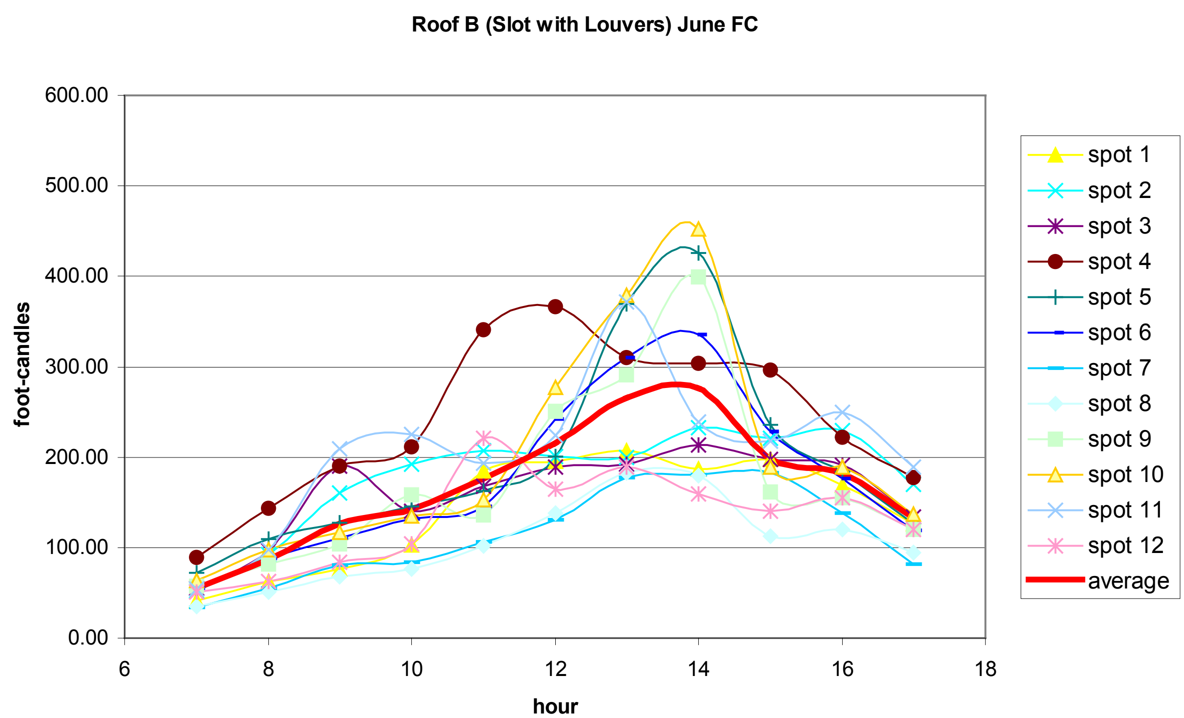


Fig. 3: Foot-candle levels were calculated at each data point - Roof A (six separate light wells - 1,000gsf) is shown above, and Roof B (slot with louvers - 890gsf) is shown below. F.C. calculations are based on using clear double-glazed skylights with transmissivity = 0.79.