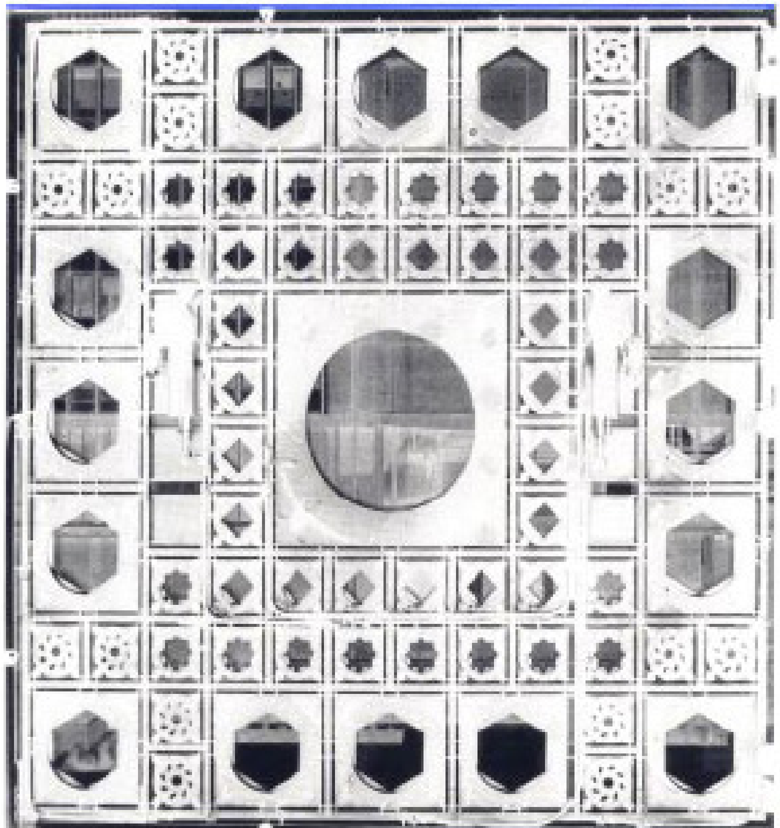
INSIDE Out

Second Edition



DESIGN PROCEDURES FOR PASSIVE ENVIRONMENTAL TECHNOLOGIES

A2 - F2 Lighting

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A2 LIGHTING

PRECEDENTS OF LIGHTING RESPONSE

INTRODUCTION

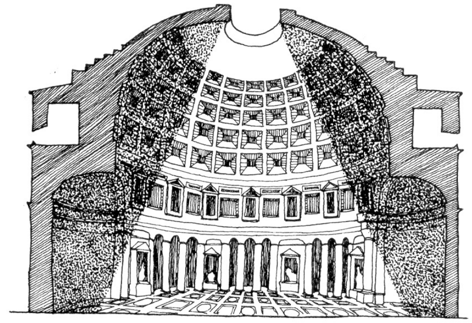
Goal

Assessing technologies in well understood ethnological and climatic contexts can yield principles of design technology that can be generalized and applied to similar contexts. Thus, through the study of less energy-intensive building technologies in either traditional or industrialized cultures, you will gain insights for solving energy-related architectural problems.

Discussion

Prior to the twentieth century, buildings depended on daylight as their primary lighting source. Haphazard window placements, though providing adequate lighting, may have allowed excessive heat in hot climates or the loss of valuable heat in cold climates. Of necessity, vernacular architecture was sensitive to both the luminous and thermal environments.

Ancient buildings that are paradigms of the advanced technology of their time reveal the connections their builders made among daylighting, building technology, and aesthetics. In the hot, mediterranean climate of Rome the Pantheon's vast domed space is adequately lighted with a single, unglazed oculus high overhead whose area is only 4% of the rotunda's floor area. The Hagia Sophia in Istanbul, which likely was modeled after the Pantheon, features a ceiling that "floats" above the rotunda. This effect is achieved by a band of small, deeply recessed clerestory windows at the spring of the dome.



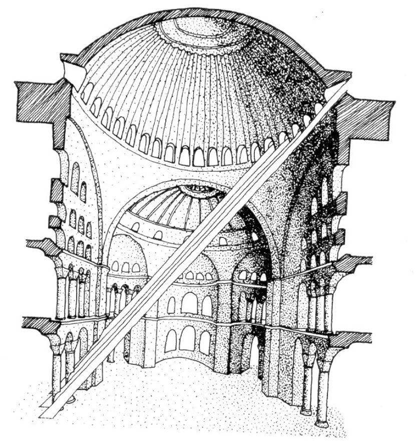


Figure A2.0.1 Toplighting Precedents. *Above,* the Pantheon under cloudy sky; *below,* the Hagia Sophia under clear sky.

This practice of blending daylighting, technology, and aesthetics has been sustained by masters of the craft. The works of Alvar Aalto, Le Corbusier, Albert Kahn, Louis Kahn, James Stirling, and Frank Lloyd Wright warrant further investigation. Excerpting principles that are appropriate to your assigned building type and climate from both vernacular and modern works can enrich your understanding and development of lighting design that is technically, culturally, and aesthetically rich.

In this section you will:

. . . the placement of these windows in a region of the Hagia Sophia's dome where tensile hoop forces were expected to be critical seemed audacious. But now it is clear that if the base of the dome had been left solid, it would have been prone to the same meridianal cracking experienced by the Pantheon. The window openings of the Hagia Sophia are thus a prudent expedient to ward off cracking, as well as a dramatic source of light.

—Robert Mark

1. Investigate precedents of daylighting response in buildings.
2. Generalize principles of daylighting response in climatic and cultural settings.

PRECEDENTS OF LIGHTING RESPONSE

ARCHITECTURE, CLIMATE, AND PEOPLE—VERNACULAR PRECEDENTS

Procedure

Assess how a particular culture's vernacular architecture, the indigenous and traditional architecture of the region, balances culture and climate. Observe how cultural, technical, and economic forces were integrated with those of climate and the luminous environment to influence building form.

Choose a vernacular building or cluster of buildings in a climate zone similar to your site's. Consider the climate of the locale and the living patterns of its residents. Look for evidence of how such patterns are affected by climate and visual comfort. Analyze the lighting strategies used in terms of their cultural and physical contexts.

Document your choice as follows:

1. Identify the location of your vernacular building.
2. Describe the climatic characteristics of its locale.
3. Draw a building response diagram to illustrate how seasonal or diurnal changes in the luminous environment affect the living patterns.
4. Document your findings using vignettes, photocopies, photographs, etc. with concise and clearly written annotations. Include any uncertainties, questions, or ambiguities that would require additional research. Your analysis should be no longer than two 8½" x 11" pages.

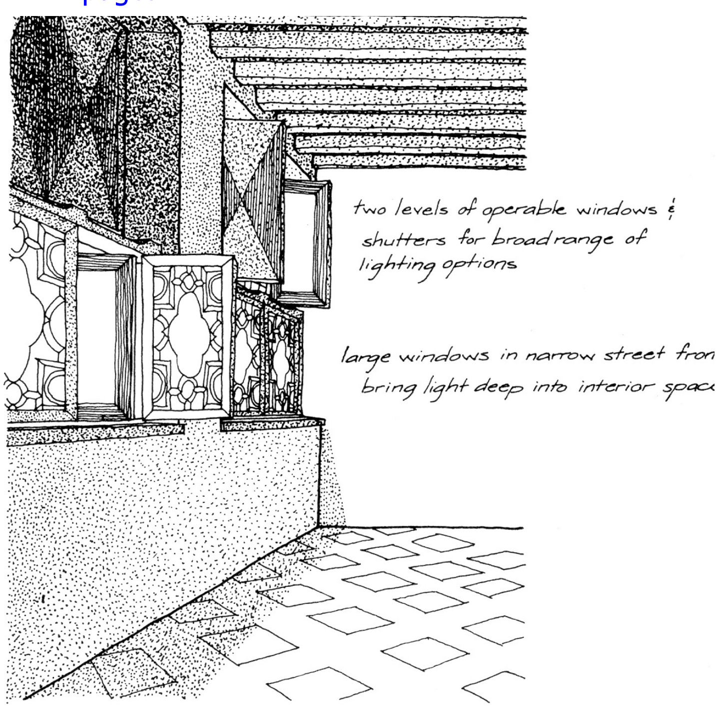


Figure A2.1.1 Dutch Row Houses, ca. 16th Century

Lighting Design Strategies

Site-Scale Strategy

- Provide an unobstructed view of the sky dome.

Cluster-Scale Strategies

- Reflect light into the building from adjacent building and ground surfaces.
- Control glare and sunlight with external shading devices, such as trees or arbors.

Building-Scale Strategies

- Place spaces that require daylight near the skin of the building.
- Position smaller spaces so they "borrow" light from larger spaces. Surround large, high-ceilinged, daylighted spaces with small, low-ceilinged spaces.

Figure A2.2.1 Cloudy Sky Strategy. Glasgow School of Art, Glasgow, Scotland, C. R. Mackintosh (architect), 1899–1909.

Component-Scale Strategies

- Bounce light deeper into the building with shading devices used as light-shelves.
- Make sidelighted rooms no more than twice as deep as the window head is high.
- Place small windows high in the room or out of the field-of-view in clear-sky climates.
- Ensure unobstructed access to the sky dome and shading appropriate to the building's balance point temperature for large windows in cloudy climates.
- Exclude direct sun penetration through skylights into critical task areas.
- Provide light from north- and south-facing apertures to avoid glare and excessive heat gain.
- Provide balanced illumination with lighting from two sides or directions to minimize glare problems.

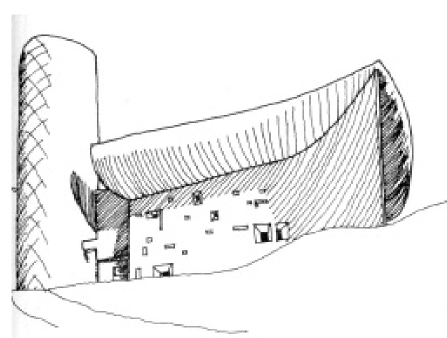


Figure A2.2.2 Clear Sky Strategy. Notre Dame du Haut, Ronchamps, France, Le Corbusier (architect), 1950–1955.

PRECEDENTS OF LIGHTING RESPONSE

LIGHTING PRECEDENTS (continued)

PROCEDURE

Choose an existing building or site that has: (1) a building program, luminous environment, or both that is similar to your assigned building program or climate and (2) a clear, conceptual approach that incorporates some of the design strategies above.

DOCUMENT YOUR CHOICE AS FOLLOWS:

1. Identify the location, program, architect (if known), and source of your information.
2. Include photocopies or drawings (whichever is quick and easy for you) to illustrate the design.
3. Evaluate the building or site design with a building response diagram and short annotations that explain how this design is organized for lighting.

B2 LIGHTING

CLIMATE AND SITE ANALYSIS

INTRODUCTION

Goal

Determine how much light is seasonally available on your site and what potential benefits or problems may arise with the changing sky conditions. Generate a glazing strategy responsive to your climate and site.

Discussion

It is never too early in the design process to address the effect of the sun's light and heat. Is your site's climate predominantly sunny or cloudy or does it change seasonally? Look at vernacular buildings in your climate for clues about well-tested responses to the luminous environment.

The amount of exterior illumination available for daylighting depends on latitude and prevailing sky condition (clear or cloudy). The lower the latitude, the brighter the light. Also, the lower the latitude, the more intense and less thermally desirable the direct sunlight. Once you determine illumination levels, perform lighting program analyses to determine which spaces you can successfully daylight and to approximate how much glazing will be required.

In this section you will:

1. Investigate your site's seasonal sky conditions.
2. Determine how much exterior illumination is available seasonally.
3. Propose a conceptual daylighting design that takes advantage of your site's sky conditions to provide the maximum use of daylighting.

B2 LIGHTING

CLIMATE AND SITE ANALYSIS

SKY CONDITIONS

B2
B2.1

Discussion

The prevailing sky condition is an important factor when developing a daylighting scheme. Clear days have higher available illumination levels and a directional light source (the sun) which, in most cases, must be prevented from shining directly into the building. Aside from the sun, the brightest part of a clear sky is near the horizon. Cloudy days have less available illumination, and light distribution does not vary with window orientation. Generally, on cloudy days the zenith is three times as bright as the horizon.

Procedure

1. Record the number of clear, cloudy, and partly cloudy days in each month for your site's climate according to NOAA climatological data [Climate Consultant, 2-D Sky Cover Range Chart].

   For each month, graph and color code the number of clear, partly cloudy, and cloudy days. To enhance the readability of your chart, plot the number of cloudy days from the right, the number of clear days from the left, and the number of partly cloudy days in the middle.

Sky Conditions Chart

	Number of Days						
	0	5	10	15	20	25	30
Jan							
Feb							
Mar							
Apr							
May							
Jun							
Jul							
Aug							
Sep							
Oct							
Nov							
Dec							

KEY: ◯ Clear ◯ Partly Cloudy ◯ Cloudy

2. For each season, determine whether cloudy or clear skies predominate. (If neither is dominant, you may analyze either your worst case or both sky conditions using the technique discussed in B2.2.)

CLIMATE AND SITE ANALYSIS

AVAILABLE ILLUMINATION

Discussion

The available exterior illumination for any location varies both seasonally and with its sky conditions. On clear days window orientation is important when determining interior light levels. North-facing windows give less intense, more even light over the course of a day and minimize solar gain (a good cooling strategy). South-facing windows may maximize solar gain (a good heating strategy) and yield a broad range of illumination levels over the course of a day. Since it is difficult to block direct sunlight in east- and west-facing windows, use them with great care in daylighting schemes. On cloudy days light is distributed more evenly across the sky and window orientation makes little difference.

Procedure

For each season:

1. Determine your exterior footcandles throughout the day.
   a. If you've determined the season is predominantly cloudy, use Table B2.2.1 below.
   b. If you've determined the season is predominantly clear, use Table B2.2.2. Note the illumination levels for all exposures you intend to use for daylighting.
   c. If your skies are neither predominantly clear nor cloudy, use the data that give you a worst-case situation or use both sky conditions' data.
2. Plot the illumination data [Figure B2.2.1]. On each graph indicate whether you are using clear or cloudy sky data.

Table B2.2.1 Cloudy Sky Illuminance Data

Equivalent sky luminance in footlamberts--average overcast day

Latitude (°N)	December 21					March 21 or September 21					June 21				
	8 a.m. 4 p.m.	9 a.m. 3 p.m.	10 a.m. 2 p.m.	11 a.m. 1 p.m.	Noon	8 a.m. 4 p.m.	9 a.m. 3 p.m.	10 a.m. 2 p.m.	11 a.m. 1 p.m.	Noon	8 a.m. 4 p.m.	9 a.m. 3 p.m.	10 a.m. 2 p.m.	11 a.m. 1 p.m.	Noon
30	420	740	1020	1210	1270	910	1320	1710	2010	2140	1270	1730	2250	2250	2250
32	350	700	960	1150	1200	880	1290	1650	1940	2070	1280	1730	2240	2240	2240
34	320	650	910	1100	1140	860	1250	1600	1870	1980	1290	1730	2220	2220	2220
36	260	600	840	1020	1070	840	1220	1560	1800	1900	1290	1730	2200	2960	2960
38	230	550	790	940	1000	800	1200	1500	1740	1840	1290	1720	2160	2840	2840
40	190	500	740	900	930	790	1140	1460	1670	1760	1290	1700	2120	2650	3060
42	150	450	660	820	860	760	1120	1410	1600	1690	1300	1690	2080	2540	2860
44	100	380	600	760	790	740	1080	1340	1540	1620	1190	1670	2050	2430	2660
46	60	340	550	680	730	710	1030	1290	1470	1550	1290	1640	2010	2330	2520
48	40	290	470	630	650	690	990	1240	1410	1480	1290	1620	1960	2250	2400
50	0	240	420	560	580	650	940	1180	1330	1400	1260	1590	1900	2160	2280

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Table B2.2.2 Clear Sky Illuminance Data

Equivalent sky luminance in footlamberts--clear days (average values, direct sun excluded)

Latitude (°N)	December 21					March 21 and September 21					June 21				
	8 a.m.	10 a.m.	Noon	2 p.m.	4 p.m.	8 a.m.	10 a.m.	Noon	2 p.m.	4 p.m.	8 a.m.	10 a.m.	Noon	2 p.m.	4 p.m.
North															
30	450	600	600	600	450	700	1000	1050	1000	700	1550	1400	1000	1400	1550
34	350	550	550	550	350	800	800	900	800	800	1350	1400	950	1400	1350
38	300	550	550	550	300	750	800	900	800	750	1350	1300	950	1300	1350
42	250	500	500	500	250	700	750	800	750	700	1300	1300	950	1300	1300
46	150	450	500	450	150	700	750	750	750	700	1300	1250	950	1250	1300
South															
30	1100	1950	2250	1950	1100	1700	2300	2800	2300	1700	1200	1600	2400	1600	1200
34	1100	1900	2200	1900	1100	1700	2650	2900	2650	1700	1350	1650	2300	1650	1350
38	900	2300	2200	2300	900	1700	2700	2950	2700	1700	1350	1650	2300	1650	1350
42	600	2100	2150	2100	600	1700	2700	2450	2700	1700	1350	2000	2500	2000	1350
46	400	1900	2100	1900	400	1700	2700	2900	2700	1700	1350	2100	2700	2100	1350
East															
30	1550	1500	1000	700	400	2000	2500	1500	900	700	2800	2650	1400	1000	700
34	1350	1400	950	700	400	2400	2600	1600	950	650	2800	2700	1450	1000	700
38	1200	1300	900	650	350	2500	2600	1500	900	600	2800	2700	1400	1050	700
42	750	1200	850	600	250	2400	2400	1450	800	600	2900	2600	1400	1000	700
46	500	1100	800	500	150	2300	2100	1400	700	600	2850	2600	1400	1000	700
West															
30	400	700	1000	1500	1550	700	900	1500	2500	2000	700	1000	1400	2650	2800
34	400	700	950	1400	1350	650	900	1600	2600	2400	700	1000	1400	2700	2800
38	350	650	900	1300	1200	600	900	1500	2600	2500	700	1050	1400	2700	2800
42	250	600	850	1200	750	600	800	1450	2400	2400	700	1000	1400	2600	2900
46	150	500	800	1100	500	600	700	1400	2100	2300	700	1000	1400	2600	2850

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CLIMATE AND SITE ANALYSIS

AVAILABLE ILLUMINATION (continued)

NOTE: For seasons where clear sky conditions predominate, graph both the north and south windows.

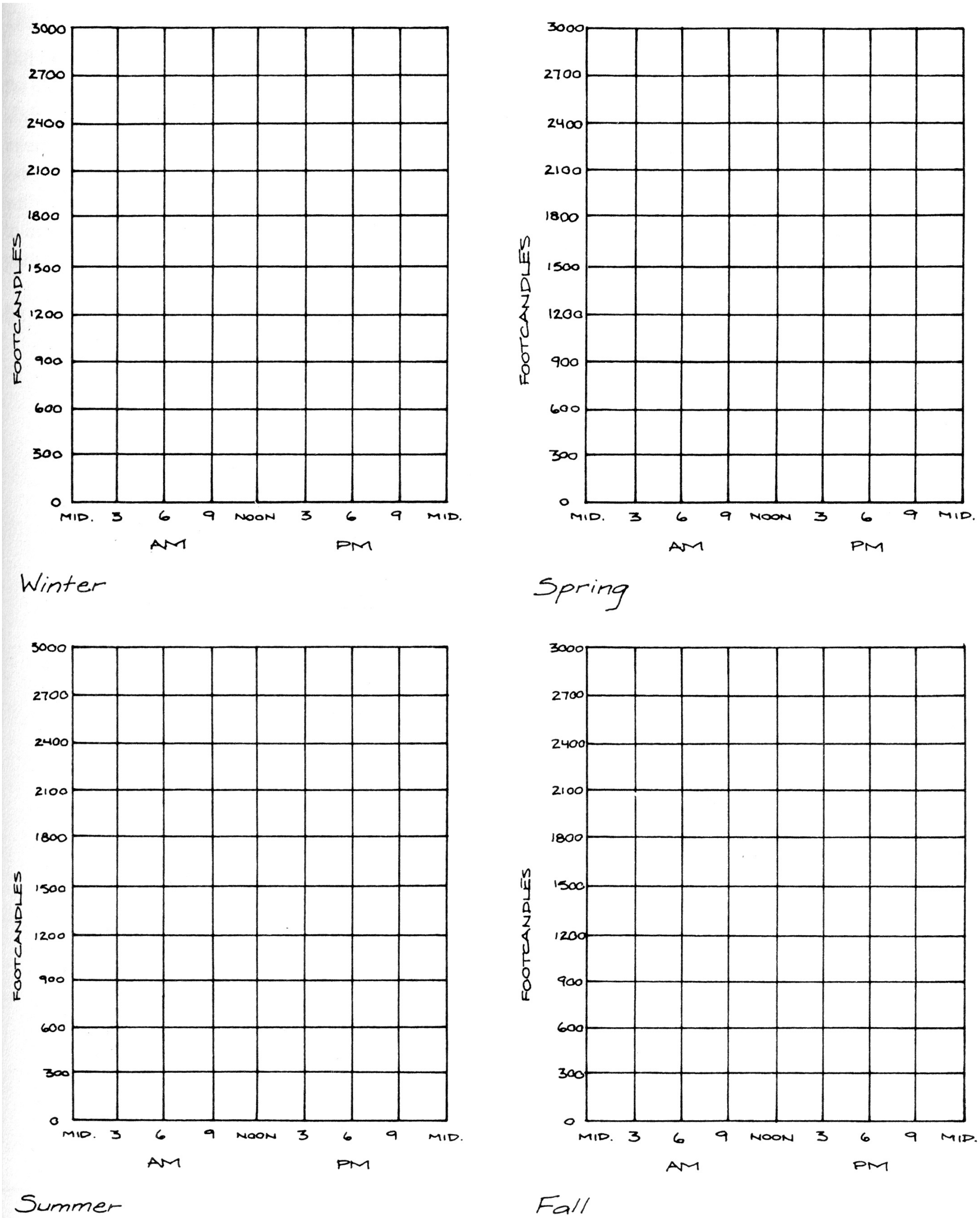


Figure B2.2.1 Available Illumination Graphs

CLIMATE AND SITE ANALYSIS

SITE CONCEPTS

Discussion

The sky conditions and available illumination graphs help you gain insights about the luminous environment on your site. You can now explore alternate placements of your building on the site and organizations to provide access to daylight for appropriate spaces. These concepts should be expressed in the form of very simple, annotated diagrams, which are the most appropriate level of detail for this stage of the design process. Show size, orientation, and relationships of the building program's elements. Be sure to respond to specific qualities of the physical and luminous environments.

Procedure

1. Diagram each site design.
2. Annotate the diagrams to explain luminous considerations.
3. Discuss the potential benefits and disadvantages of your scheme with respect to views, thermal control, and daylighting.

PROGRAM ANALYSIS
INTRODUCTION

Goal

Determine how much light your building's occupants need and whether the available external illumination is adequate to daylight your building.

Discussion

Different tasks have different lighting requirements—the greater the visual difficulty, the higher the illumination level required. Areas closer to the windows and beneath the skylights receive more daylight than areas farther from the windows. The amount of internal illumination you achieve varies with the amounts of glazing and available exterior illumination. To maximize the effectiveness of daylighting design, group tasks with similar lighting needs and place those task groups that require more light closest to apertures. These decisions and climate and site analyses determine whether a particular fenestration scheme will provide adequate light.

In this section you will:

1. Determine what tasks are performed in your building and set a recommended lighting level and lighting energy budget for each task.
2. Determine how much exterior illumination is required to successfully daylight each task according to your glazing strategy.
3. Propose a schematic daylighting design for your building.

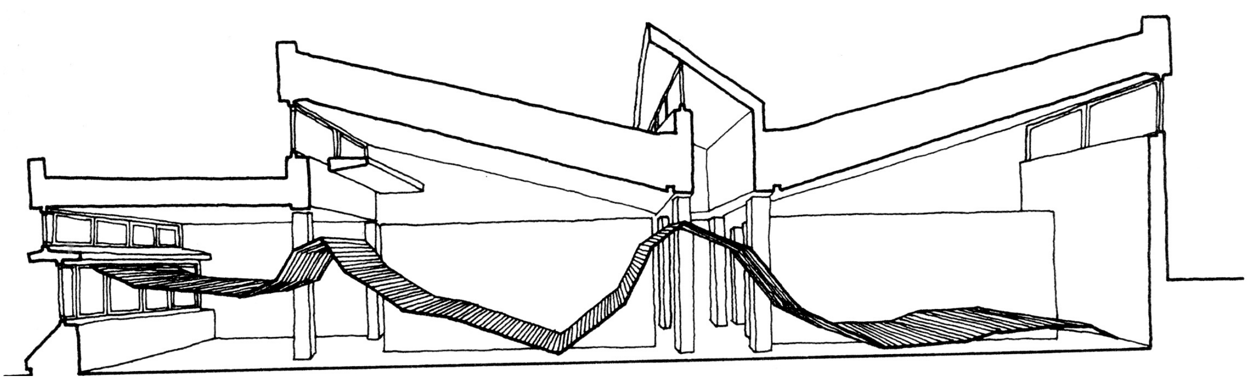


Figure C2.0.1 Lighting Section. Mount Airy Public Library, Mount Airy, NC, Ed Mazria (architect), 1981.

PROGRAM ANALYSIS

RECOMMENDED FOOTCANDLE LEVELS

Discussion

Space use determines lighting levels (footcandles). Spaces may be illuminated by uniform (ambient), localized (task), or a combination of both ambient and task lighting. For example, if a task requires a high light level, it may be best to use lower-level, ambient lighting and provide small areas of higher-level, separately operable, task lighting.

Procedure

1. Identify all the major tasks performed in your building. Use energy-conscious lighting recommendations [Table C2.1.1 below] to assign a footcandle level for each task.
2. Note the hours during which each task is performed. This information will be useful later when you determine whether daylighting can be used to provide the necessary light levels.

Lighting Schedule [suggested format]

Task/Space	Light Level (fc)	Hours of Operation
lobby	*15*	*6a.m.–midnight*

Table C2.1.1 Illumination Requirements Rules-of-Thumb

VISUAL TASKS	ILLUMINATION (FC)	ILLUMINATION LUX
Circulation spaces & Dining	10 – 20 fc	100 – 200 lux
Light work space (reading, etc.)	20 – 40 fc	200 – 400 lux
Visually intense tasks (fabrication, etc.)	60 – 100 fc	600 – 1,000 lux
Display areas	100 – 150 fc	1,000 – 1,500 lux

PROGRAM ANALYSIS

RECOMMENDED LIGHTING ENERGY BUDGET

Discussion

Most building codes include an energy code that prescribes an electric lighting energy budget based on building type. The basic energy budget for a building may be adjusted upward if electric lighting control schemes based on daylighting, occupancy, or fixture performance are used.

Specific control schemes eligible for energy credits are:

1. **Continuous Dimming + Daylighting**: A photocell senses exactly how much daylight is available and informs the controller which then compensates by continuously adjusting the lights to provide required lighting.
2. **Stepped Switching + Daylighting:** A photocell senses exactly how much daylight is available and informs the controller which then compensates by adjusting the lights only when preset thresholds are reached.
3. **On–Off Switching + Daylighting:** A photocell senses exactly how much daylight is available and informs the controller which then compensates by switching on electric lights when necessary.
4. **Occupancy Sensor Switching:** A body heat or motion detector switches off the light shortly after it senses the room is unoccupied.
5. **Lumen-Maintenance Control:** The controller reduces the wattage delivered to new electric lamps and gradually increases the wattage to full power as the lamps becomes older and less efficient.
6. **Programmable Timing Control:** A microprocessor turns the lights on and off according to a programmed building occupancy schedule.

The energy code may also limit the types of lamps and fixtures you may use in your building.

Procedure

1. Select the basic lighting energy budget for the spaces in your building or for the building as a whole [Table C2.2.1].

2. Calculate your adjusted lighting energy budget based on control schemes appropriate to your design [Table C2.2.2]. Specify at least two alternatives. Call these schemes "Y" and "Z."

Lighting Energy Budget [suggested format]

Applicable Energy Code *MCS*

Space	Basic Energy Budget	Scheme Y	Scheme Z
office	*1.5 watts/ft²*	*1.95 watts/ft²* (*continuous dimming + daylighting*)	*2.16 watts/ft²* (*occupancy sensors + daylighting*)

Table C2.2.1 Model Codes for Interior Lighting Power Budgets

Comparison of codes for interior lighting allowances (watts/ft²)

	MCS	OR.1986	WA.1986	ASHRAE 90.1P		DOE STANDARD			CEC
				ULPA	LPB	ULPA	LPB		
							1987	1992	
Office	1.5	1.7	1.7	1.9	2.3	1.9	2.3	1.6	1.5
Retail									2.0
<1000 ft²	4.5	4.0	4.0						
1000-6000 ft²	3.5	4.0	4.0						
6000-20,000 ft²	2.5	2.3	3.0	3.1	3.1	3.1	3.1	2.6	
>20,000 ft²	1.5	2.3	2.0						
Warehouse	0.7	0.7	0.7	0.4	0.3	0.4	0.3	0.3	1.0
Restaurant	1.85	1.2	1.85					1.0	
Fast Food			1.4	1.3	1.4	1.3	0.8		
Leisure Dining			2.1	2.5	2.1	2.5	1.4		
School	2.0	2.0/1.8	1.7	1.8	NC	1.8	NC	NC	NC

NC = not covered

Reprinted from Northwest Power Planning Council, "Staff Briefing Paper on Commercial Lighting," 15.

Table C2.2.2 Lighting Code Credits for Model Lighting Codes

Control credits (comparison of codes for lighting requirements)

	MCS	OR.1986	WA.1986	ASHRAE 90.1	DOE BEPS	CEC
Control Credits		none				
Occupant Sensor	30%		30%	30%	30%	30%
Continuous + Daylighting	30%		30%	30%	30%	30%
Stepped + Daylighting	20%		20%	20%	20%	20%
On/Off + Daylighting				10%	10%	
Lumen Maintenance	10%		10%	10%	10%	10%
Occupancy + Daylighting	44%		44%	40%		
Occupancy + Lumen	37%		37%	35%		
Programmable Timing				15%		

Reprinted from Northwest Power Planning Council, "Staff Briefing Paper on Commercial Lighting," 19.

REQUIRED EXTERIOR DAYLIGHT LEVELS

Discussion

There is a range of possible daylighting strategies to choose from. By using "lots of big windows," about 50% of the floor area in glazing, you can produce interior illumination levels of about 10% of exterior levels (a daylight factor of 10%); call this one "Strategy A." At the other extreme, by using "a few, small windows," about 5% of the floor area in glazing, you can produce interior illumination levels of about 1% of exterior levels (daylight factor of 1%); call this one "Strategy C." The recommended glazing level for your location will probably fall between these extremes. You can experiment with different ratios of glazing to floor area for each space; call these "Strategy B."

Procedure

For each task:

1. State the recommended interior illumination level [C2.1, step 1].
2. Investigate the range of possible glazing configurations.
   a. Calculate the minimum required exterior illumination for daylighting with "lots of big windows" (Strategy A) and "a few, small windows" (Strategy C).
   b. Determine the minimum exterior illumination required to supply the recommended interior footcandle level. For "big windows" DF is 10% or .10, for "small windows" DF is 1% or .01.

      $fc_{ext} = (fc_{int}) / (DF)$

      where:

      fc_{ext} = minimum required exterior illumination (fc)
      fc_{int} = recommended interior illumination (fc)
      DF = daylight factor
3. Estimate the percentage of exterior illumination that will be available as interior illumination (DF).
   a. Find your location's recommended glazing level or choose a glazing level you wish to investigate (Strategy B). You may change the glazing percentage for each task.
   b. Calculate the minimum required exterior illumination levels. Use the nomograph on the next page [Figure C2.3.1] to help convert percentage of floor area in glazing to DF.

REQUIRED EXTERIOR DAYLIGHT LEVELS (continued)

C2.3

Required Exterior Daylight Level Chart [suggested format]

Task	Recommended Interior Illumination (fc_{int})	Strategy A: 50% of Floor in Glazing DF = 10% (fc_{ext})	Strategy B: Recommended Glazing ____Level % Glass	Strategy B: DF	Strategy B: (fc_{ext})	Strategy C: 5% of Floor in Glazing DF = 1% (fc_{ext})
lobby	*3*	*30*	*15*	*3%*	*100*	*300*

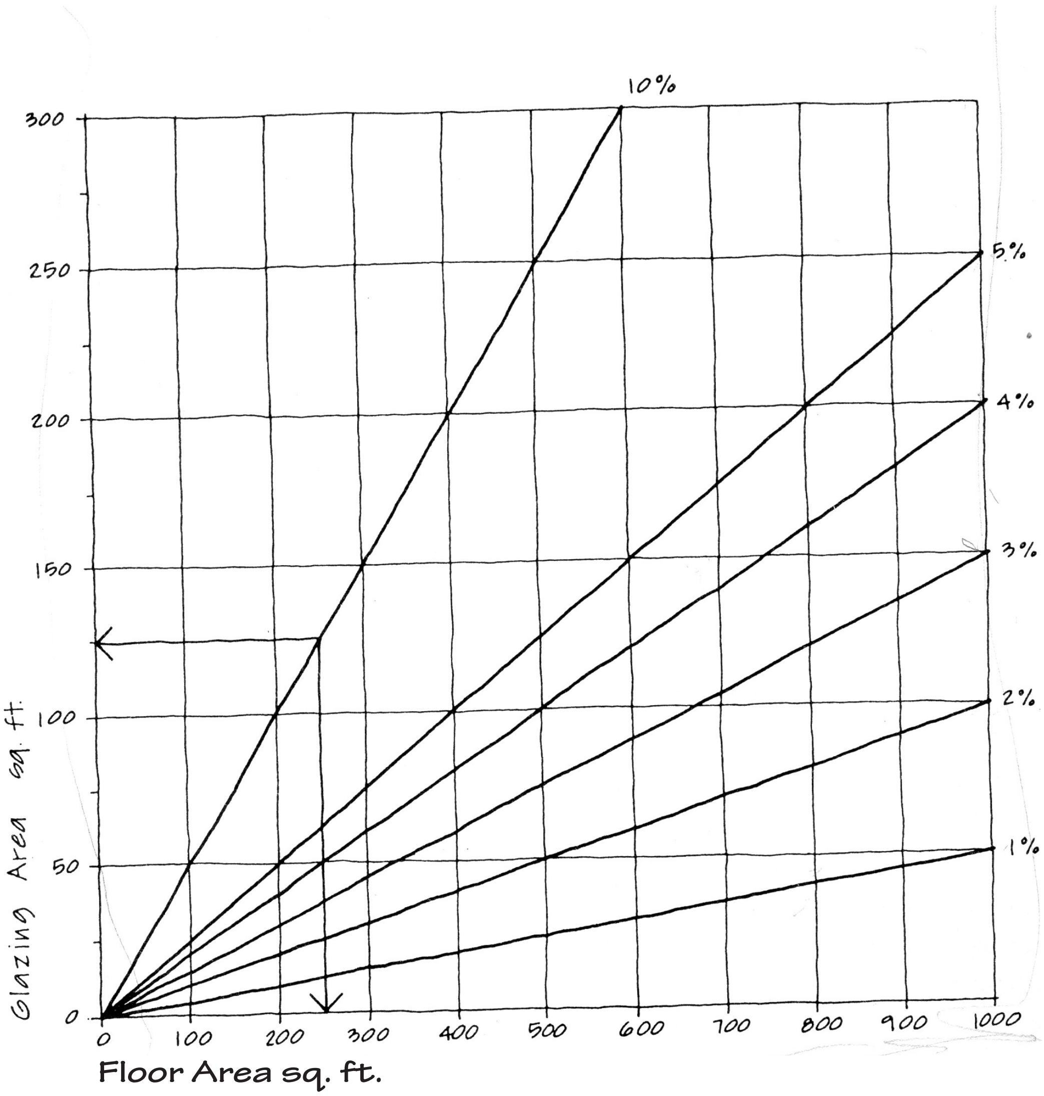


Figure C2.3.1 Daylight Factor Nomograph. Sidelighting and vertical monitors. Reprinted, by permission, from Brown, *Sun, Wind, and Light*, 127, copyright © 1985, John Wiley & Sons, Inc.

Discussion

Now that you know the required exterior illumination for several daylighting strategies and your actual seasonal exterior illumination levels [B2.2], you can determine which daylighting strategy is appropriate for each task in your building.

Procedure

For each task or group of tasks:

1. Photocopy the graphs you completed in B2.2.
2. Plot and label the seasonal minimum required exterior illumination at the required footcandle level for each daylighting strategy (A, B, and C) [C2.3, step 3b]. These plots, which represent each task's hours of operation [C2.1, step 2], should be horizontal lines. Your graph should be similar to that shown in Figure C2.4.1.
3. Identify the times of effective daylighting as plotted on the graph for each strategy for each season.

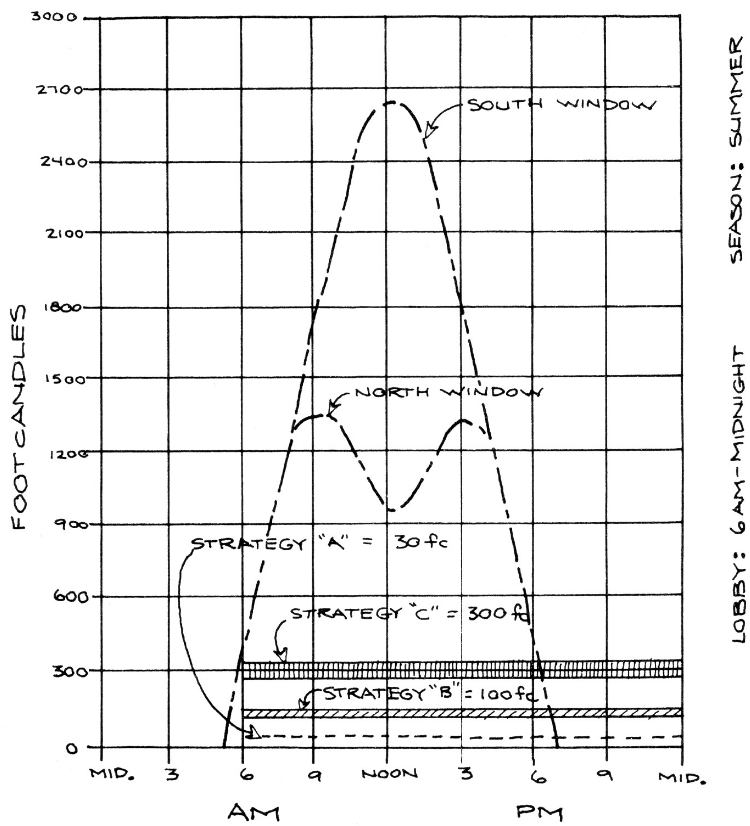


Figure C2.4.1 Sample Available Illumination Graph. Required summer illumination levels support strategies A–C in the lobby from 6 a.m. to midnight. All three strategies provide adequate illumination from 6 a.m. to 6 p.m.. Therefore, the design can be greatly influenced by other factors.

4. Select the daylighting strategy or glazing percentage that would adequately meet your lighting needs. Circle or highlight your choice in the hours of effective daylighting table.

Hours of Effective Daylighting (for each task) [suggested format]

Task *office work*

Season	Hours of Operation	Hours of Effective Daylighting: Strategy A (big windows)	Strategy B (medium windows)	Strategy C (little windows)
Spring	*8a.m.–5p.m.*	*7a.m.–5p.m.*	*8a.m.–4p.m.*	*9a.m.–3p.m.*

Discussion

The illumination potential graphs indicate how difficult or easy it will be to daylight each space in your building. Remember, windows and skylights are potentially major sources of heat loss or heat gain in a building. If you are using more than the recommended amount of glazing for your site and building program, you must justify your decision. Daylighting apertures can also be ventilation apertures.

Procedure

1. Illustrate your daylighting choices with an annotated, schematic diagram of your proposed fenestration strategies.
2. Discuss whether you will use year-round daylighting or will require supplemental electric lighting.
3. Discuss conflicts and harmonies between thermal and lighting needs in your design.

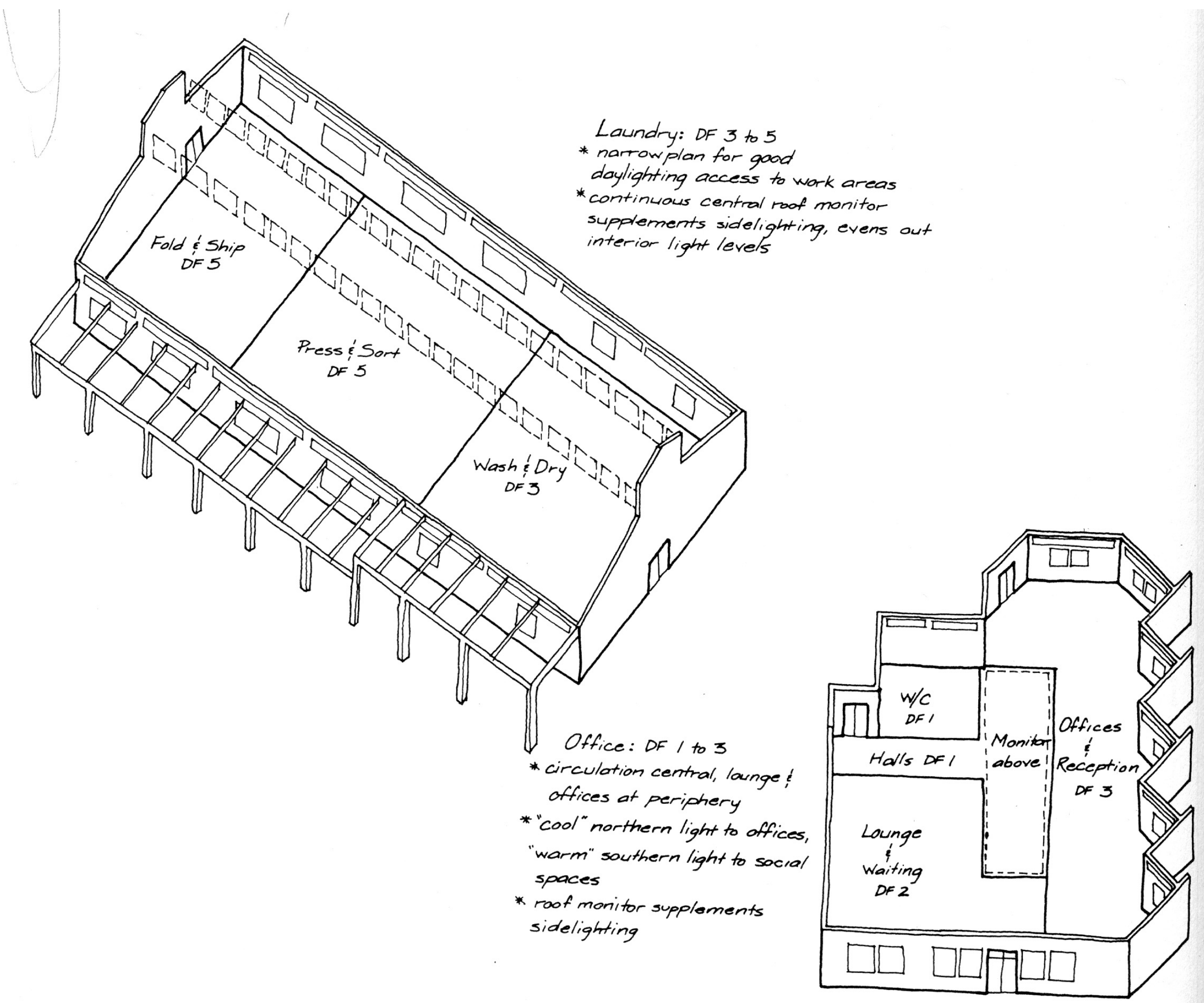


Figure C2.5.1 Daylighting Strategies. Linen supply, Charleston, South Carolina.

D2 LIGHTING

SCHEMATIC DESIGN

INTRODUCTION

D2
D2.0

Goal

Design a building that synthesizes the information you have acquired through the study of precedents; the analyses of your site, climate, and program requirements; and the application of lighting design strategies.

Lighting Schematic Design Goals

A. Daylighting is distributed so there is adequate light where people need it.
B. Gradual changes in lighting levels inside, outside, and within rooms prevent glare problems.
C. Window apertures are sized to attain the minimum levels of illumination required for tasks and spaces, the recommended daylight factor (DF).
D. Solar collecting and ventilating apertures are maintained as required for heating and cooling.

Discussion

Until 100 years ago, daylighting was the prevalent means of lighting buildings. Artificial lighting sources were installed, but provided far less light than daylight and tended to be used only at night. Once mechanical cooling systems and inexpensive fluorescent lighting were developed it became possible to exclude daylight from buildings. The heat from electric lighting had to be expelled with the heat from the occupants. The outdoors became hotter while the indoors stayed cool.

<u>Why Would Anyone Exclude Daylight?</u>

Daylight is highly variable; there is much less of it at 8 a.m. than at noon and less in winter than in summer. An overcast sky distributes daylight very differently than a clear sky, and sky conditions can shift several times a day. If absolutely uniform, steady light is desirable, electric lighting is a more reliable source.

<u>Why Would Anyone Use Daylight?</u>

Electric lighting is energy intensive. Electricity production by nuclear and fossil thermal processes captures, at best, about 40% of the fuel's value; the remainder is dumped in the environment as waste heat. Hydroelectric, geothermal, and wind-generated power, though more efficient in

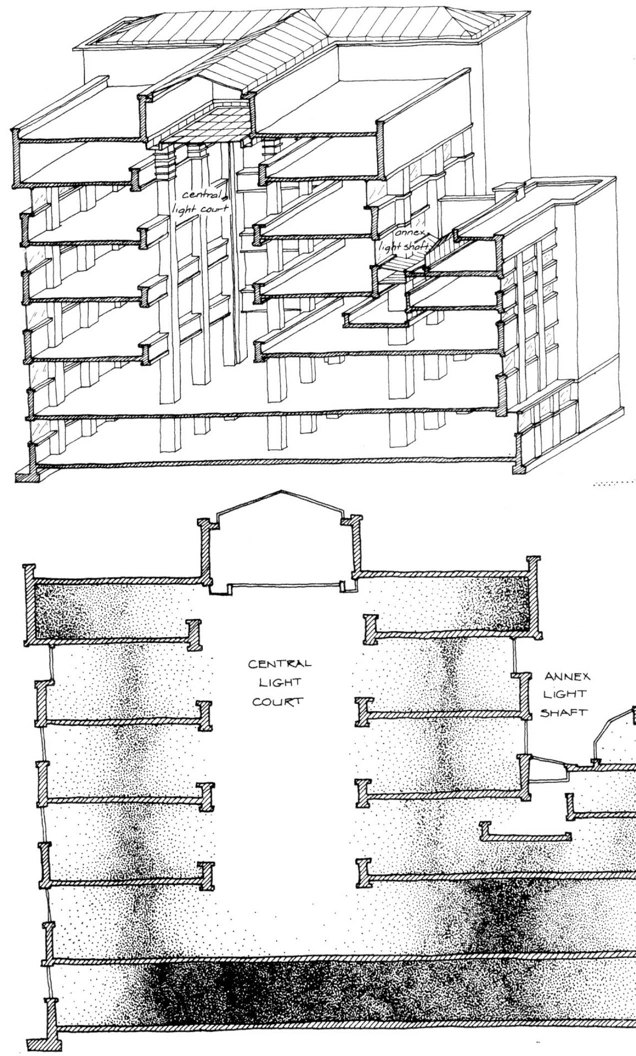


Figure D2.0.1 ***Above*, Spatial Section; *below*, Lighting Section. Larkin Building, Buffalo, New York, Frank Lloyd Wright (architect), 1905.**

INTRODUCTION (continued)

producing electricity, lose energy as waste heat when transmitted from the point of production to the point of use. The farther the energy must travel, the more energy is lost. Finally, as electric light is created, it brings about twice as much heat per unit of light to the space as does daylighting. Because energy conservation is important, daylighting is a more appropriate, economical choice.

What Are the Tradeoffs Between Using Electric Light *vs.* Daylight?

More electric lights mean more internal heat gain year-round. This increased load becomes the winter friend of the skin dominated load building but the year-round enemy of the internally dominated load building. More windows to provide more daylight mean more heat loss in winter. In summer daylight windows can be rendered relatively harmless to heat gain if properly shaded. In skin dominated load buildings neither lighting method is more advantageous than the other from the standpoint of energy use. However, daylighted, internally dominated load buildings usually require less energy to operate successfully.

In this section you will:

1. Employ appropriate lighting design strategies.
2. Complete your luminous schematic design.
3. Use a variety of techniques to test the performance of your schematic design and alter it where appropriate.
4. Review and critique your schematic design.

Lighting Schematic Design Strategies

Site-Scale Strategies

- Locate buildings and spaces to either use or avoid sky obstructions.
- Open your site to the sky in proportion to the sky's brightness and the amount of light you need.

Cluster-Scale Strategies

- Arrange buildings and ground surfaces to reflect or absorb light.
- Place light-colored walls north of north-facing spaces to increase reflected light.
- Control glare and heat gain by using thermal buffer zones (e.g., arbors, vestibules, courtyards, atria, greenhouses).
- Use snow as a highly effective reflector of light, but avoid its capacity for glare.

Building-Scale Strategies

- Zone tasks according to their visual difficulty. Put spaces or activities that need light near openings in the skin.
- Employ the strategy for combining daylighting and artificial lighting that is most appropriate to your building's climate and functions:
  - ◁ Supply adequate interior daylight under average sky conditions. When sky illumination conditions are below average, use supplemental lighting.
  - ◁ Provide minimum required daylighting under worst-case sky conditions (such as a cloudy, December day at 9 a.m.). Use supplemental lighting when daylighting is not adequate.
  - ◁ Maintain adequate daylight for typical working hours. Provide supplemental lighting for other hours of use.
  - ◁ Achieve the minimum lighting everywhere. Use supplemental artificial lighting in areas farthest from apertures rather than oversupplying daylight to areas nearest apertures.
- Locate tasks and proportion rooms to take full advantage of the 15' perimeter where maximum light from side windows is available.
- Avoid over-daylighting your spaces in hot climates, where darker places are associated with cooler temperatures.
- In hot climates use light reflected through windows placed near the ceiling to avoid glare at eye level and reduce heat gain from direct light.
- LEED requires a minimum DF of 25 FOR 755 of the normally occupied space.

DESIGN (continued)

Component-Scale Strategies

- Orient openings toward the brightest part of the sky (the zenith for overcast skies, the horizon for clear skies).
- Prevent discomfort from excessive brightness or contrast.
- Provide ambient illumination from skylights to areas directly below.
- Use side lighting to provide task illumination to nearby areas.
- Use specular surfaces out of the field of view to reflect light yet avoid glare problems.
- Zone tasks to best use available light rather than trying to manipulate light to reach task areas.
- Provide glazing at a ratio of approximately 5–10% of the floor area for standard ambient lighting (office, lobby, circulation).
- Provide glazing at a ratio of approximately 25% of the floor area for intensive, task lighting (display, drafting, typing, factory work).
- Proportion window head height to equal half the depth of the room for optimal daylight penetration and distribution.
- Arrange shading devices so their reflective surfaces do not cause glare at eye level in the shaded spaces beyond.

Procedure

Propose a schematic design for your building based on analyses of precedent [A2], site and climate [B2], and program [C2]. Use the appropriate lighting design strategies for your design.

Document your design as follows:

1. Site plan, including parking and access drives (scale: 1" = 100').
2. Cluster plan, including outdoor spaces (scale: 1" = 40').
3. Floor plans (scale: 1" = 20').
4. Roof plan and elevations, or axonometrics, illustrating all building sides and roof (scale: 1" = 20').
5. Sections (scale: 1/8" = 1'-0").
6. Design diagram, annotated to identify design strategies and luminous zones.

SCHEMATIC DESIGN
LIGHT DISTRIBUTION RENDERING

Procedure

Evaluate how well your building attains Lighting Schematic Design Goal A—**Daylighting is distributed so there is adequate light where people need it.**

1. Render your building's shaded and lighted areas based on the predominant sky condition in your climate.

   a. Draw a plan and section on a single page. Use media that allow you to quickly approximate the relative patterns of light and dark. Pencil or charcoal on tracing paper or colored pencils on brown paper are common methods.

   b. Identify task areas and draw the furnishings to clearly show the light–task relationships.

2. Discuss whether or not your building and site improvements meet Goal A, and describe how your design must be altered if the goal has not been met.

For a discussion of daylight zoning see *GSH* pp87–91.

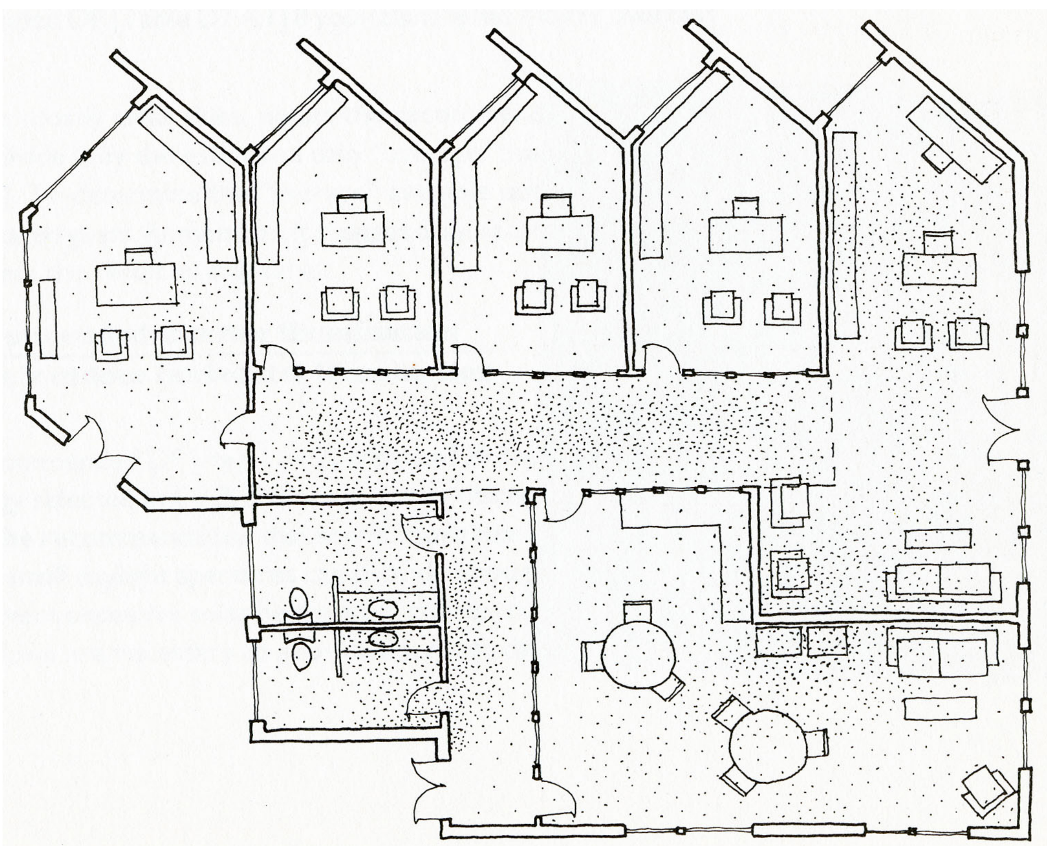


Figure D2.2.1 Light Distribution. Linen supply office, Charleston, South Carolina.

Procedure

Evaluate how well your building attains Lighting Schematic Design Goal B—**Gradual changes in lighting levels inside, outside, and within rooms prevent glare problems.**

1. Develop detailed renderings based on your drawings [D2.2] to show how you have designed for gradual changes in brightness. Include studies of one entry and of one room.
2. Discuss whether or not your building and site improvements meet Goal B, and describe how your design must be altered if the goal has not been met.

RECOMMENDED DAYLIGHT FACTORS

Discussion

Table D2.4.1 lists recommended minimum daylight factors under overcast sky conditions. For clear sky conditions daylight factors must be calculated by dividing the required illumination level by the "average" exterior illumination level. This "average" level is dependent on the window orientation you have chosen for day-lighting. You must make an educated guess at this "average" for each space and task.

When designing for daylighting the minimum DF recommendations should be met or exceeded to provide adequate daylighting. However, if the recommendations are exceeded by twice or more, thermal problems (summer overheating or excessive winter heat loss) may result. Therefore, daylighting levels should meet or barely exceed DF recommendations.

Procedure

Evaluate how well your building attains Lighting Schematic Design Goal C—**Window apertures are sized to attain the minimum levels of illumination required for tasks and spaces, the recommended daylight factor (DF).**

For each task:

1. List the recommended DF [Table D2.4.1 or *GSH* Table 4.4 p84.] if your climate has mostly overcast skies.
2. If your climate has mostly clear skies, obtain the recommended footcandle level [C2.1], and divide it by the estimated daily "average" available outdoor illumination [B2.2]. To determine the "average" available outdoor illumination, make an educated guess. Remember, it changes daily, seasonally, and with orientation. Express the result as a decimal.

$$DF = \frac{\text{recommended interior illumination}}{\text{“average” outdoor horizontal illumination}}$$

3. Compare the recommended DF [step 1 or 2] with the DF determined by the daylighting strategy selected in C2.3. If there is a large discrepancy between the two, choose the recommendation that seems more reasonable. In clear-sky climates very small daylight apertures can provide enough light from the bright sky yet prevent excessive solar heat gain. In cloudy-sky climates large, well-shaded windows are necessary to provide adequate daylighting.

RECOMMENDED DAYLIGHT FACTORS (continued)

D2.4

Recommended Daylight Factors [suggested format]

Task Activity Area	Recommended DF*	DF [C2.3 or C2.4]
office (general)	*.04 or 4%*	*.03 or 3%*
circulation	*.01 or 1%*	*.01 or 1%*

* DFs are often expressed as percentages rather than ratios.

Table D2.4.1 Required Daylight Factors for Various Functions

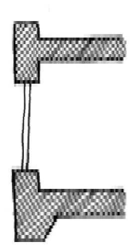
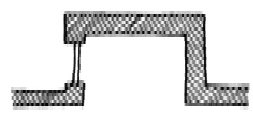
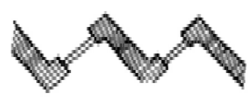
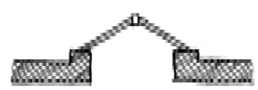
Building Type	Activity	DF (%)	Comments
All Public Buildings	Circulation	0.5-3.0	Minimum is sufficient; higher levels required in transition areas from bright space
	Lobbies, Foyers, Lounges	1	Individual task lighting may be necessary for reading.
	Reception Desks	1.0-2.0	Dependent on difficulty of task involved.
	Restrooms	0.0-1.0	Need not be daylighted.
Assembly, Concert Halls	General	0.0-1.0	Do not daylight if incapable of blacking out light for media presentations.
Banks	General	2.0	
Churches	Congregation	1.0	
	Pulpit	1.5-4.0	
Hospitals	Wards, Public	1.0	Provide individual task lighting for reading.
	Laboratories	3.0	Provide task lighting.
	Operating Room, Examining Room	3.0-5.0	Privacy and thermal considerations may override use of daylighting.
Industrial	High Resolution Work	5.0	Toplighting is recommended.
	Other Work	2.0-3.0	Provide task lighting where appropriate.
Libraries	Stacks	1.0	Additional artificial lighting is required.
	Reading, Study Areas	1.0	Provide individually controlled task lighting.
Musea, Galleries	General	1.0	Additional artificial lighting may be required for emphasis; daylighting may be inadvisable where light-sensitive materials are displayed.
Offices	General	2.0	Provide task lights or lower DF with photocontrolled electric lighting.
	Typing	4.0	May require task lighting; be careful of reflected glare on video displays.
	Drafting	5.0	May be difficult to provide uniformly high level with only sidelighting.
Residential	Kitchens	2.0	Provide task light at work stations; recommended levels should penetrate one-half to three-quarters of the room; if elderly people are often present, higher levels are suggested.
	Living Rooms	1.0	
	Bedrooms	0.5	
Schools	Assemblies, Classrooms	2.0	
	Art Rooms	4.0	
	Laboratories	3.0	
	Staff Areas	1.0	
Sports	Playing	2.0	
Swimming	Water	2.0	
	Deck	1.0	

Reprinted from Schiler (ed.), Simulating Daylight with Architectural Models, 211-212.

Discussion

Table D2.5.1 lists recommended aperture to floor area ratios for achieving average DFs with various kinds of daylight openings. This table is included as a rule-of-thumb to help further organize your basic building form. While imprecise, it is more specific than the floor to glazing ratio calculated in C2.4.

Table D2.5.1 Aperture Sizing for Daylighting—Estimated Average Daylight Factors

SIDELIGHTING		average DF = $.2\ (A_g / A_f)$ (near the window—less than $2H_{win}$ away) minimum DF = $.1(A_g / A_f)$ (away from the window—more than $2H_{win}$ away)
TOPLIGHTING Vertical Monitors		average DF = $.2(A_g / A_f)$
North-Facing Sawtooth Openings		average DF = $.33(A_g / A_f)$
Horizontal Skylights		average DF = $.5(A_g / A_f)$

where:

DF = daylight factor as percentage of outdoor horizontal illumination

A_g = area of exterior glazing (ft^2)

A_f = area of floor to be lighted (ft^2)

H_{win} = window-head height (ft)

Reprinted, by permission, from Millet and Bedrick, "Manual: Graphic Daylight Design Method," 5–6.

SCHEMATIC DESIGN

DAYLIGHTING APERTURE SIZING (continued)

PROCEDURE

Evaluate how well your building attains Lighting Schematic Design Goal C—**Window apertures are sized to attain the minimum levels of illumination required for tasks and spaces, the recommended daylight factor (DF).**

For each task area:

1. Calculate the glazing area required for adequate daylighting by solving the appropriate aperture sizing equation [Table D2.5.1] for A_g. If two or more glazing strategies are used, you can add the equations (DFs are additive), and solve for each A_g.

   If $DF = y\ (A_g\ /\ A_f)$,

   then $A_g = [(DF)\ (A_f)]\ /\ y$.

   where:

   y = efficiency ratio [Table D2.5.1]

2. Compare the required glazing area, A_g, with the glazing area you have designed and its resultant daylight factor.

Daylight Aperture Size [suggested format]

Task Area	Floor Area (ft^2)	Target DF [D2.5]	Glazing Strategy	Glazing Area Required (ft^2)	Glazing Area Provided (ft^2)	Resultant DF
office	*600*	*.04 (4%)*	*north-facing sawtooth*	*72*	*100*	*.06*

3. Discuss whether or not your building and site improvements meet Goal C, and describe how your design must be altered if the goal has not been met.

PROCEDURE

Evaluate how well your building attains Lighting Schematic Design Goal D—**Solar collecting and ventilating apertures are maintained as required for heating and cooling.**

1. Calculate the total solar aperture area.
2. Calculate the total ventilation aperture area.
3. Compare your solar and ventilation total aperture area calculations with the requirements specified in D1.7 and D1.5.
4. Draw a schematic plan and section of your building. Annotate your drawings to describe your heating, shading, ventilation, and lighting strategies. Discuss whether or not your building and site improvements meet Goal D, and describe how your design must be altered if the goal has not been met.

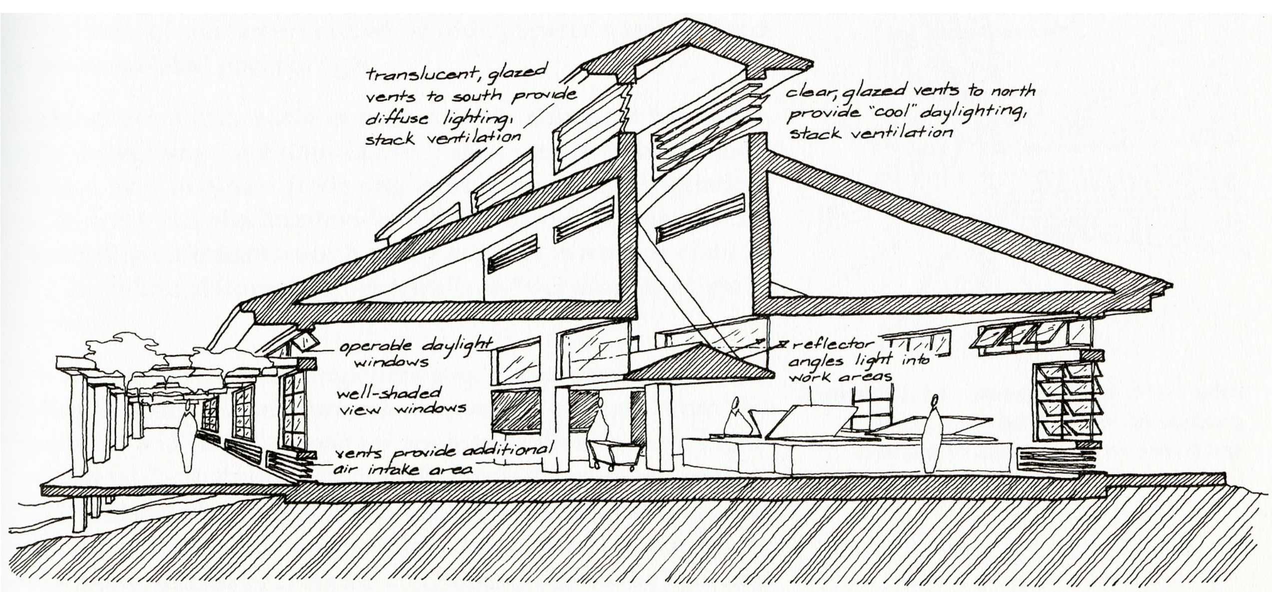


Figure D2.6.1 Integrated Lighting and Thermal Strategies. Linen supply, Charleston, South Carolina.

Discussion

You have formulated a schematic design for your building and site, chosen appropriate lighting strategies, and ensured access to appropriate environmental forces. Each step has been accomplished independently and conflicting decisions may have been made. This design review affords you the opportunity to synthesize your cumulative design decisions.

Procedure

Review how well your design accomplishes Lighting Schematic Design Goals A–D.

1. Discuss the tradeoffs between the lighting and thermal strategies that your design required.
2. Discuss situations where your lighting and thermal strategies worked effectively together.
3. Make a schematic design sketch that combines all your lighting design strategies. Indicate how and why your design has evolved in response to meeting D2.0 goals.

E2 LIGHTING

DESIGN DEVELOPMENT — E2

INTRODUCTION — E2.0

Goals

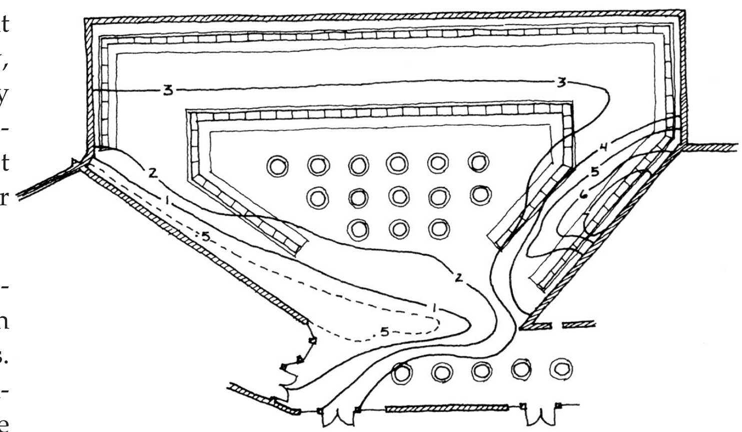
Refine and further develop your building's lighting design without sacrificing desirable views or thermal performance. Use your schematic design as the foundation for your design development.

Lighting Design Development Goals

A. Recommended daylight factors are achieved in each task area.
B. The range of DFs in each task area does not exceed a ratio of three to one.

Discussion

There are four major daylight components to consider when developing a daylight design—sunlight, light from the sky, externally reflected light, and internally reflected light. The details of the fenestration and room surface finishes must interact appropriately with these four components.



In most cases, apertures should be designed to reject the sun component, which can cause thermal and glare problems. Exterior shading devices, lightshelves, interior light baffles, and deep lightwells are examples of components that effectively reject the sun, yet admit daylight.

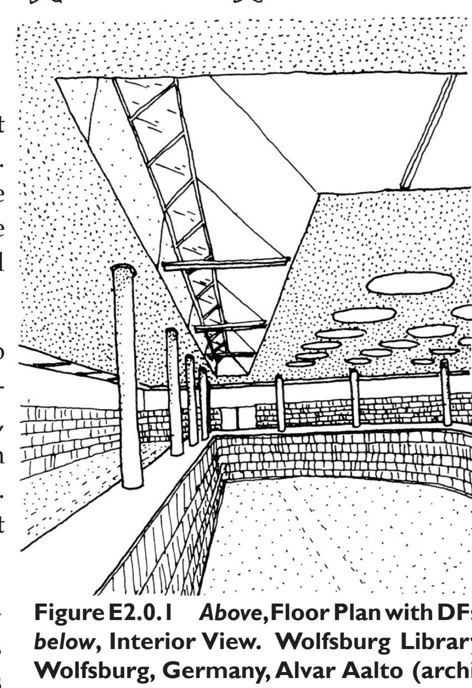


Figure E2.0.1 *Above*, Floor Plan with DFs; *below*, Interior View. Wolfsburg Library, Wolfsburg, Germany, Alvar Aalto (architect), 1959.

The sky component is the primary source of daylight. Placement of apertures determines how light from the sky enters the space. Apertures placed in more than one plane tend to provide more balanced light. Apertures placed close together tend to provide larger areas of more even light, while widely spaced apertures tend to create isolated pools of light.

Light reflected from surfaces outside the building can be used to alter the lighting conditions inside. The externally reflected component may originate from neighboring buildings, vegetation, walls, or external shading devices. A light-colored, garden wall can increase light through a north-facing window in a sunny climate. Or light reflected from a red, brick wall can "warm up" the light in a space.

The internally reflected component plays the major role in illuminating a space. Room surfaces receive the daylight from the apertures and act as secondary sources of illumination. Light-colored surfaces (those with a high, internally reflected component) redistribute the light more evenly throughout the space and maximize the illumination potential. Dark-colored surfaces (those with a low, internally reflected component) absorb the light and reflect little, so that the apertures, in effect, only provide pools of light.

INTRODUCTION (continued)

Surfaces adjacent to apertures can be sculpted to direct reflected light to specific areas. Apertures can be placed normal and adjacent to planar surfaces to wash them with light.

How you use the apertures and the surfaces to admit and manipulate the four daylight components determines the character of the architectural space.

In this section you will:

1. Complete the luminous design development of your project.
2. Predict the interior illuminance.
3. Evaluate your lighting design decisions.
4. Critique your building's lighting design.

Lighting Design Development Strategies

Site-Scale Strategy

- Use a variety of landscape surfaces for their reflective characteristics. These will change seasonally, especially in climates with snow. Remember, snow can cause glare on sunny days.

Cluster-Scale Strategies

- Provide reflected light in hot, sunny climates where shading devices block direct sun and greatly reduce light from the sky.
- Avoid extremely large, exterior, daylight obstructions in overcast climates.

Building-Scale Strategies

- Proportion rooms to include the lighting effect of overhangs. The room effectively begins at the edge of the overhang, not where the glazing is located.
- Use sidelighting for task lighting to minimize veiling reflections and supply useful modeling.
- Use toplighting for uniform, ambient lighting.

Component-Scale Strategies

- Bevel the wall adjacent to a narrow, vertical window to reduce glare caused by the contrasting bright window and the darker wall.
- Reduce glare by using lighter colors and higher reflectances near openings.
- Choose internal surface reflectances to take advantage of the primary source of incoming light.
  - ◁ In temperate climates use the floor to reflect light from the sky.
  - ◁ In tropical climates use the ground then the ceiling to reflect light from the sun.
- Increase light in dimmer areas by using lighter colors and higher reflectances on surfaces farthest from openings.
- Reduce daylight near the window wall and increase daylight deep in the room with lightshelves.
- Diffuse light from skylights and prevent direct sunlight from entering the space by using baffles and deep lightwells.

DESIGN (continued)

Procedure

Refine your final schematic design [D2] to include component design considerations. Use the appropriate strategies to aid your lighting design development. Modify your schematic design drawings to include the components you have developed.

Document your design as follows:

On all drawings, state the sky condition (clear or overcast) for which you are designing.

1. Site plan, including parking and access drives (scale: 1" = 100').
2. Cluster plan, including outdoor spaces (scale: 1" = 40').
3. Floor plans (scale: 1" = 20').
4. Roof plan and elevations, or axonometrics, illustrating all building sides and roof (scale: 1" = 20').
5. Sectional perspective, labeling finishes, materials, colors, and square footage of each surface (scale: $^1/_8$" = 1'-0").
6. Design diagram, annotated to identify design strategies and lighting zones.
7. Details of lighting components (e.g., mullions, lightshelves, baffles, glazing, and shading devices) of all daylight apertures in elevation and section.

"RAW" ILLUMINANCE FOOTPRINTS

Discussion

The graphic daylighting design method (GDDM) is the best available hand calculation method for predicting daylight distribution for most spaces. However, there are complications that arise when applying it to non-orthogonal openings or rooms of complex shape. It also does not evaluate the localized effects of interior or exterior room reflectances, exterior obstructions, or fixed shading devices.

For fixed shading devices simply estimate the percentage of daylight that gets through them. Do not use shading coefficients used for heat gain estimations, since these refer more to direct sun than daylight from all sources. Thus, the percentage of daylight will be somewhat higher than shading coefficients would indicate. For example, louvered shading devices that block the majority of direct sun (high shading coefficient) will admit a majority of the daylight available.

The GDDM uses the principle that each aperture contributes a characteristic pattern of light based on its geometry. These patterns are described by "footprints" of contours of equal illumination (expressed in daylight factors). The footprints can be added because illumination levels are additive.

The footprints [Appendix F] can be used without modification on floor plans at one-eighth scale for windows that are completely above the workplane and 5' x 10', 10' x 10', or 10' x 5'. For other sizes and shapes they must be re-scaled and combined so each pattern's solid rectangle is the same size as the window projection. Any portion of the window below the workplane will not contribute "raw" illumination to the workplane.

The GDDM involves three basic steps:

1. Match openings with available footprints.
2. Draw isolux contours that describe the light distribution and the "raw" DF range in your space.
3. Correct the DFs applied to the isolux contours.
   a. Increase the DF for factors that increase light in the space (principally interior reflectances).
   b. Reduce the DF for factors that reduce light in the space (glass transmission, dirt, and shading devices).

For more information

Millet and Bedrick, "Manual: Graphic Daylighting Design Method," pp.23–30 (distribution patterns, refinement steps, and procedures for dealing with obstructions).

"RAW" ILLUMINANCE FOOTPRINTS (continued)

Procedure

Evaluate how well your design attains Lighting Design Development Goals A and B—**Recommended daylight factors are achieved in each task area (A), and the range of DFs in each task area does not exceed a ratio of three to one (B).**

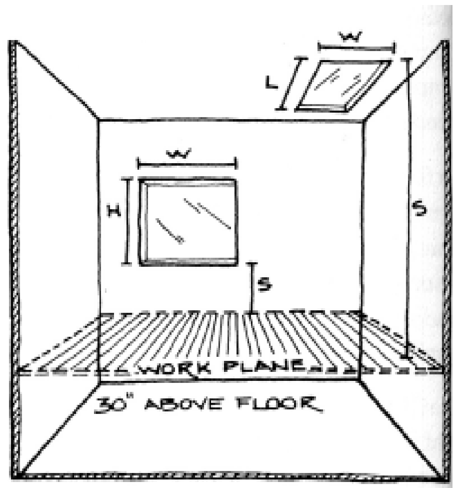


Figure E2.2.1 Dimensions for GDDM Ratios

For the largest, most important daylighted space in your building:

1. Match the openings to footprints. For sloped openings, see Figure E2.2.2.

   a. List your windows and skylights and their dimensions.

      H = height of window (above the workplane only)

      W = width of window or skylight

      L = length of skylight

      S = distance from workplane to sill (if the sill is at or below the workplane, S = 0)

   b. Find the appropriate footprint for each aperture [Table E2.2.1].

      (1) For apertures with an S/H or S/W ratio between 1:3 and 3:1, choose the footprint with ratios that best match the aperture's ratios.

      (2) For apertures with an S/H or S/W ratio not between 1:3 and 3:1 or of non-rectilinear shape, subdivide the aperture into rectangles with S/H or S/W ratios between 1:2 and 2:1. Then choose the most appropriate footprint for each subdivision of the original aperture.

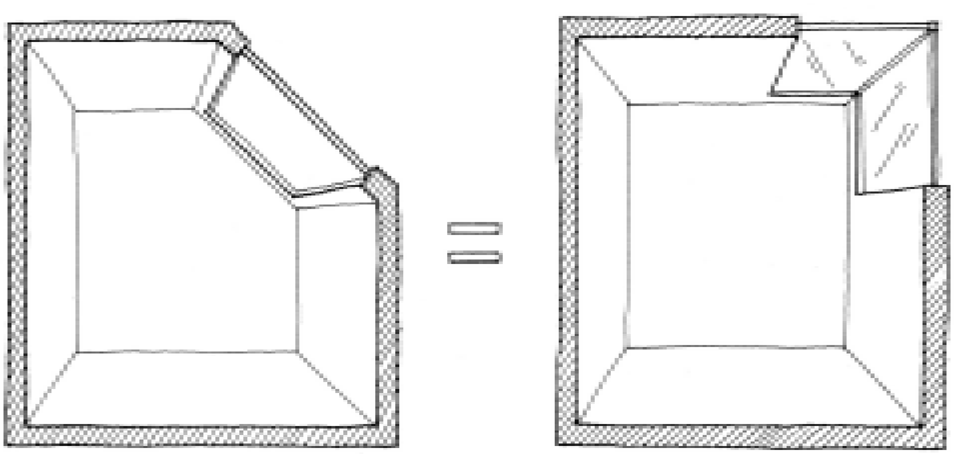


Figure E2.2.2 Sloped Skylight Simulation for Footprint Procedure. For a square skylight with an area of 141 ft² at a 45° slope, the resulting window and horizontal skylight will each be 10' x 10'. When estimating the IRC, use the actual area (141 ft²) in Table E2.3.1 for toplighted rooms.

DESIGN DEVELOPMENT
"RAW" ILLUMINANCE FOOTPRINTS (continued)

Table E2.2.1 Index for Footprints Included in Appendix F

Windows			Skylights		
(H/W)	(S/H)	Footprint ID	(L/W)	(S/W)	Footprint ID
0.5	0.0	A-7	1.0	1.0	A-30
0.5	0.5	A-8	1.0	2.0	A-31
0.5	1.0	A-9	1.0	3.0	A-32
0.5	2.0	A-10	1.0	4.0	A-33
0.5	3.0	A-11	2.0	1.0	A-34
0.5	4.0	A-12	2.0	2.0	A-35
1.0	0.0	A-13	2.0	3.0	A-36
1.0	0.5	A-14	2.0	4.0	A-37
1.0	1.0	A-15			
1.0	2.0	A-16			
1.0	3.0	A-17			
1.0	4.0	A-18			
2.0	0.0	A-19			
2.0	0.5	A-20			
2.0	1.0	A-21			
2.0	2.0	A-22			
2.0	3.0	A-23			
2.0	4.0	A-24			

c. Specify any assumptions you made to accommodate the GDDM requirements, such as approximating sloped glazing, elongated openings, or non-rectilinear apertures with smaller rectilinear window or skylight components.

Footprint Selection Table [suggested format]

Aperture	Height or Length (H) or (L)	Width (W)	Sill Height (S)	Ratios (H/W) (L/W)	window skylight	(S/H) (S/W)	Footprint Selected
skylight 1	*L = 6'*	*6'*	*18'*	*1.0*		*3.0*	*A–32*

"RAW" ILLUMINANCE FOOTPRINTS (continued)

2. Draw the footprints on an overlay of your plan at the workplane (recommended scale: $^1/_8$" = 1'-0").

    a. Sketch the apertures [Figure E2.2.3].

    For skylights project the aperture outline to the workplane.

    For windows rotate them 90° to the workplane (as though they were hinged at the intersection of the workplane and the vertical plane).

    b. Adjust the footprints. On the footprint the rectangle scribed by the solid line must be approximately the same size as its aperture on the plan. If they don't match, the footprint must be adjusted.

    (1) Mechanically: Use a photocopier to reduce or enlarge the footprint to the proper scale.

    (2) Manually: Redraw the footprint at the correct scale by using the actual dimensions of the aperture as the solid rectangle. Construct a proportional grid based on the aperture dimensions to guide redrawing the contours.

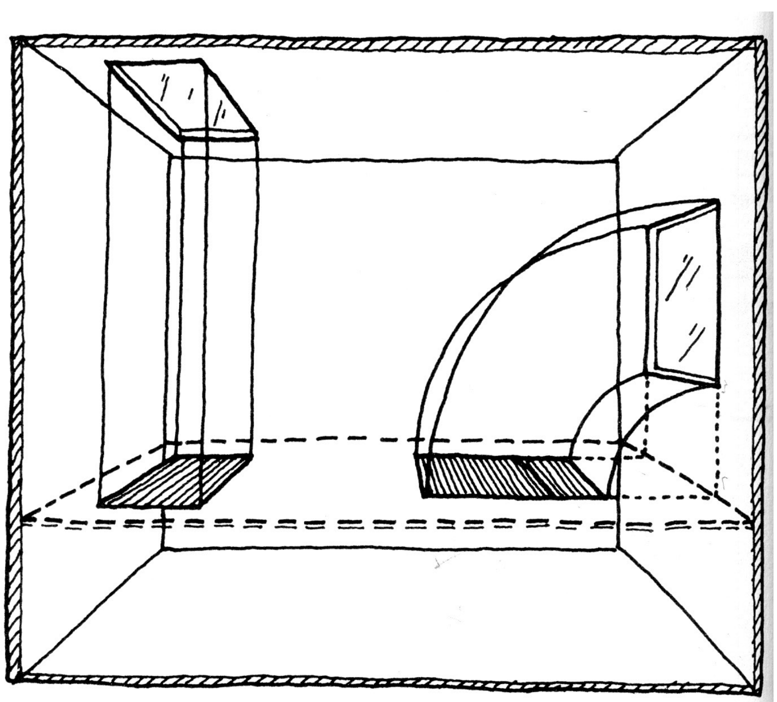


Figure E2.2.3 For GDDM, Drop a Skylight, Rotate a Window

E2 LIGHTING

DESIGN DEVELOPMENT

E2
E2.2

"RAW" ILLUMINANCE FOOTPRINTS (continued)

c. Sketch the contours for each aperture.

(1) Align the footprint's solid rectangle with the outline of the aperture. For sidelight footprints, the solid line at the bottom indicates the position of the window wall. Don't position them upside-down!

(2) Note DF contour values on your plan. These values are percentages of available daylight. The dotted contour is 0.5% DF, the adjacent solid contour is 1.0% DF, and they increase by 1% each contour. The number in the center of the contours indicates the maximum DF value.

d. Combine the contours. (This overlay will be the final "raw" DF isolux contour drawing for your space.)

(1) On this overlay, mark all the points where the contours intersect, and note the sum of their DF values. If your building has many apertures that are close together, add two or three footprints at a time to derive "macro" footprints, and then add these "macro" footprints to get the final contours.

(2) Draw the resulting contour lines by connecting points of equal value. If there is no overlap, trace the original contour. Label each contour with its DF value.

3. If your DF contour distribution is not close to meeting Goals A and B, change the design now, and re-draw the contours.

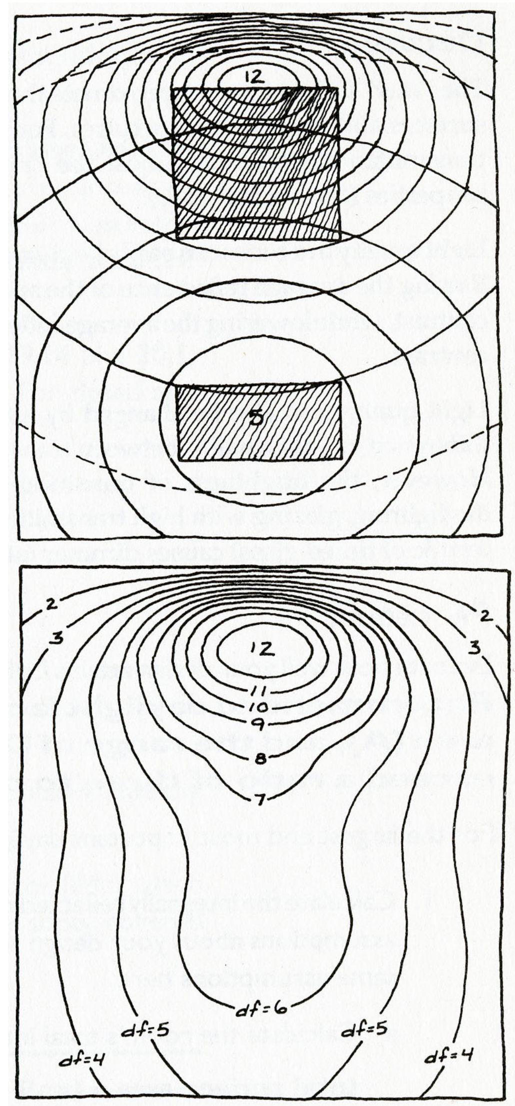


Figure E2.2.4 ***Above*****, Contours for Window and Skylight;** ***below,*** **Combined Contours.**

DESIGN DEVELOPMENT
"CORRECTED" ILLUMINANCE FOOTPRINTS

Discussion

The "raw" DF contours approximate the distribution of light in a room with all black surfaces and transparent apertures. For rooms with any other surface reflectance or transmittance, you must adjust the "raw" DFs to compensate for their luminous properties ("corrected" DFs).

Light quality in a room can easily be changed by altering the reflectances of its surfaces. Raising the average reflectance of the space will brighten the room and even out the contrast, while lowering the average reflectance will darken the room and sharpen the contrast.

Light quality can also be changed by altering the transmittance of the glazing. The difference in light quality between transparent and translucent surfaces is minimal. However, the brightness of translucent surfaces may cause glare. To maximize daylighting, glazing with high transmittance is required. Low transmittance (characteristic of tinted glass) causes dimmer interiors.

Procedure

Evaluate how well your design attains Lighting Design Development Goals A and B—**Recommended daylight factors are achieved in each task area (A), and the range of DFs in each task area does not exceed a ratio of three to one (B).**

For the largest and most important daylighted space in your building:

1. Calculate the internally reflected component (IRC) for your space. If you made assumptions about your design to select the footprints in E2.2, maintain the same assumptions here.

   a. Calculate the room's total interior surface area.

   total surface area = (wall area) + (floor area) + (ceiling area)

   b. Calculate separately the net exterior glazing surface areas for sidelighting and toplighting apertures. In your calculations, use only the actual glazed area. Omit non-glazed components such as mullions or glazing bars. Alternately, you could calculate the glazing surface areas by multiplying the total opening size by a typical glazing reduction factor.

Glazing Reduction Factors

Window Type	Net Glazed Factor
all metal windows	.80
metal windows in wood frames	.75
all wood windows	.65–.70

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"CORRECTED" ILLUMINANCE FOOTPRINTS (continued)

c. Calculate the ratio of glazed area to total room surface area for sidelighting and toplighting.

d. Calculate your average room reflectance. (If you are working with one typical bay or a large space such as a factory, assume 100% reflectance from the "sidewalls" that represent adjacent bays, and include their area in the total surface area for a typical bay. It is not necessary to calculate the entire factory.)

To find the values for reflectance, see *MEEB*, Tables 11.10 and 13.1, pp.504, 568. Assume clear glass reflectance is zero. For tinted and diffusing glass values, use colors in *MEEB*, Table 13.1.

$$R_{room} = [(SA_1)\ (R_1) + (SA_2)\ (R_2) + (SA_n)\ (R_n)] / (SA_{room})$$

where:

R_{room} = average room reflectance

SA_1, SA_2, SA_n = area of each surface (ft^2)

R_1, R_2, R_n = reflectance of each surface

SA_{room} = total surface area (ft^2)

e . Find the toplighted IRC values in Tables E2.3.1 and E2.3.2 below. Find the sidelighted IRC values in Table E2.3.3 below.

f. Correct the IRC values for the interior maintenance factor (IMF) which accounts for light absorption due to soiled surfaces (dusty, sooty, covered with other particulate matter).

adjusted IRC = (IRC) (IMF)

IMF Values

Work Areas	Non-Industrial	Industrial
Cleaned	.9	.8
Not Cleaned	.7	.6

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IRC Correction [suggested format]

Space	Total Surface Area (ft^2)	Net Sidelight Glazing (ft^2)	Net Toplight Glazing (ft^2)	Average Room Reflectance	Top-lighted IRC	Side-lighted IRC	IMF	Adjusted Toplight IRC	Adjusted Sidelight IRC
office	*3,800*	*114*	*38 horiz.*	*.55*	*1.09*	*1.17 avg. 0.98 min.*	*.9*	*.98*	*1.05 0.88*

Table E2.3.1 Internally Reflected Component for Toplighted Rooms Glazing from Horizontal up to 60°									
Net Glazing Area to Total Room Surface Area Ratio	Average Reflectance (IRC) of Room Surfaces								
	20%	25%	30%	35%	40%	45%	50%	55%	60%
.01	.22	.32	.40	.49	.6	.72	.88	1.09	1.4
.02	.46	.62	.78	.9	1.2	1.5	1.8	2.2	2.6
.03	.6	.9	1.15	1.4	1.8	2.15	2.7	3.4	4.1
.04	.9	1.2	1.65	1.9	2.4	3.0	3.7	4.4	5.3
.05	1.15	1.5	1.9	2.4	3.0	3.7	4.3	5.4	6.6
.06	1.4	1.85	2.3	2.9	3.7	4.4	5.4	6.6	8.0
.07	1.65	2.1	2.3	3.8	4.2	5.0	6.2	7.4	8.6
.08	1.35	2.9	3.2	3.5	4.7	5.9	7.2	8.6	10.5
.09	2.0	2.8	3.6	4.4	5.4	6.6	8.0	9.6	11.7
.10	2.2	3.1	4.1	4.5	5.9	7.3	8.8	10.7	13.0

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Table E2.3.2 Internally Reflected Component for Toplighted Rooms Vertical Glazing									
Net Glazing Area to Total Room Surface Area Ratio	Average Reflectance (IRC) of Room Surfaces								
	20%	25%	30%	35%	40%	45%	50%	55%	60%
.01	.09	.13	.16	.20	.25	.31	.37	.45	.54
.02	.19	.25	.32	.41	.50	.62	.76	.90	1.1
.03	.27	.38	.48	.60	.75	.90	1.2	1.3	1.65
.04	.38	.50	.69	.80	1.0	1.2	1.48	1.8	2.2
.05	.47	.63	.80	.99	1.22	1.6	1.85	2.2	2.7
.06	.56	.77	.95	1.2	1.5	1.8	2.2	2.7	3.4
.07	.66	.88	.96	1.4	1.72	2.1	2.55	3.2	3.7
.08	.77	.99	1.25	1.6	1.95	2.4	3.0	3.7	4.4
.09	.86	1.15	1.42	1.8	2.2	2.7	2.45	4.1	5.0
.10	.94	1.2	1.65	2.0	2.4	3.1	3.8	4.5	5.5

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Table E2.3.3 Internally Reflected Component for Sidelighted Rooms

Net Glazing Area to Total Room Surface Area Ratio		Average Reflectance (IRC) of Room Surfaces								
		20%	25%	30%	35%	40%	45%	50%	55%	60%
.01	avg IRC	.05	.07	.10	.13	.18	.25	.32	.40	.50
	min IRC	.02	.03	.05	.08	.12	.17	.25	.33	.43
.02	avg IRC	.09	.13	.20	.27	.36	.48	.62	.78	.96
	min IRC	.03	.06	.10	.16	.24	.34	.47	.64	.84
.03	avg IRC	.13	.20	.29	.40	.54	.74	.94	1.17	1.45
	min IRC	.03	.09	.15	.24	.36	.52	.72	.98	1.24
.04	avg IRC	.18	.27	.39	.53	.72	.96	1.25	1.60	1.95
	min IRC	.07	.12	.20	.31	.48	.70	.96	1.27	1.66
.05	avg IRC	.23	.34	.48	.66	.85	1.18	1.55	1.95	2.40
	min IRC	.08	.15	.26	.39	.60	.86	1.18	1.60	2.08
.06	avg IRC	.27	.41	.58	.80	1.07	1.43	1.80	2.35	2.92
	min IRC	.10	.18	.30	.46	.72	1.03	1.43	1.95	2.50
.07	avg IRC	.32	.47	.68	.92	1.25	1.68	2.15	2.70	3.40
	min IRC	.11	.21	.35	.56	.84	1.20	1.67	2.22	2.90
.08	avg IRC	.36	.54	.78	1.07	1.42	1.95	2.50	3.15	3.90
	min IRC	.13	.24	.41	.64	.96	1.38	1.85	2.60	3.33
.09	avg IRC	.41	.60	.87	1.18	1.61	2.15	2.80	3.52	4.39
	min IRC	.15	.27	.45	.72	1.06	1.55	2.12	2.92	3.70
.10	avg IRC	.45	.68	.96	1.30	1.74	2.40	3.10	3.90	4.80
	min IRC	.16	.29	.50	.79	1.18	1.71	2.39	3.20	4.15
.12	avg IRC	.54	.80	1.15	1.58	2.10	2.85	3.70	4.65	5.80
	min IRC	.20	.35	.60	.94	1.40	2.00	2.70	3.80	4.90
.14	avg IRC	.64	.94	1.35	1.85	2.50	3.33	4.30	5.40	6.90
	min IRC	.24	.42	.71	1.10	1.65	2.40	3.32	4.50	5.80
.16	avg IRC	.72	1.07	1.55	2.10	2.80	3.80	4.90	6.55	7.70
	min IRC	.27	.47	.82	1.25	1.90	2.72	3.80	5.10	6.60
.18	avg IRC	.81	1.20	1.70	2.35	3.20	4.30	5.50	6.90	8.30
	min IRC	.29	.53	.92	1.38	2.10	3.10	4.25	5.70	7.40
.20	avg IRC	.90	1.30	1.80	2.60	3.50	4.70	6.00	7.70	9.70
	min IRC	.33	.60	1.00	1.55	2.35	3.80	4.70	6.40	8.10

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2. Calculate corrections to the DFs [E2.2].

   a. Calculate the reduction in daylight resulting from glass transmission losses and shading devices.

      (1) Find the daylight reduction due to soiled surfaces.

Transmission Loss

Building Location	Inclination of Glazing	Interior Conditions	
		Cleaned	Not Cleaned
Non-Industrial Area	Vertical	.9	.8
	Sloping	.8	.7
	Horizontal	.7	.6
Industrial Area	Vertical	.8	.7
	Sloping	.8	.7
	Horizontal	.6	.5

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      (2) Find your glazing's transmisison reduction factor [*MEEB*, Table 19.6, p.996].

   b. Correct all the GDDM daylight factors you have found.

      (1) Correct the contours in the dimmer areas (lowest daylight factors).

$$\text{corrected DF} = (\text{DF} + \text{IRC}_{top} + \text{IRC}_{slm})\ (\text{TL})\ (\text{GTL})$$

where:

IRC_{top} = toplighted IRC

IRC_{slm} = minimum sidelighted IRC

TL = transmission loss from soiled surfaces

GTL = glazing transmission loss

"CORRECTED" ILLUMINANCE FOOTPRINTS (continued)

(2) Correct the remaining contours.

$$\text{corrected DF} = (DF + IRC_{top} + IRC_{sla})\,(TL)\,(GTL)$$

where:

IRC_{sla} = average sidelighted IRC

DF Correction [suggested format]

Raw DF	IRC_{top}	IRC_{sla}	IRC_{slm}	TL	GTL	Corrected DF
0.5	*1.09*	*NA*	*.98*	*.8*	*.85*	*1.75*
1.0	*1.09*	*NA*	*.98*	*.8*	*.85*	*2.09*
2.0	*1.09*	*1.17*	*NA*	*.8*	*.85*	*2.90*

(3) Relabel your raw DF contours with the corrected DF values that you have calculated.

3. Discuss the success of your lighting strategy, and indicate any design changes you view as necessary to meet Goals A and B.

Discussion

Corrected GDDM contours accurately describe the daylight distribution as an abstract diagram resembling a topographical or weather map. By rendering the GDDM contours to correlate with their light levels [Figure E2.4.1] you can produce a visualization of the lighting throughout the space. Alternately, plotting the DF values in section [Figure E2.4.2] will lend context to the light distribution.

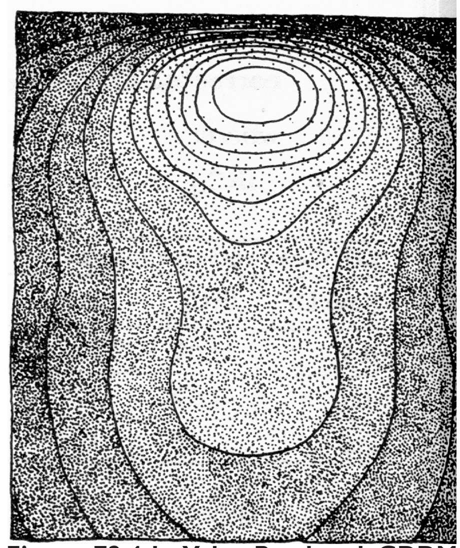

Figure E2.4.1 Value-Rendered GDDM Contours

Procedure

Evaluate how well your design attains Lighting Design Development Goals A and B—**Recommended daylight factors are achieved in each task area (A), and the range of DFs in each task area does not exceed a ratio of three to one (B).**

For the largest and most important daylighted space in your building:

1. Redraw new contours at integer intervals on an overlay by visually interpolating for the corrected values [E2.3].
2. Plot the DF contours in context. Choose a section that cuts through an aperture and vital task areas.
   a. Draw a section.
   b. Plot the DF contours on a vertical scale from zero to maximum.
3. Value- or color-render the plan and section to visualize the change and distribution of lighting.
4. Compare these renderings with your schematics in D2.2 and D2.3. Discuss any changes you deem necessary to meet Goals A and B.

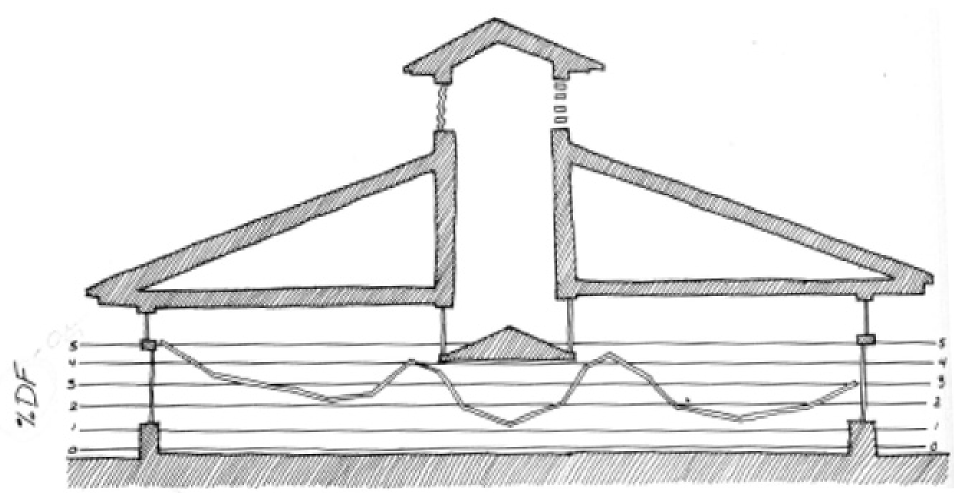

Figure E2.4.2 Daylight Section. Linen supply, Charleston, South Carolina.

DAYLIGHT MODEL

E2.5

Discussion

It is advantageous to use physical models to test daylight designs. Models can be accurate representations of daylighted spaces and easily modified to test minor design changes, such as the substitution of one set of shading devices for another. They can be subjected to tests using a variety of observation techniques, such as:

- general visual assessment
- comparative photographic studies
- light meter readings.

The most critical factor when testing your model is matching as closely as possible the sky condition for which you are daylighting:

- Overcast skies should be truly overcast—the actual position of the sun should not be discernible. Avoid partly cloudy skies due to rapidly fluctuating daylight levels and unpredictable light distribution.
- Clear skies are a problem because the sun position should be at an altitude/ azimuth similar to the time of day and year in the climate for which you are designing. Do not tilt the model with a sun peg to achieve this altitude/ azimuth because your building's openings will "see" a wildly different proportion of sky *versus* the ground when your model is not horizontal. Measurements must be taken to exclude the sun component yet include the sky component.

Also critical is the constancy of the outside light, against which interior measurements are compared to obtain the daylight factor. You must simultaneously measure exterior and interior levels to ensure that your DFs will be based on accurate comparative measurements. Some meters with multiple probes will automatically calculate DFs.

A less critical factor is the ground reflectance. To obviate ground reflectance, match the texture and reflectance of your site. For the first 10' height of opening above grade, a 40' width of controlled ground reflectance is necessary.

For more information

Evans, *Daylight in Architecture*, Chapter 6.

Moore, *Concepts and Practice of Architectural Daylighting*, Chapter 14.

Procedure

Evaluate how well your design attains Lighting Design Development Goals A and B—**Recommended daylight factors are achieved in each task area (A), and the range of DFs in each task area does not exceed a ratio of three to one (B).**

For the largest and most important daylighted space in your building:

1. Build a model of the space you are investigating.

   a. Your model must be at least ½" = 1'- 0" to accurately use a standard light meter. Draw a 5' x 5' grid (minimum) on the floor of your model. Measurements will be taken at the grid intersections. Plan to take at least 15 measurements spaced equally throughout the floor area. Be accurate in your replication of details around the daylight openings—the size and depth of the mullions, the depth and reflectivity of the sill, louvers, or other shading devices, and the reflectivity of surfaces just outside the daylight openings.

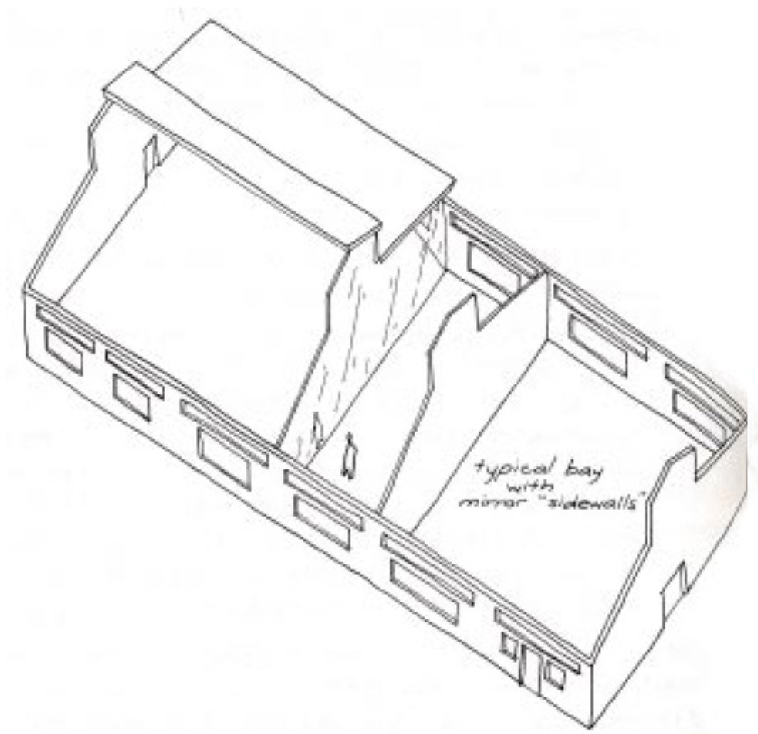

Figure E2.5.1 Modeling a Typical Bay. Linen supply, Charleston, SC

   b. Choose materials that reasonably match the opacity, surface texture, and percentage reflectance of the floors, walls, and ceilings of your space. For large spaces with repetitive bays, such as a factory, build just one bay and insert mirrored "side walls" where adjacent bays would occur [Figure E2.5.1]. The reflectance of these "walls" should be at least 90%.

   c. Place glazing over model openings only if it matches the transmission characteristics of the actual glazing. Since it is difficult to obtain matching model glazing, omit it and adjust interior readings for transmission loss through the glazing [*MEEB*, Table 14.5, p.610 and Table 14.7 p.616].

   d. Tape joints between walls, floors, ceilings, etc. to avoid inaccurate measurements resulting from daylight entering through cracks.

   e. Ensure that light at each point can be measured accurately. If necessary, add a light-tight flap of some sort. To quickly and accurately position the light meter probe, determine its size and put stops for it on the model floor at each measurement point.

DAYLIGHT MODEL (continued)

2. Prepare recordkeeping and measurement tools.

   a. Draw a grid on a copy of your floor plan. This grid must be the same size as and aligned with the grid on your model. Make a copy of this gridded floor plan for each alternative you wish to test.

   b. Prepare the light meter so it will take measurements at the appropriate workplane height (usually 30" above the floor). The surface of the light meter's probe must be at this level. If necessary, add material under the probe to bring it to the proper height.

3. Test the model.

   At each grid intersection point, measure and record the daylight inside the model and, simultaneously, outside the model in a large open area. Don't affect the measurement by leaning over the probe.

4. Calculate your daylight factor for each point.

   DF = (interior fc / exterior fc) (total reduction factor)

5. Use the DF values at the grid intersections as a guide when plotting the daylight factor contours on your plan, and graph them in section as described in E2.4, step 2.

6. Discuss the success of your daylighting strategy as evaluated by model testing, and indicate any design changes you view as necessary to meet Goals A and B.

DESIGN DEVELOPMENT
DESIGN REVIEW

Discussion

You have just completed design development of the largest, most important space in your building. The methods you have used should give you some insight for successfully lighting the rest of the building. This design review affords you the opportunity to view your lighting design holistically and to discuss the conflicts and tradeoffs with other design considerations for the entire building.

Procedure

1. Compare the developed design with the schematic design [D2]. Discuss how it has evolved and why.
2. You have explored the use of daylighting, external and internal shading devices, thermal zoning, design of the building's skin, and various cooling strategies. Comment on what tradeoffs have been made and what strategies worked well together.
3. Illustrate your discussion of points (1) and (2) with annotated, schematic diagrams of your building.

INTRODUCTION F2.0

Goal

Provide electric lighting that complements the daylighting design for your building.

Electric Lighting Integration Goals

A. Lighting power densities comply with code, while illumination to meet the needs of users is provided throughout the building.
B. Daylighting is supplemented with electric lighting only where and when necessary.
C. Daylight provides more than half the annual required lighting.
D. Substantial savings over nondaylight-integrated electric lighting systems will be realized.

Discussion

It is highly desirable to provide electric lighting that complements and supplements the daylighting in a naturally lighted building. In a daylighted building, the entire building acts as a lighting fixture—the structure and surfaces of the building allow the light to enter and direct its distribution throughout the space. Generally, daylight is most intense near the apertures and diminishes with distance from them. Therefore, electric lighting should be switched to illuminate areas farthest from the apertures first, then areas nearer the apertures as daylight intensity fades.

In this section you will:

1. Determine how much lighting is required based on building program.
2. Design the electric lighting system to accommodate nighttime lighting.
3. Propose an electric lighting strategy to augment your daylighting.
4. Design switching controls for daytime lighting.
5. Calculate how much energy is saved because you used daylighting.

ELECTRIC LIGHTING INTEGRATION DESIGN

Electric Lighting Integration Design Strategies

Component-Scale Strategies

- Use architectural features to reflect and direct both daylight and electric lighting.
- Switch electric lighting according to the daylight level provided. Lights near the aperture are switched separately from those away from the aperture.
- Control electric lighting automatically with daylight or occupancy sensors. Lights are not on when daylight is adequate or when no one is using the space.
- Segregate electric light into ambient and task lighting. Ambient lighting complements daylighting, while task lighting supplements it.

Procedure

Refine your daylighting design [E2] to include electric lighting systems. Generate schematic drawings illustrating your design.

Document your design as follows:

1. Site plan, including parking, access drives, circulation paths, exterior lighting (scale: 1" = 100').
2. Floor plans (and roof plans, if necessary), indicating electric lighting layout (scale: 1" = 20').
3. Design diagram, annotated to identify design strategies.
4. Rendered night perspectives of your building's exterior and a major interior space.

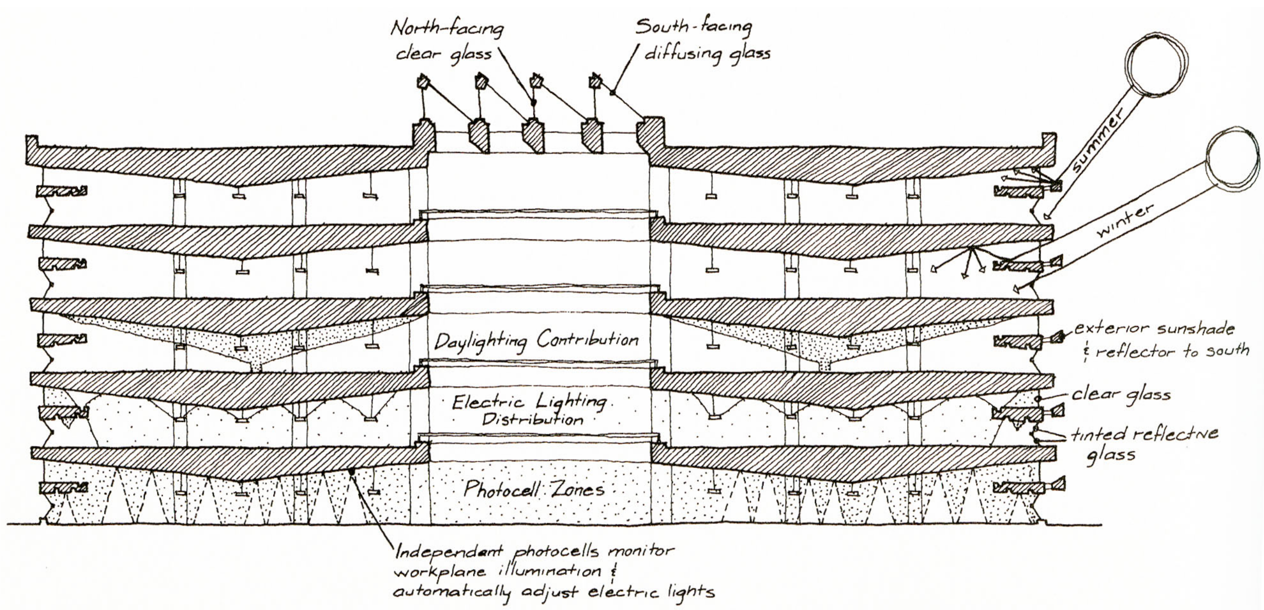

Figure F2.1.1 Lighting Section. Lockheed Building, Sunnyvale, California, Leo Daley (architect), 1983.

100% ELECTRIC LIGHTING

Discussion

Energy conservation guidelines call for the electric lighting system to operate at or less than a maximum power density of 2 watts/ft^2. Accomplishing this standard requires careful consideration of the task and ambient lighting systems operating under worst-case or nighttime conditions in your building.

The types of light sources you choose will have a great impact on the total lighting load. Because of poor energy efficiency, incandescent lamps are usually avoided in favor of fluorescent or high intensity discharge (HID) lamps, except where low initial cost, good color rendition, or point sources of light are required. Fluorescents are the lamps of choice for most situations, but HIDs have the advantage of longer life and higher efficacy, though their color rendition tends to be worse. In designing the layout of fixtures consider not only the task areas to be lighted but also the architectural impact of the layouts [*MEEB*, Figure 15.12–15.16, pp.690–693].

Procedure

Evaluate how well your design attains Electric Lighting Integration Goal A—**Lighting power densities comply with code, while illumination to meet the needs of users is provided throughout the building.**

For each task area:

1. Choose appropriate lamp types for ambient and task lighting. Use the chart below and the color rendition chart [*MEEB*, Table 13.8, p.636] to help make your selections.

Lamp Type	Application
Incandescent	Closets, confined spaces, storage, short-term use areas, performance lighting for theatres, auditoria stage spotlighting, decorative display lighting, tasks requiring a small point source of light.
Fluorescent	Multi-purpose areas, offices, classrooms and other low-ceiling applications, desk lamps and other task lighting, display cases, advertising signs, office station islands.
HID	Offices, auditoria and other high-ceiling applications, industrial areas (factories, greenhouses), outdoor area lighting, outdoor security lighting.

100% ELECTRIC LIGHTING (continued)

2. Identify the footcandle level provided by each lighting source [C2.1 for interior spaces; *MEEB*, Chapter 14 pp.639–669, for exterior lighting], and determine the total wattage of electric lighting required.

   W_{total} = (watts/ft^2) (area)

   where:

   watts/ft^2 = for each source [*MEEB*, Chapter 14]

   area = floor area affected by each source (ft^2)

Total Lighting System [suggested format]

Task Area	Design Condition	Lamp Type	fc	watts/ft^2	Area (ft^2)	TOTAL Watts
offices	*task*	*incandescent*	*25*	*3.0*	*100*	*300*
	ambient	*metal halide*	*50*	*1.6*	*900*	*1,440*
			TOTAL	*1.93*	*900*	*1,740*

3. Calculate the total watts/ft^2.

   $$\text{total watts/ft}^2 = \frac{\text{(total watts from all sources)}}{\text{(total floor area)}}$$

4. Illustrate on your building and site plans the operation of your nighttime electric system. Clearly identify all task areas, light sources, and exterior circulation paths.

5. Discuss the success of your electric lighting strategy, and indicate any design changes you view as necessary to meet Goal A.

ELECTRIC LIGHTING INTEGRATION

BACKUP DAYTIME LIGHTING

Discussion

Where daylighting alone is less than adequate, backup lighting is required, but a 100% electrical lighting system may be excessive. Therefore, you must determine how much backup lighting is required and where it is needed in order to design switching or dimming control systems that use all or part of the 100% electrical lighting system as needed.

For more information

MEEB, Chapter 15, Sections 16.13–16.17, pp.717–727 (discussion of lighting control options).

Procedure

Evaluate how well your design satisifies Electric Lighting Integration Goal B—**Daylighting is supplemented with electric lighting only where and when necessary.**

Design this backup lighting system for the major space analyzed in E2.

1. Determine the minimum and maximum daylight factor in the space.
   a. Review the final GDDM footprints [E2.4] for your space.
   b. Record the minimum and maximum DF in the daylight level matrix [Table F2.3.1].
2. Record the seasonal daylight availability [B2.2].
3. Calculate the seasonal internal daylight footcandles.

   $FC_{intmin} = (FC_{ext})\ (DF_{min})$

   $FC_{intmax} = (FC_{ext})\ (DF_{max})$
4. Compare the footcandle levels supplied by daylight (daylight level matrix) to the recommended footcandle levels [C2.1]. Determine when and how much supplemental electric lighting is required.
5. Calculate the percentage of the total electric lighting required to supply the supplemental lighting.

   % electric lighting = $(fc_{reg})\ /\ (fc_{sup})$

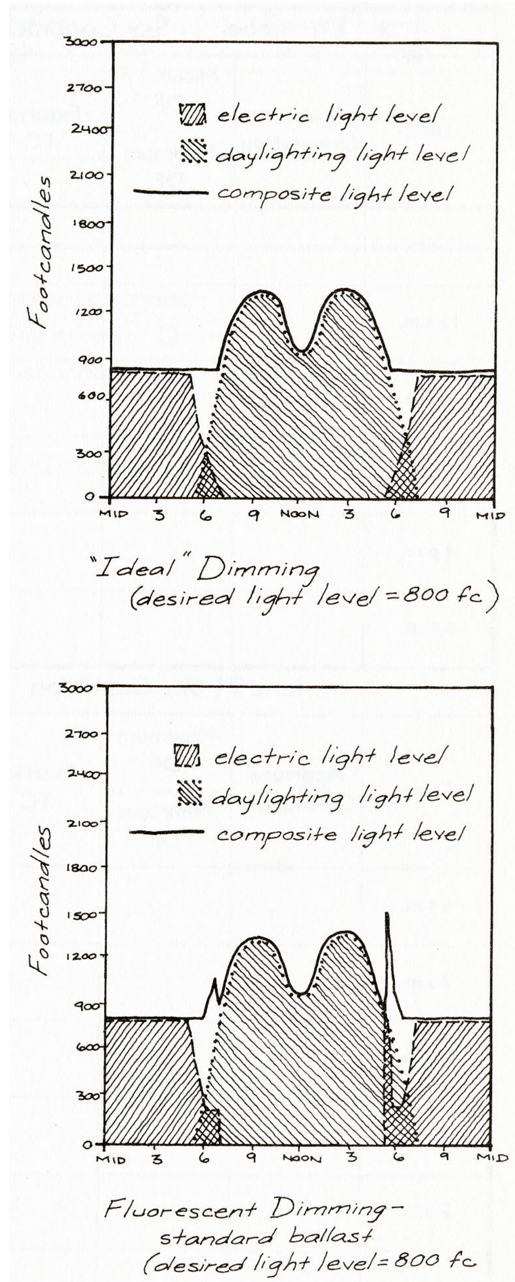

Figure F2.3.1 ***Above,* Ideal Dimming vs. *below,* Actual Dimming for Fluorescent Lamps.**

Table F2.3.1 Daylight Level Matrix

December 21 Sky Condition					March 21 Sky Condition				
Time	Aperture Orientation	Maximum DF / Minimum DF	Exterior FC	Maximum Interior FC / Minimum Interior FC	Time	Aperture Orientation	Maximum DF / Minimum DF	Exterior FC	Maximum Interior FC / Minimum Interior FC
8 a.m.					8 a.m.				
10 a.m.					10 a.m.				
noon					noon				
2 p.m.					2 p.m.				
4 p.m.					4 p.m.				
6 p.m.					6 p.m.				

June 21 Sky Condition					September 21 Sky Condition				
Time	Aperture Orientation	Maximum DF / Minimum DF	Exterior FC	Maximum Interior FC / Minimum Interior FC	Time	Aperture Orientation	Maximum DF / Minimum DF	Exterior FC	Maximum Interior FC / Minimum Interior FC
6 a.m.									
8 a.m.					8 a.m.				
10 a.m.					10 a.m.				
noon					noon				
2 p.m.					2 p.m.				
4 p.m.					4 p.m.				
6 p.m.					6 p.m.				

NOTES: For clear sky conditions, list the maximum and minimum footcandles for each hour for the window orientation that suppli most light.
If the March and September sky conditions are the same, the March and September charts above are the same.

BACKUP DAYTIME LIGHTING (cont.) F2.3

Supplemental Illumination [suggested format]

Task Area	Season	Hours of Inadequate Daylight	Footcandles Reqd	Footcandles Daylight	Footcandles Supp	Electric Lighting Required (%)
office	*Spring*	*9a.m.–10a.m.*	*60*	*45*	*15*	*25*

6. Illustrate, with schematics, your lighting switching and control strategies. Discuss any requisite changes to the 100% electrical lighting system. On building plans indicate which lights will be used under the various supplemental conditions.
7. Discuss the success of your electric lighting control strategy, and indicate any design changes you view as necessary to meet Goal B.

ELECTRIC LIGHTING PERFORMANCE F2.4

Discussion

Since a scheme that sensitively integrates electric light and daylight will operate at less than 100% of the electric lighting capacity during the daytime, it is necessary to determine a weighted average electric load in order to compare the lighting energy used in your building with the code requirements.

Procedure

Evaluate how well your design attains Electric Lighting Integration Goal C—**Daylight provides more than half the annual required lighting.**

For each task area:

1. Identify the operating characteristics in terms of percentage of lighting in use, hours of lighting operation, and watts per square foot for each supplemental lighting condition.

2. Calculate the total watt-hours of electric lighting provided under each condition.

   watt-hours/day = (watts/ft^2) (hours/day) (floor area)

   > NOTE: Dimming provides lower watts per square foot over the entire task area, while switching gives less floor area affected by the total watts per square foot.

3. Determine the total watt-hours per day for each season.

4. Calculate the weighted average lighting loads for each season in watts/ft^2.

   load = (WH) / [(area) (operation hours/day)]

   where:

   WH = total watt-hours per day [step 3]

   area = total floor area (ft^2)

Supplemental Lighting Levels [suggested format]

Task Area	Season	Total Lighting in Use (%)	Total Lighting in Use (watts/ft^2)	Hours/Day in Use	Floor Area Affected (ft^2)	Watt-Hours
offices	*Winter*	*100*	*1.5*	*2*	*900*	*2,700*
		60	*0.9*	*4*	*900*	*3,240*
		20	*0.3*	*4*	*900*	*1,080*
	TOTAL					*7,020*

5. Discuss the success of your electric lighting strategy, and indicate any design changes you view as necessary to meet Goal C.

SAVINGS FROM DAYLIGHTING

F2.5

Procedure

Evaluate how well your design attains Electric Lighting Integration Goal D—**Substantial savings over nondaylight-integrated electric lighting systems will be realized.**

For each task area:

1. Determine the lighting load [F2.4, step 3] in watt-hours per day for each season.
2. Compare your daylighted building design to itself as a 100% electrically lighted building (assume all the lights are on when your building is in use).

   Calculate the load in watt-hours per day.

   nondaylighted load = (night watts) (hours) (area)

   where:

   night watts = total watts/ft^2 for the 100% electric system [F2.2, step 3]

   hours = total daily operating hours

   area = total floor area (ft^2)
3. Calculate, for each season, the percentage of energy saved by employing daylighting.

$$\% \text{ savings} = 100\% - \frac{(\text{daylighted watt-hours/day})}{(\text{nondaylighted watt-hours/day})}$$

Savings from Daylighting [suggested format]

Space	Season	Lighting Load Daylighted (watt-hours/day)	Lighting Load Nondaylighted (watt-hours/day)	Lighting Energy Savings (%)
office	*Winter*	*7,020*	*13,500*	*48*

4. Discuss the success of your daylighting strategy, and indicate any design changes you view as necessary to meet Goal D.

DESIGN REVIEW

Discussion

Providing proper switching and control systems, the use of ambient and task lighting schemes, and specifying low-energy lamps ensure energy-conserving lighting capabilities in your design. However, the aesthetic aspects of lighting design should never be ignored. Rooms should be lighted to provide an appropriate luminous environment and rich spatial definition. It is time once again to think about and demonstrate how your lighting scheme contributes to the overall aesthetics of your design.

Procedure

1. Make schematic drawings or renderings of your lighting design that reveal the space's architectural character.
2. Annotate the drawings to explain the design.
3. Discuss changes, tradeoffs, further improvements, and how they affect the aesthetics of your design.