

LBL DAYLIGHTING NOMOGRAPHS

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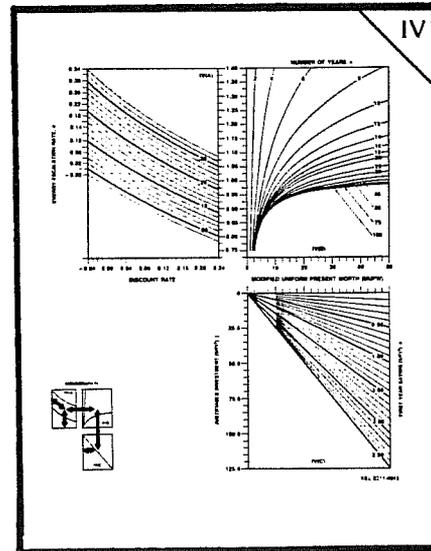
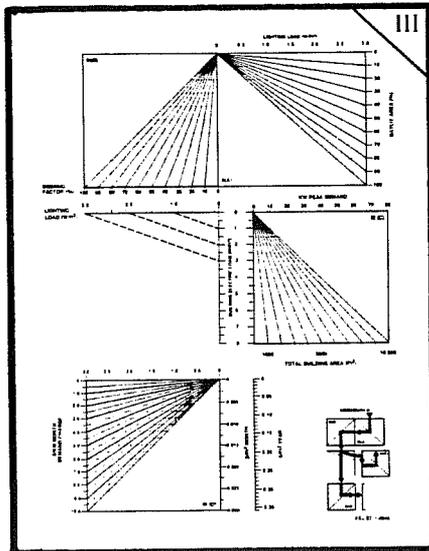
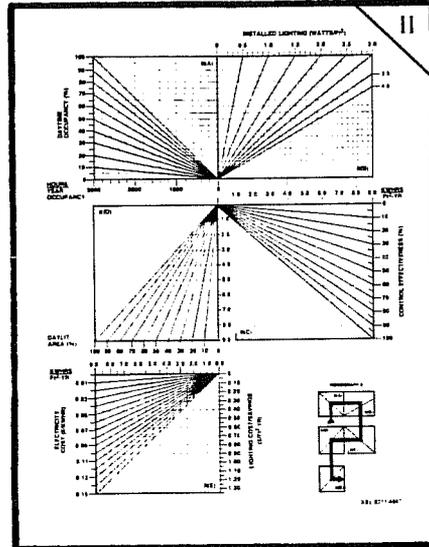
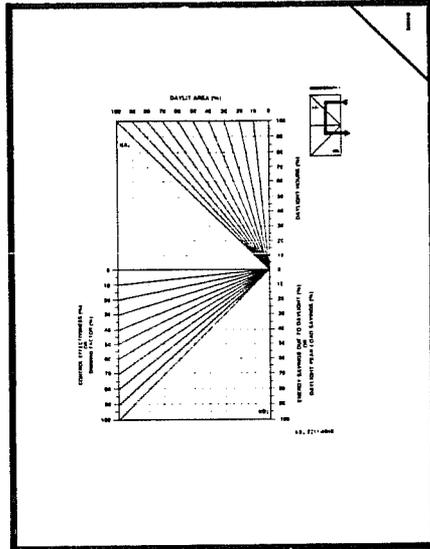
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January 1984

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INTRODUCTION

The nomographs presented here are intended to assist designers in making initial decisions concerning daylighting's potential as a strategy for energy conservation and load management in commercial buildings. Once the basic operation of the nomographs is understood, they can be used to evaluate a design quickly. Each is intended to facilitate rapid comparison of alternative designs. Note that the thermal benefits and costs of windows or skylights and the heating/cooling impact of daylighting are not considered here.

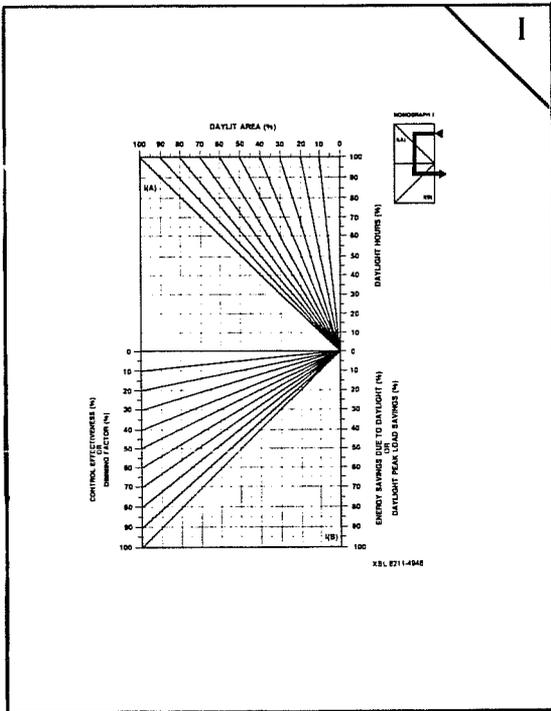
These nomographs can be used to determine the potential daylighting benefits and costs, and thus the importance that should be assigned to further investigations of daylighting strategies. A poor showing would indicate that daylighting probably will not be a significant energy-conservation strategy; a large potential savings indicates that additional effort should be expended to better define the impact of daylighting on all building systems.

The nomographs provide answers that suggest general design directions for cost-effective, daylighted buildings. They do not provide detailed design solutions. They offer a quick estimate of the magnitude of potential savings but do not provide the level of detail required to guarantee a workable solution.

Read through the entire package first and test the nomographs step by step to be sure you are using them properly. The small diagram on each nomograph indicates the direction of movement through that nomograph. With a little practice, you'll find the nomographs very simple and easy to use.

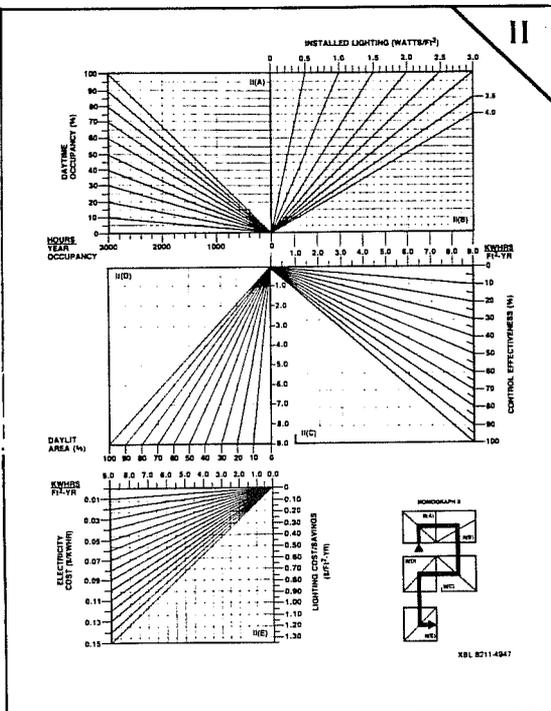
Again, the nomographs address annual electric lighting energy savings and peak load savings but exclude the thermal effects of fenestration systems.

Nomograph I: Relative Importance of Daylighting in Reducing Lighting Energy Consumption and Peak Electric Loads



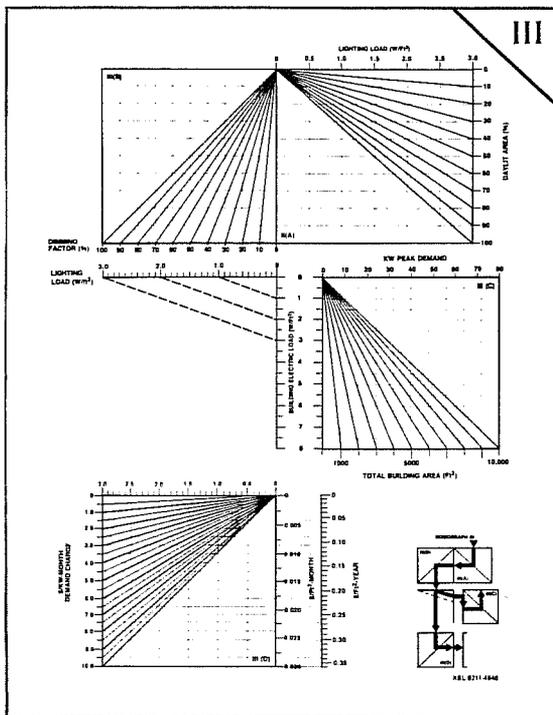
The first nomograph is used to determine the potential impact of daylighting in a commercial building, based upon initial design constraints of overall building size and configuration, site conditions, and occupancy. It can be employed in two ways: to predict potential electrical energy savings, and to predict potential electrical load reductions.

Nomograph II: Annual Lighting Energy Use/Cost With and Without Daylighting



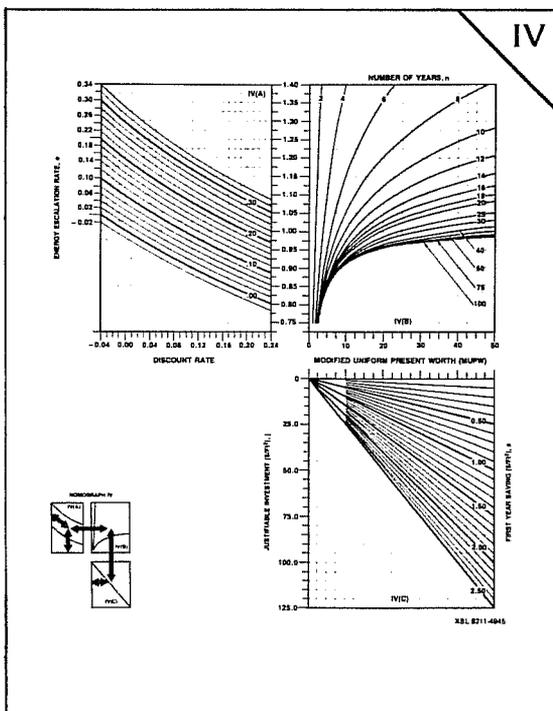
The second nomograph is used initially to determine the annual energy consumption (kWh/ft²-yr) of the electric lighting system and the associated cost (\$/ft²-yr). It can then be used to estimate the annual energy and cost savings of that same electric lighting system when daylighting strategies are employed.

Nomograph III: Peak Electrical Load/Cost With and Without Daylighting



The third nomograph is similar to the second but predicts the impact of daylighting on peak electrical loads and demand charges.

Nomograph IV: Justifiable Economic Investment in Daylighting Design



The fourth nomograph determines the justifiable economic investment in daylighting (lighting controls, sun controls, and other costs directly associated with daylighting) based upon the energy and load savings determined with the second and third nomographs.

Disclaimer

* * * * * S T O P ! * * * * *

USE OF THE NOMOGRAPHS WITHOUT READING THIS MAY BE
RUINOUS TO YOUR PROFESSIONAL REPUTATION.

* * * * *

The nomographs and supporting charts presented here can be employed as a preliminary tool for assessing the potential impact of daylighting on the energy performance of new or retrofit non-residential buildings. The overall method is useful in estimating the value of daylighting in a particular building as a function of key design parameters. Tentative answers to several important design issues can be obtained in a matter of minutes. However, the nomographs and charts contain built-in assumptions that must be noted before this method can be used properly. Carefully review "Appendix A: Assumptions" before you begin to use the nomographs. Remember that the nomographs indicate potential savings; they do not by themselves provide a sufficient level of design detail to guarantee an effective lighting solution.

Design Variables

The nomographs and charts provide flexibility in accounting for several aspects of the building design:

Latitude of building location.

Annual hours of occupancy.

Daily occupancy schedule.

Total building floor area, ft².

Daylight floor area, % of total floor area.

Visible light transmittance of glazing, including a "well factor" for top lighting.

Glazing area.

Choice of continuous dimming or one step (on/off) lighting controls.

Maximum light dimming factor, %.

Interior illumination level, footcandles.

Installed lighting load, watts/ft².

Non-lighting electrical load, watts/ft².

Electricity cost, \$/kWh.

Peak demand rate, \$/kW-month.

These variables are reflected in the values entered on Page 1 of the Worksheet. The answers that come out of the nomographs are entered on Page 2 of the Worksheet explained in the next section.

Other design features are accounted for in the nomographs through the use of average values for fixed assumptions. These assumptions, described in Appendix A, should be carefully reviewed.

Any one of the following economic variables or requirements may be tested when all the others are held constant:

Justifiable investment, \$/ft²-yr.

First year saving, \$/ft².

Rate of return on investment or discount rate.

Energy escalation rate.

Payback period, years.

USE OF THE NOMOGRAPHS

Once the user becomes familiar with the input requirements and organization of each nomograph, several alternative designs can be compared in a few minutes. Each nomograph is constructed so that the design choices that are most likely to be varied are located near the end of the nomograph calculation sequence.

Nomographs are a graphic representation of a calculation procedure. The daylighting calculation procedure is described in the Appendix. It can easily be converted for use on a programmable calculator or microcomputer.

Always check to be sure the results are "reasonable" in light of your own experience and intuition.

If you find yourself operating in a region of the nomograph where the lines are close together, double or triple one of the next values in order to move into a portion of the nomograph that permits more accurate selection of design values. However, be sure to divide the final answer by the same factor. The only exception to this technique is Nomograph IV, where some of the relationships are not linear. The alternative is to use the calculation procedure listed in Appendix B.

A worksheet is provided, (see p. 9,11) to clarify and organize preliminary information required in using the nomographs. Supplementary charts (S.1 - S.7) are included to assist in determining other values. The worksheet and charts are explained first; then how to use the nomographs is described.

Use the worksheet as a written record of intermediate calculated results and final results. A collection of worksheet results for many design variations should prove a useful educational resource.

WORKSHEET & CHARTS

The worksheet serves to keep track of assumptions that affect the daylighting performance of new or retrofit building designs under study with the nomographs. Values used in the base-case design and in several design variations are recorded on the worksheet and then used as the basis for nomograph studies. The worksheet documents the process by which specific design variations and assumptions are compared. Space is available on each page of the worksheet for a project title, date, and description of the daylighting study being performed with the nomographs. Supplementary charts S.1 through S.7 are reference material from which appropriate values can be selected.

Required Preliminary Design Data: Worksheet Items 1-11, (13), 15; Page 1

Items 1-11, (13), 15 must be completed in order to refer to the supplementary charts and nomographs. The small boxes to the left of each item of required information on the worksheet indicate the nomograph for which that item is either an input or output value ("i" or "o").

"Daily Occupancy Schedule" refers to the normal hours of operation of the building, Item 2.

"Typical Floor Shape" may be expressed as a length-to-width ratio, or may be a graphic symbol that represents a particular building configuration. This value, Item 4, is used in conjunction with charts S.5, S.6, and S.7 in determining "Daylit Area (%)", Item 13. For buildings not shaped like rectangular boxes, "Daylit Area (%)" is calculated directly from floor plans after the depth of the daylight zone is established. For side lighting we suggest a nominal 15 foot deep perimeter zone, assuming a floor-to-ceiling height of 8'-6". However, you may increase the 15' daylight zone depth proportionally as the floor-to-ceiling height increases proportionally above 8'-6" as described in Appendix A.

Item 5a-5d include, respectively, the type of lighting control, the specification of design illuminance level, the fractional glazing area above the workplane, and the visible light transmittance of the glazing ("TVIS"). Note that for side lighting, "Glass Area Fraction" is the square feet of glazing above the workplane divided by the total (gross) wall area between floor and ceiling. For top lighting, "Glass Area Fraction" is the glazed aperture divided by the flat ceiling area (or floor area) which it daylight. Skylights are assumed to be horizontal or nearly flat in their tilt.

Data from Charts: Worksheet Items 12-14; Page 1

Item 12:

For "Daylight Hours," refer to chart S.1. Daylit hours of occupancy are shown as a percent for a given latitude and daily occupancy schedule. If the occupancy schedule of the building being studied is not found in S.1, use chart S.2 as follows: Choose the curve corresponding to the AM portion of the desired occupancy, find the point where the latitude line crosses the curve, and read off the value on the left vertical axis labeled "Daylit Hours During Occupancy." Do the same with the PM portion of the occupancy and add the AM and PM values together. Divide the sum by the total number of daily occupancy hours, and multiply by 100. The result is the "Daylight Hours (%)" found directly in chart S.1. Note that charts S.1 and S.2 account for Daylight Savings Time.

Item 13:

"Total Daylit Area (%)" is read from charts S.5, S.6, and S.7 assuming a 10-, 15-, or 20-ft deep perimeter daylighted zone, respectively, for a specified length-to-width ratio and total area per floor. For irregularly shaped buildings without a consistent

length-to-width ratio, or with different floor plans on each level, the daylighted area can be calculated by dividing the floor area of the daylighted perimeter zone by total building floor area. For a skylighted building with uniform skylight distribution, "Total Daylit Area" would be the entire floor area (100%). Side lighted and top lighted areas may be treated as one using a weighted average or be handled separately.

Item 14:

"Control Effectiveness" is found from chart S.3 or S.3A (one step, on/off) and charts S.4 or S.4A (continuous dimming) from the specification of Item 5a. Overall control effectiveness, expressed as a percent saving, is defined as a function of design illuminance level (in footcandles), "TVIS" and "AREA." "TVIS" is the total visible light transmittance of the glazing assembly (do not include the effect of operable shading). It should, however, include the effect of any fixed shading solutions (e.g., reflective coatings, sunscreens, etc.) and any allowance for a maintenance factor to account for dirt accumulation on the glazing. "AREA" is the net glazed window area above the work plane divided by the total (gross) wall area between floor and ceiling. "TVIS X AREA" is the product of those two values.

To determine "control effectiveness" for top lighting (in charts S.3A and S.4A), a "WELL FACTOR" is included in the (TVIS X AREA) product. A well factor of 1.0 is used when the skylight is virtually flush with the finished ceiling, e.g., when each light well has a depth of 0 feet and/or a net reflectance of 100%. As the depth of the light well increases, and the reflectance of the light well surfaces decreases, the well factor is reduced.

If a building has more than one type of glazing assembly, calculate a weighted average as follows:

Overall Control Effectiveness =

$$\left[\begin{array}{l} \text{(type 1 glazing} \\ \text{control effectiveness)} \end{array} \right] \times \frac{\text{(daylit area, by type 1 glazing)}}{\text{(total daylit area)}} \quad +$$

$$\left[\begin{array}{l} \text{(type 2 glazing} \\ \text{control effectiveness)} \end{array} \right] \times \frac{\text{(daylit area, by type 2 glazing)}}{\text{(total daylit area)}} \quad +$$

...

Alternatively one could use the nomographs on a zone by zone basis, treating each distinct building zone as a separate "building" for analysis. If a building has daylighted areas with several different occupancy schedules, calculate each type separately and sum the results at the end.

Item 15:

"Dimming Factor" is the maximum reduction of electric lighting power in the daylighted zone. Expressed as a percent, this value is a function of the lighting control hardware and type of load management strategy being employed.

Data from Nomographs: Worksheet Items 16-34, Page 2

Nomograph I

- Item 16: Annual Energy Savings Due to Daylight (%)
- Item 17: Peak Load Savings Due to Daylight (%)

Nomograph II

- Item 18: Non-Daylighted Lighting Energy Consumption (kWh/ft²-yr)
- Item 19: Non-Daylighted Lighting Cost (\$/ft²)
- Item 20: Daylighting Energy Savings (kWh/ft²-yr)
- Item 21: Daylighting Savings (\$/ft²)
- Item 22: Annual Daylighting Savings (\$/building)

Nomograph III

- Item 23: Non-daylighted Peak Demand (kW)
- Item 24: Non-daylighted Monthly Demand Charge (\$/kW-month)
- Item 25: Non-daylighted Annual Demand Charge (\$/kW-yr)
- Item 26: Daylighted Peak Demand Savings (kW)
- Item 27: Daylighted Monthly Demand Savings (\$/ft²-month)
- Item 28: Daylighted Annual Demand Charge (\$/ft²-yr)
- Item 29: Total Annual Savings (\$/ft²-yr)

Nomograph IV

- Item 30: Justifiable Investment (\$/ft²-yr), j
- Item 31: First-Year Saving (\$/ft²)
- Item 33: Rate of Return on Investment or Discount Rate, i
- Item 34: Energy Escalation Rate, e

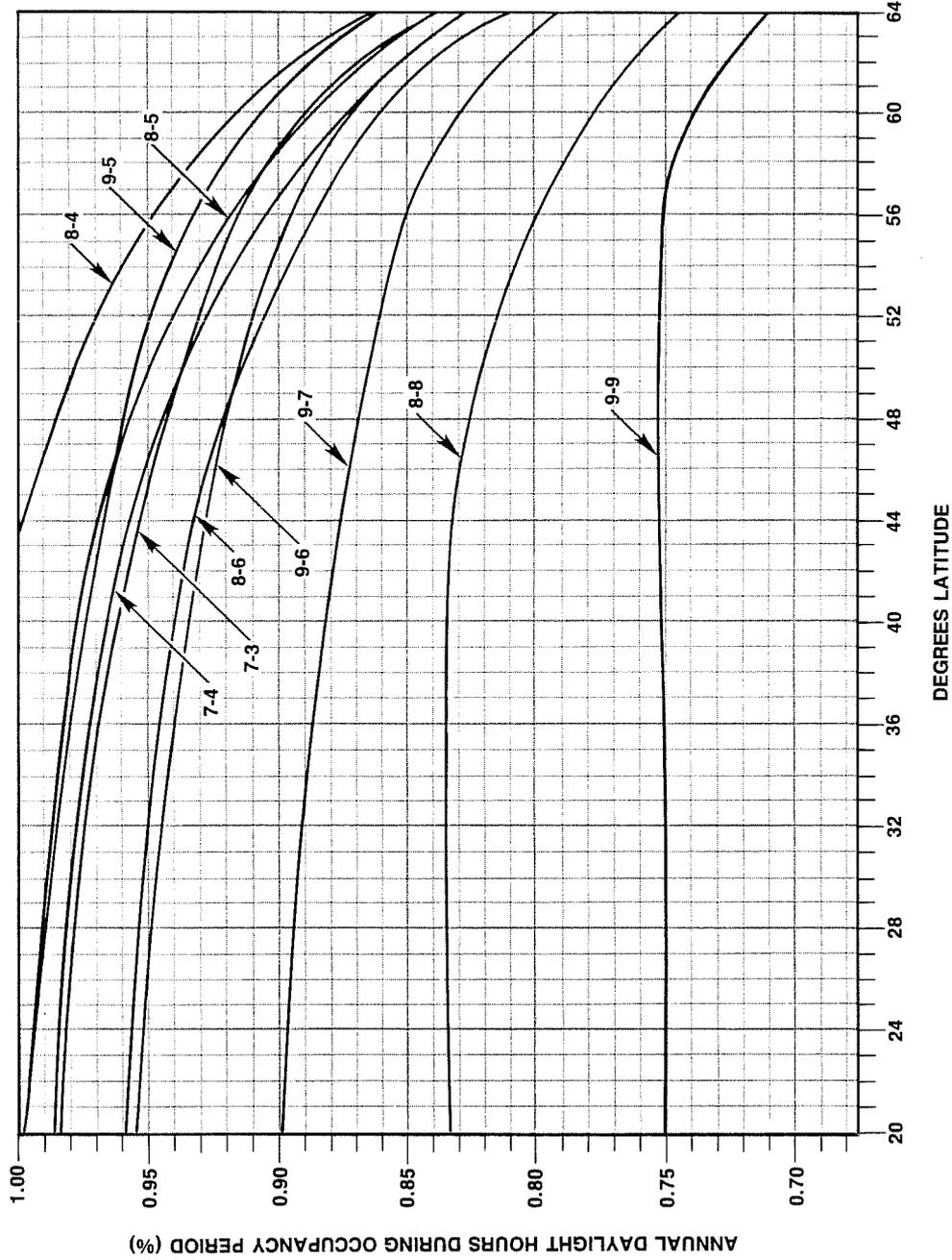
Nomograph IV can be used in several ways depending upon the approach one chooses to take. For example, the "Payback Period" can be found according to the values selected for the discount rate ("i"), the energy cost escalation ("e"), the incremental installation cost or justifiable investment ("j") and the first year savings ("s"). In order to find the "Rate of Return on Investment," work back through the nomograph to the appropriate discount rate. Parameters can be alternately fixed or varied to examine the sensitivity to various economic assumptions.

Description of Study / Remarks

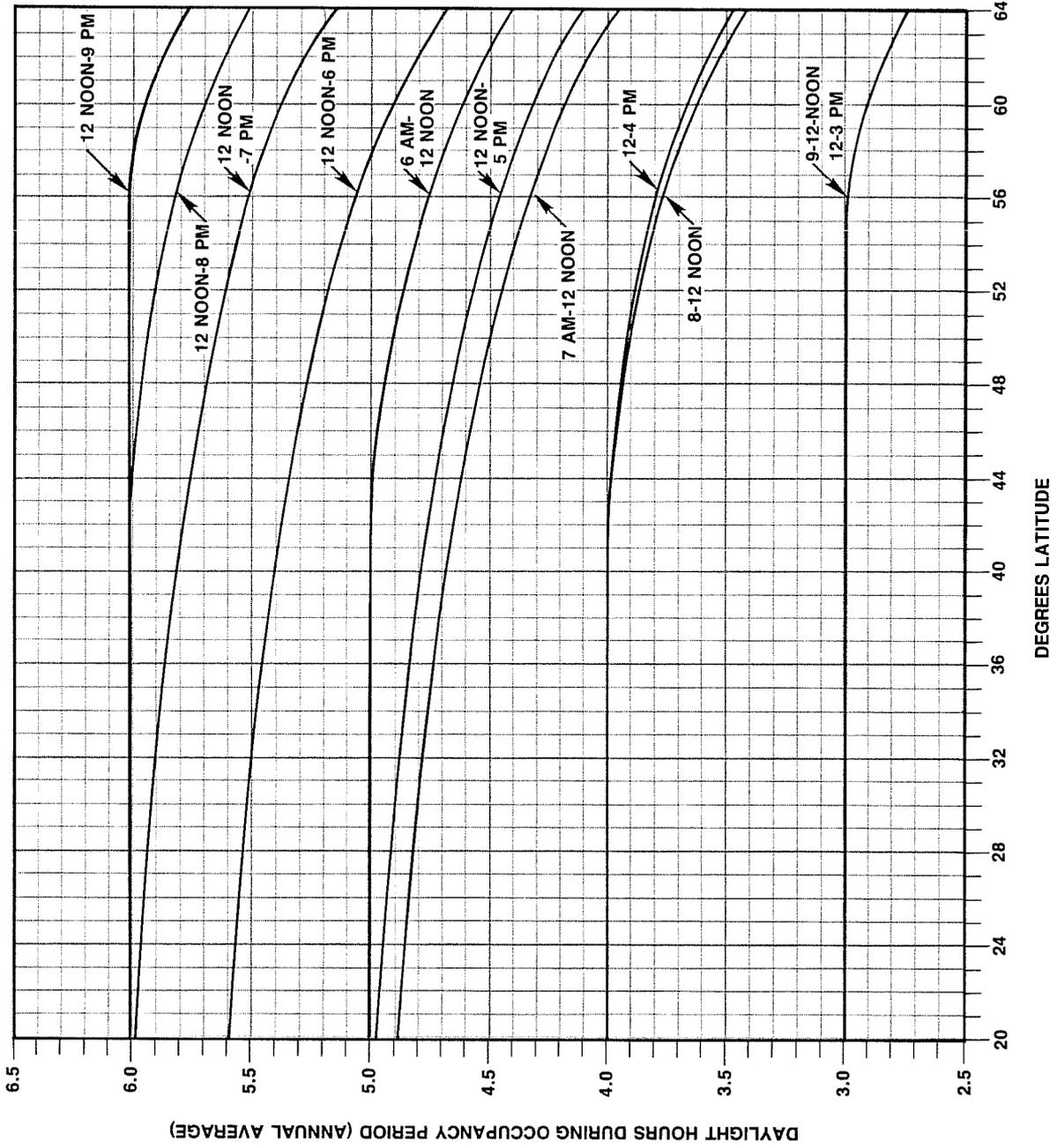
Input (1) or output (o) value for the specified nomograph or chart.		Charts S.1 - S.7							Work-sheet Item No.	Description of Worksheet Item	Base Case	Case 1.	Case 2.	Case 3.	Case 4.
		I	II	III	IV	1	2	3							
									1	Latitude of Building Location					
									2	Daily Occupancy Schedule					
									3	Gross Area Per Floor (ft ²)					
									4	Typical Floor Shape: Length-to Width Ratio					
									5a	Lighting Control Type					
									5b	Illumination Level (fc)					
									5c	Side Lighting: Glass Area Fraction					
										Top Lighting: Glass Area Fraction					
									5d	Side Lighting: Glass Visible Transmittance (TVIS)					
										Top Lighting: Glass Visible Transmittance (TVIS) X Well Factor					
									6	Annual Hours of Occupancy					
									7	Installed Lighting Load (watts/ft ²)					
									8	Electricity Cost (\$/kWh)					
									9	Gross Total Building Area (ft ²)					
									10	Non-Lighting Electric Loads (watts/ft ²)					
									11	Peak Demand Rate (\$/kW-month)					
									12	Daylit Hours (%)					
									13	Total Daylit Area (%)					
									14	Control Effectiveness (%)					
									15	Dimming Factor (%)					

Description of Study / Remarks

I	II	III	IV	Charts S.1 - S.7							Work-sheet Item No.	Description of Worksheet Item	Base Case	Case 1.	Case 2.	Case 3.	Case 4.
				1	2	3	4	5	6	7							
0										16	Annual Energy Savings Due to Daylight (%)						
0										17	Daylight Peak Load Savings (%)						
0										18	Non-Daylit Lighting ² Energy Consumption (kWh/ft ² -year)						
0										19	Non-Daylit Lighting Cost (\$/ft ² -yr)						
0										20	Daylighting Energy Consumption Saving (kWh/ft ² -year)						
0										21	Daylighting Saving (\$/ft ² -year)						
0										22	Annual Daylighting Savings (\$/building)						
0										23	Non-Daylit Peak Demand (kW)						
0										24	Non-Daylit Monthly Demand Charge (\$/ft ² -month)						
0										25	Non-Daylit Annual Demand Charge (\$/ft ² -year)						
0										26	Daylit Peak Demand Saving (kW)						
0										27	Daylit Monthly Demand Saving (\$/ft ² -month)						
0										28	Daylit Annual Demand Saving (\$/ft ² -year)						
0	0	0	0	0	0	0	0	0	0	29	Total Annual Savings (\$/ft ² -year)						
0	0	0	0	0	0	0	0	0	0	30	Justifiable Investment (\$/ft ² or \$/building), j						
0	0	0	0	0	0	0	0	0	0	31	First Year Saving (\$/ft ² or \$/building), s						
0	0	0	0	0	0	0	0	0	0	32	Payback Period (years), n						
0	0	0	0	0	0	0	0	0	0	33	Rate of Return on Investment or Discount Rate, i						
0	0	0	0	0	0	0	0	0	0	34	Energy Escalation Rate, e						



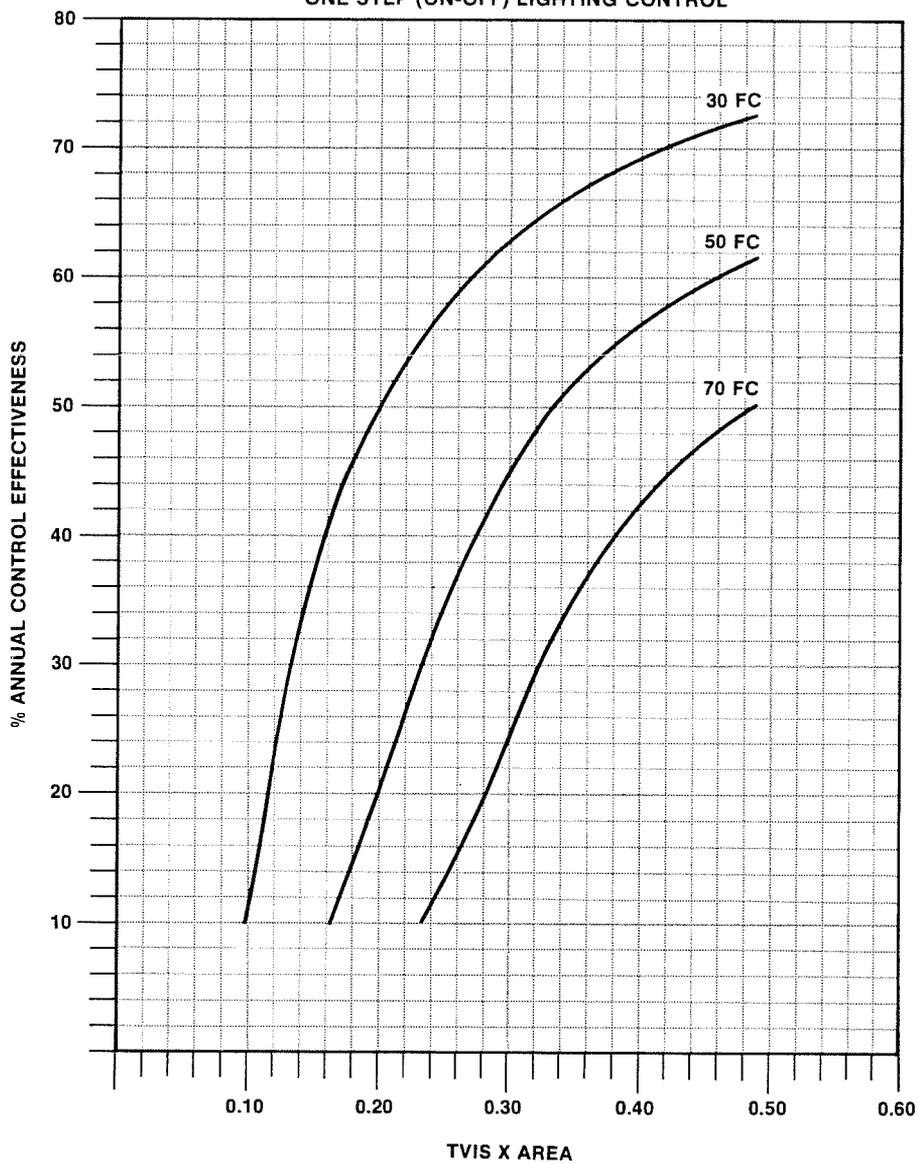
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SIDE LIGHTING

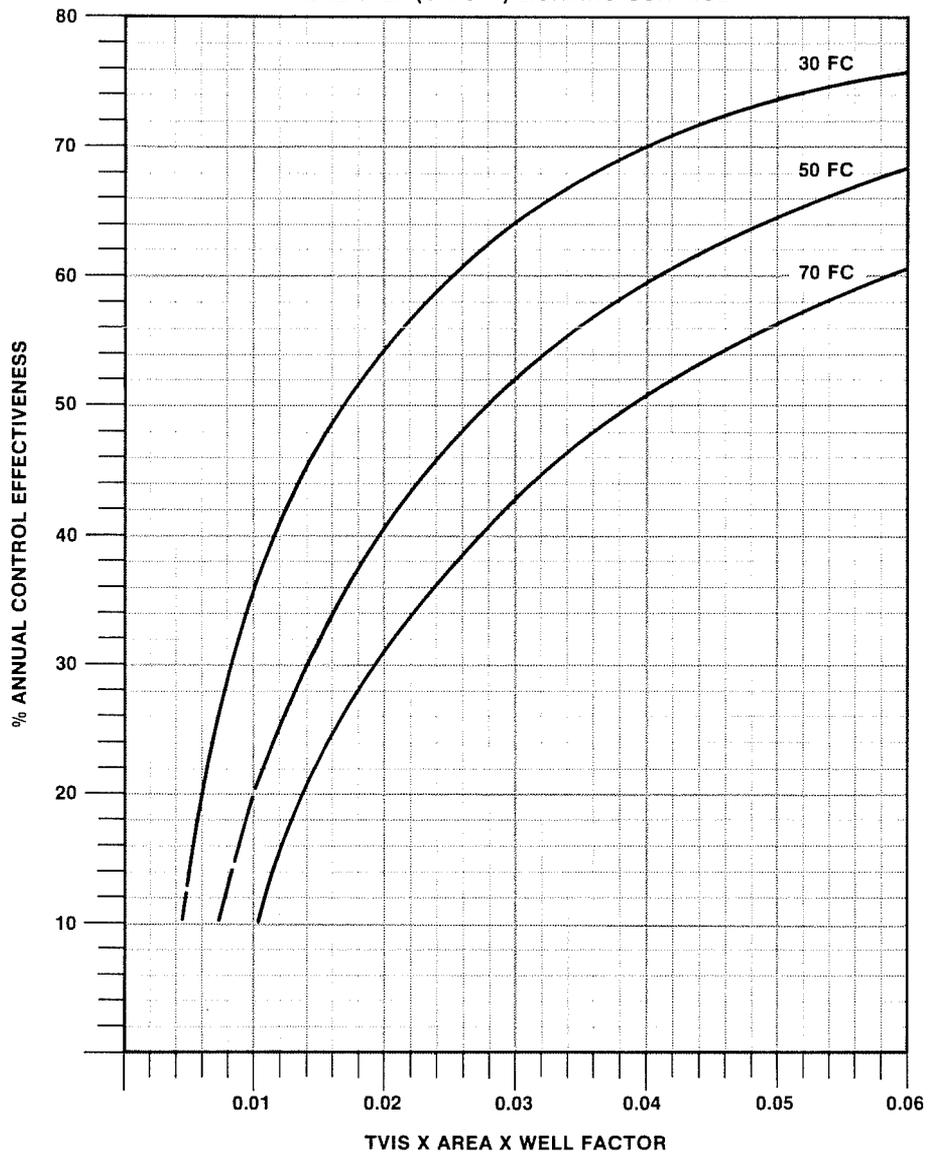
"ONE STEP (ON-OFF) LIGHTING CONTROL



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TOP LIGHTING

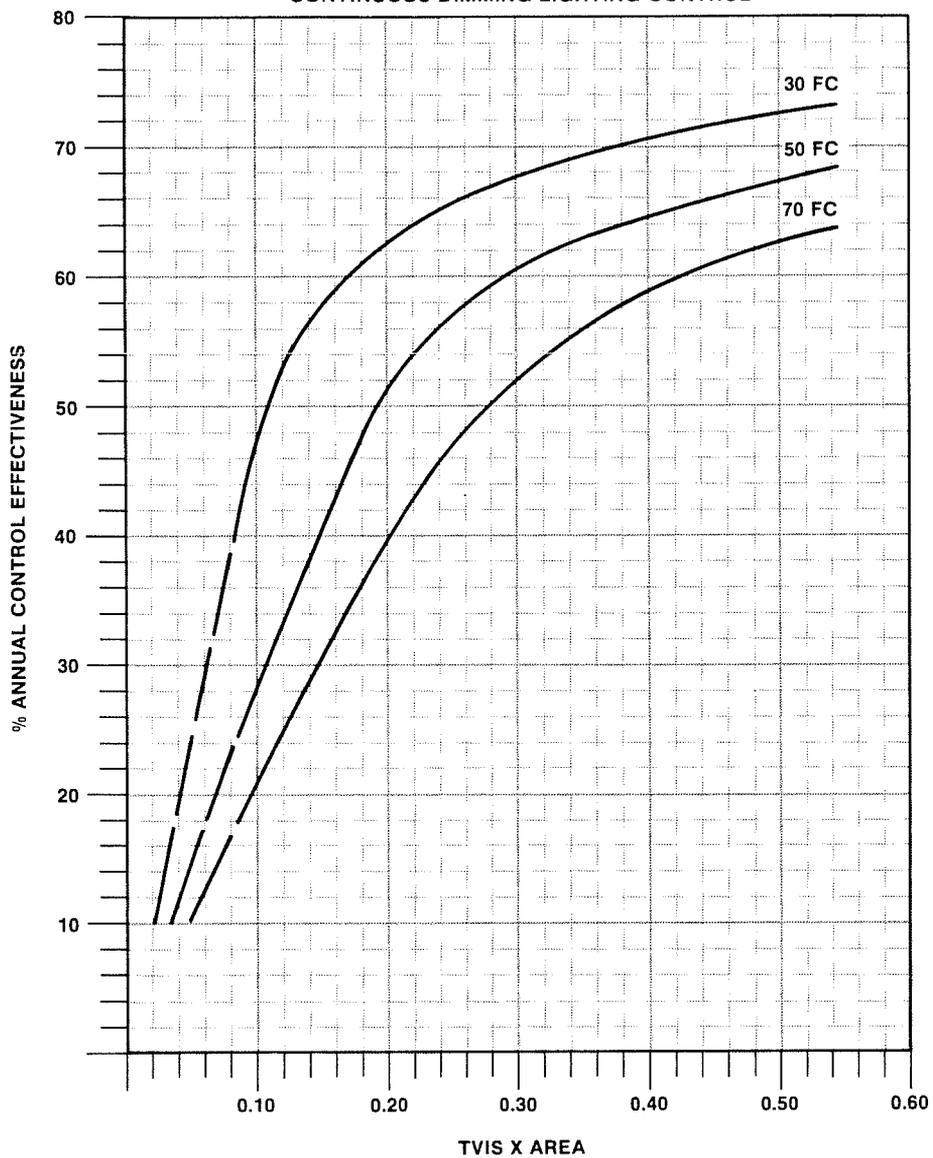
"ONE STEP (ON-OFF) LIGHTING CONTROL"



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SIDE LIGHTING

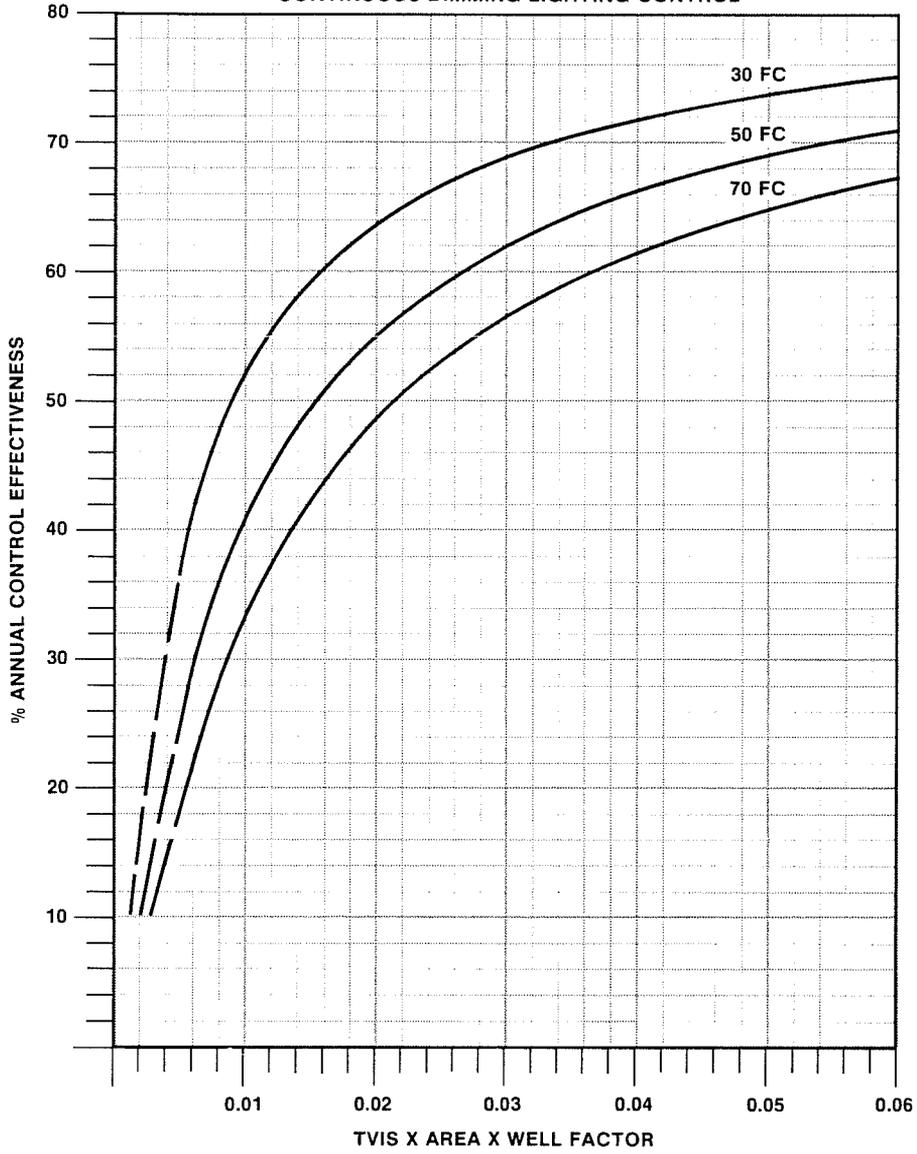
CONTINUOUS DIMMING LIGHTING CONTROL



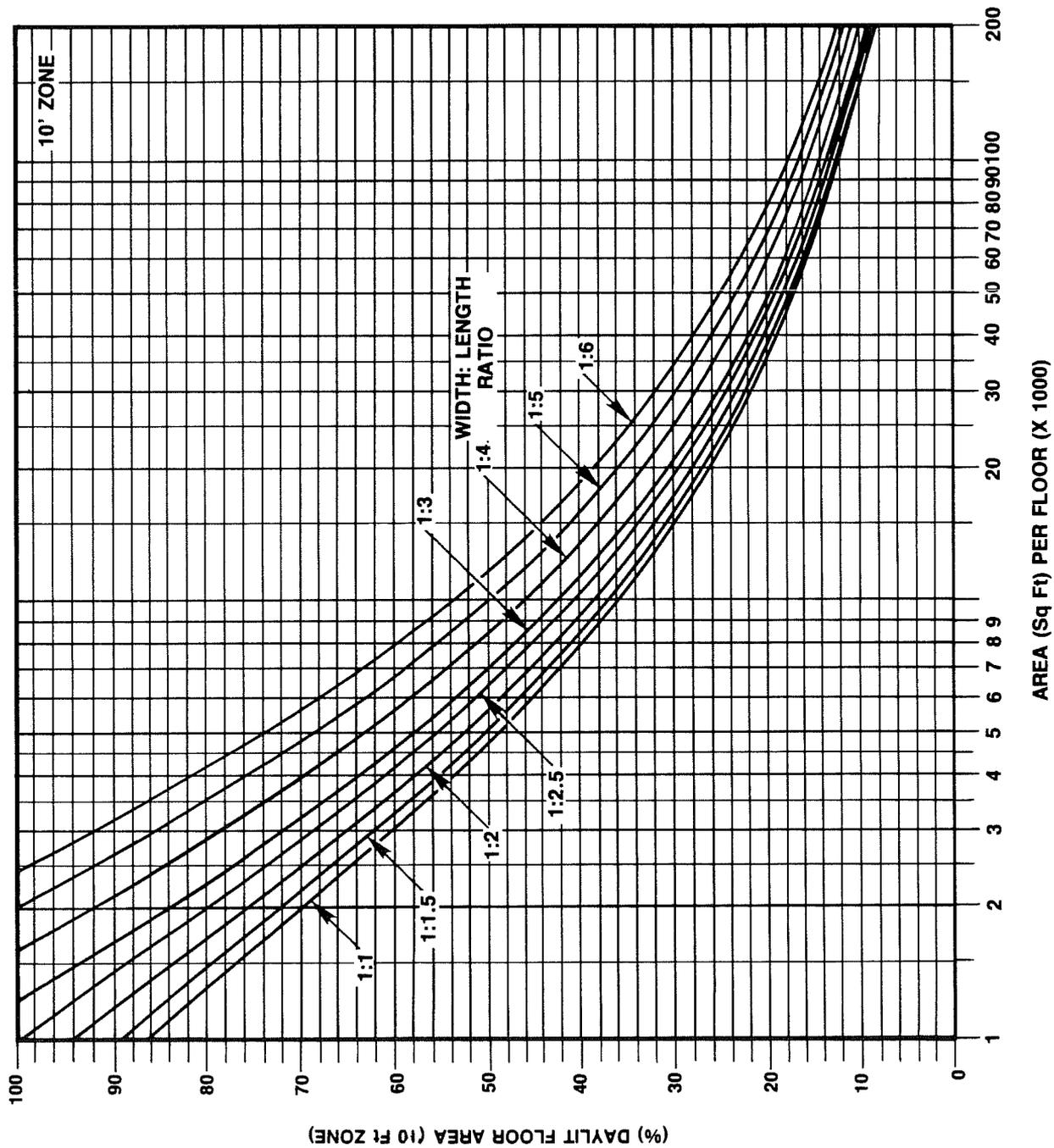
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TOP LIGHTING

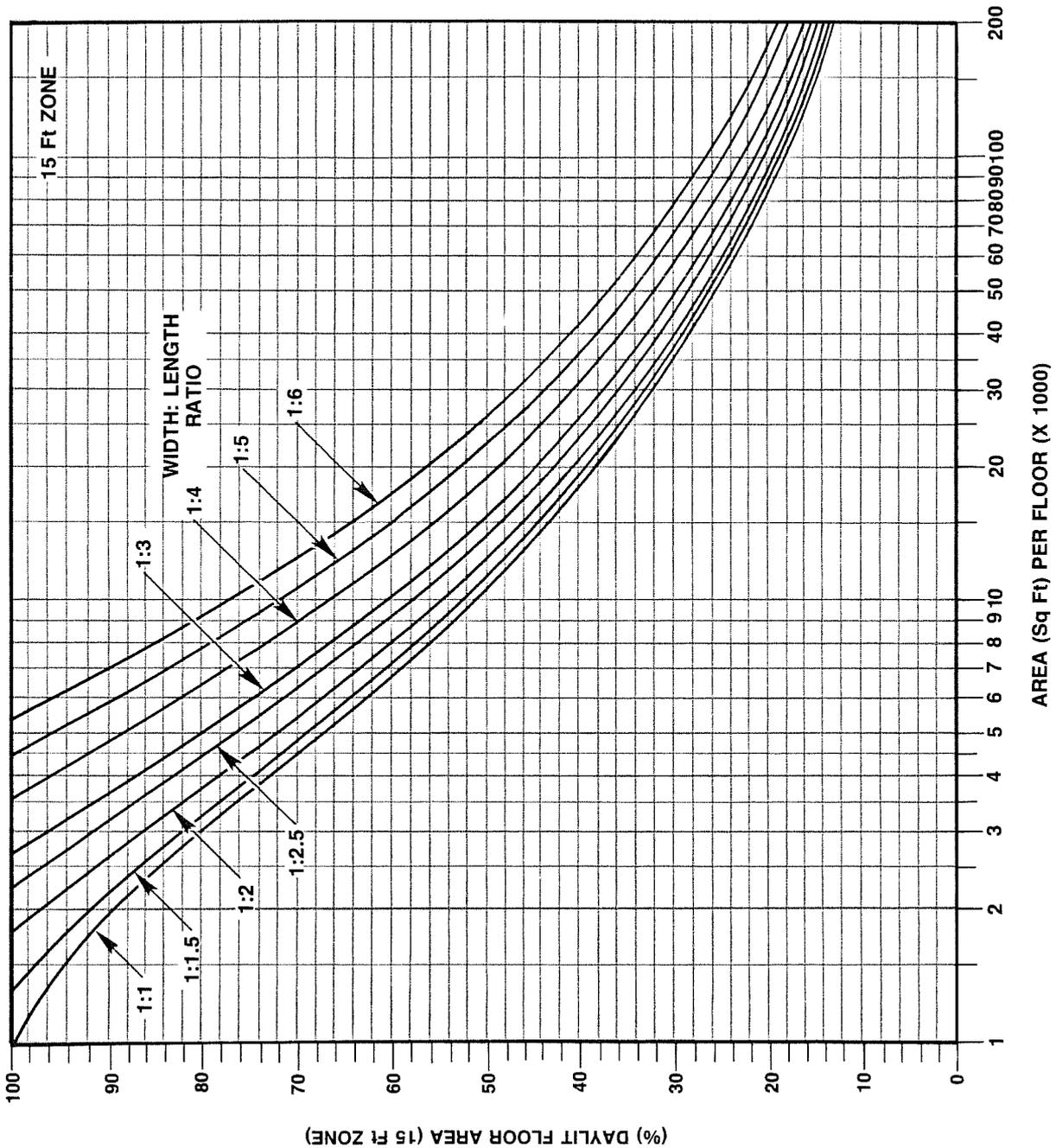
CONTINUOUS DIMMING LIGHTING CONTROL



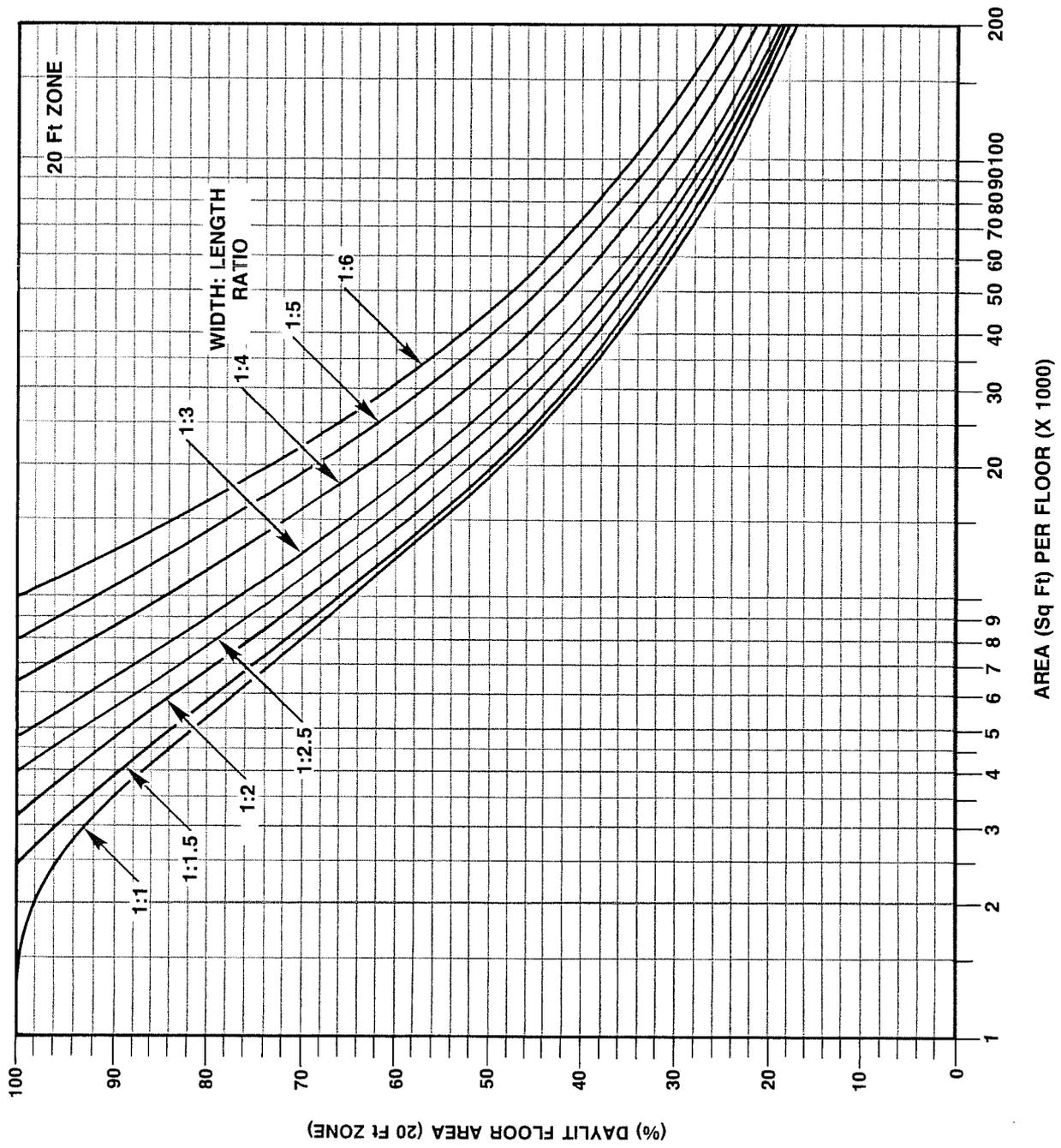
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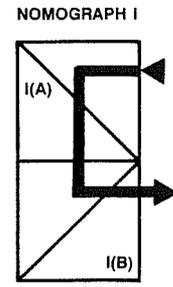
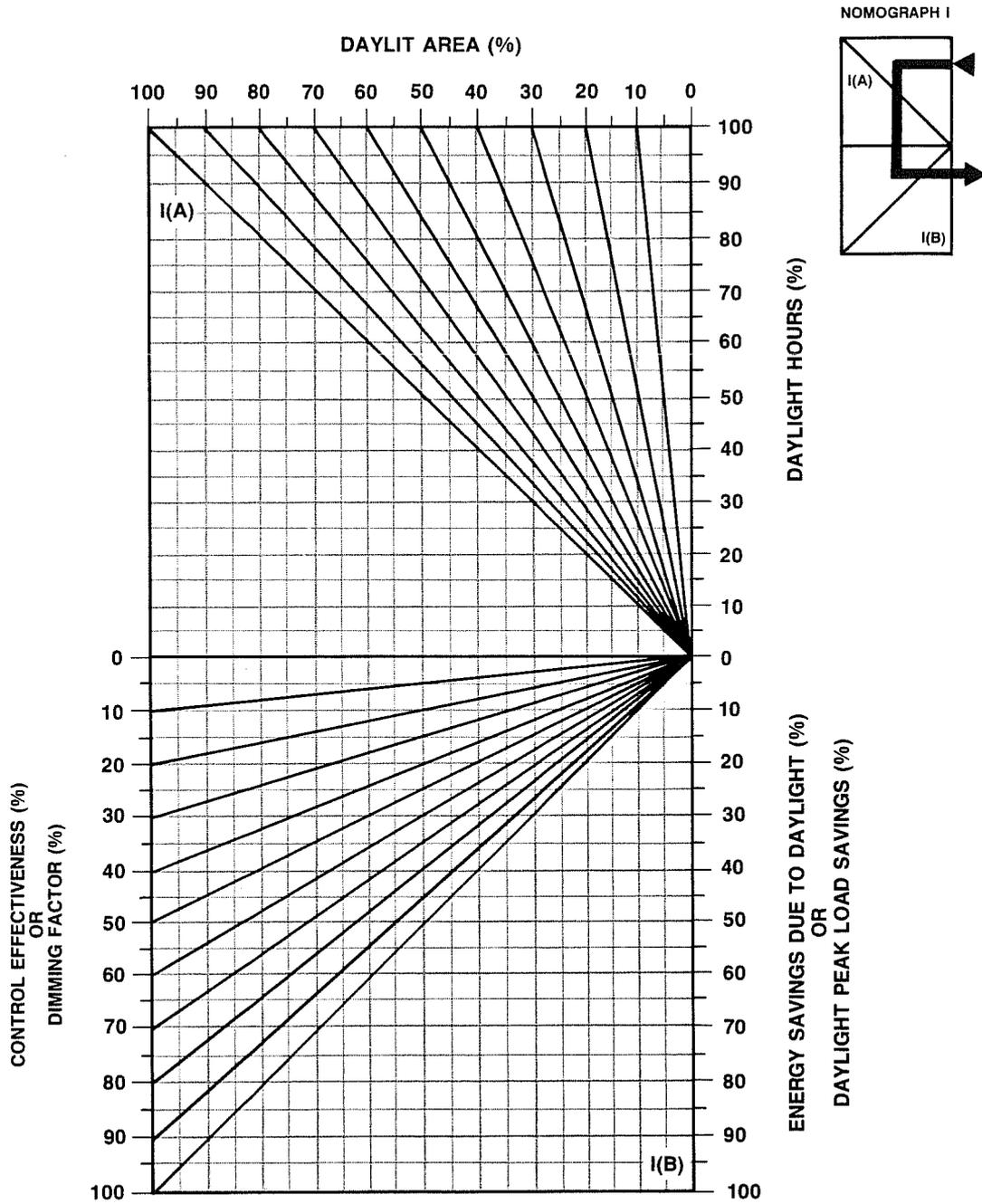
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XBL 8211-4938



XBL 8211-4939



XBL 8211-4948

RELATIVE IMPORTANCE OF DAYLIGHTING

NOMOGRAPH I

Required Preliminary Data: Worksheet Items 1-5, 12-15

Use of the Nomograph

This nomograph is used to determine the magnitude of potential energy and load savings from daylighting relative to a base-case electrical lighting system in which no daylighting is used. Note that peak load reduction assumes the peak occurs at the peak daylighting time. However, this may not always be true for buildings with unusual loads and/or occupancy schedules.

POTENTIAL FRACTIONAL ENERGY SAVINGS

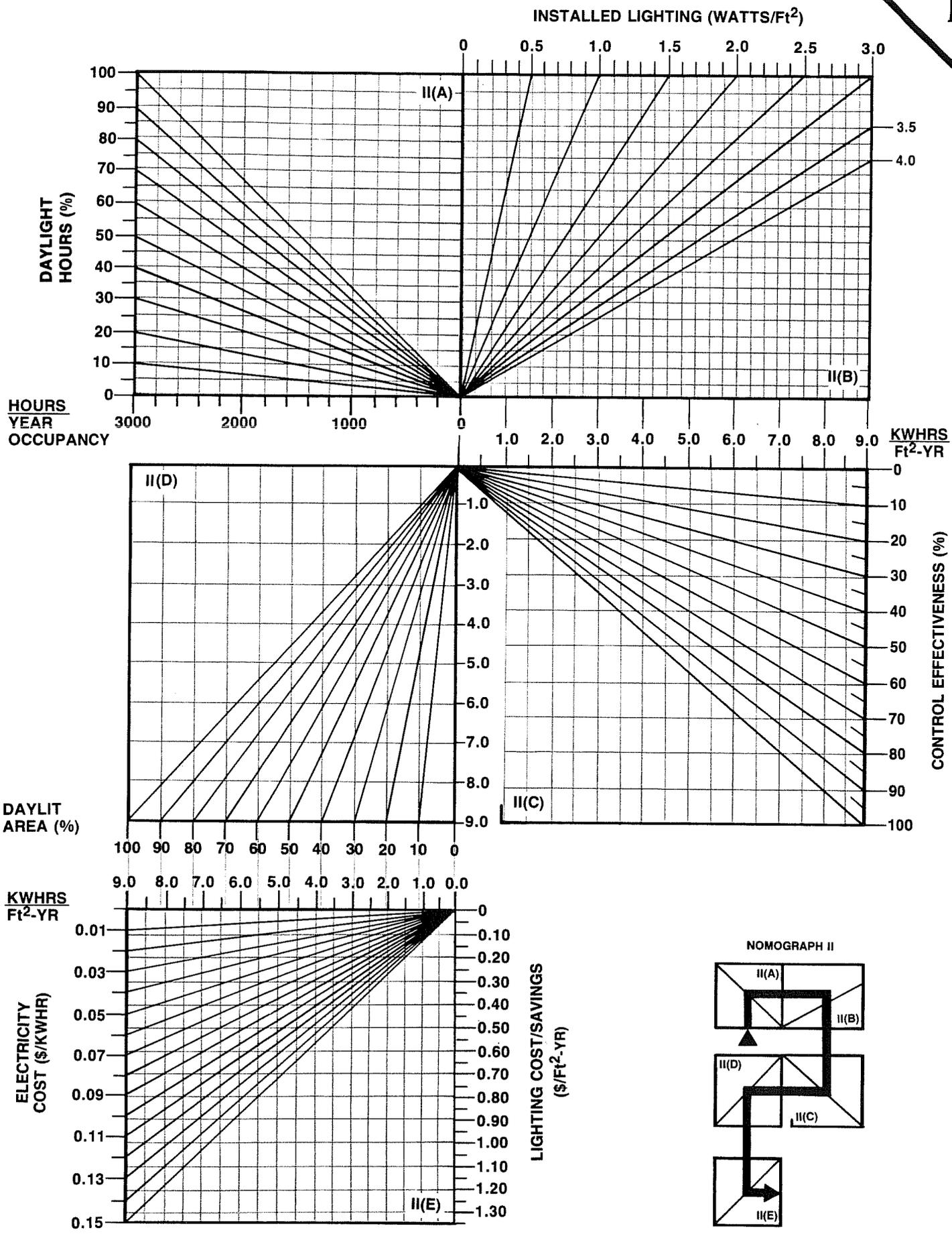
1. Enter the nomograph at the upper right-hand scale. Find the place along that vertical scale ("Daylight Hours") corresponding to the value designated in Item 12. This value represents the average daylight hours of occupancy as a percent, given the latitude of the building site and the occupancy pattern.
2. Move horizontally to the left, stopping at or near the appropriate diagonal line labeled "Daylit Areas (%)", Item 13. This number is the percent of the floor area that is daylit, as a function of total area and configuration of each floor.
3. Move vertically down from that point toward the diagonal line labeled "Control Effectiveness" in the segment of the nomograph marked "I-B". Stop at the value of control effectiveness taken from Item 14.
4. Finally, move horizontally to the right to intersect the vertical scale at the lower right entitled "Energy Savings Due to Daylight (%)." Note the point of intersection, and record that value as Item 16.
5. Repeat steps 1-4 using different building massings, floor layouts, lighting control systems, and so forth. Making systematic changes in each of the design variables will illustrate which factors have the greatest influence on total daylighting savings.

POTENTIAL FRACTIONAL POWER (ELECTRICAL LOAD) SAVINGS

1. Retrace steps 1 and 2 described above. Then move vertically down to the diagonal lines designated "Dimming Factor (%)." Stop at or near the line corresponding to the value of Item 15, which depends upon the lighting control hardware and load management strategy. It generally will be greater than the similar value selected in Item 14, which is an annual reduction factor. A reasonable value for the dimming factor is 80% of the maximum lighting power

reduction. Be sure to use the percent reduction in power, not light output, since these may have different values.

2. Move horizontally to the right to intersect the vertical scale labeled "Daylight Peak Load Savings (%)." Record the value at that point as Item 17, which is the percent of total electrical lighting peak load that the daylight system would save. It generally will be higher than Item 16, which is the savings in annual energy consumption.
3. Repeating steps 1-4 with design variations will quickly indicate which design choices have the greatest overall impact. Note that these results are percent savings relative to the electric lighting load only.



ANNUAL ENERGY USE AND COST FOR DAYLIGHTED VS. NON-DAYLIGHTED BUILDINGS

NOMOGRAPH II

Required Preliminary Data: Worksheet Items 1-8, 12-15

Use of the Nomograph

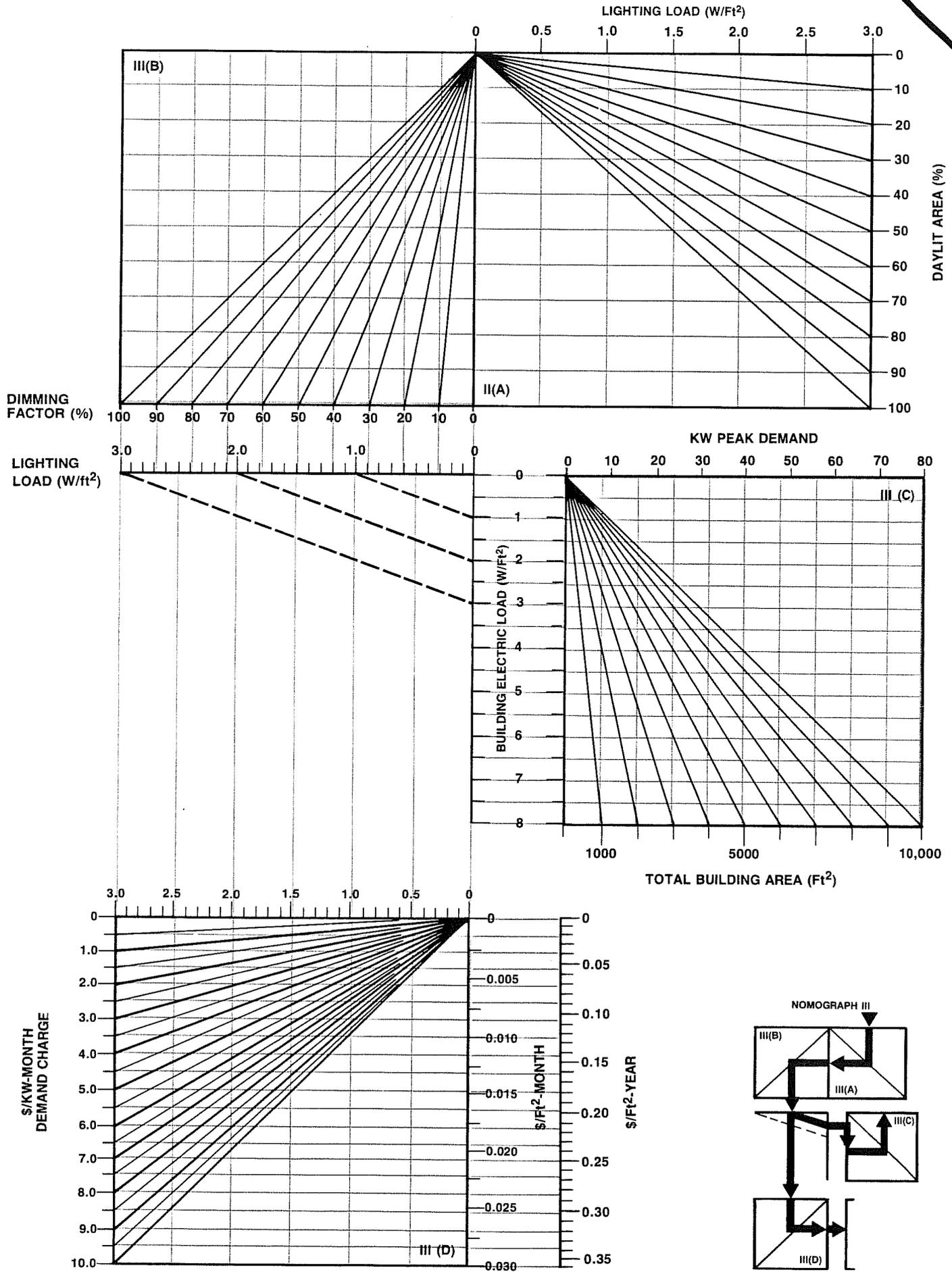
This nomograph is used to determine (1) annual energy consumption and associated costs for an electrically lighted building and (2) the potential energy and cost savings that will accrue if daylighting strategies are utilized.

LIGHTING ENERGY CONSUMPTION AND COST IN A NON-DAYLIGHTED BUILDING

1. Enter the nomograph at the upper left-hand horizontal scale entitled "Hours/Year Occupancy." Use the appropriate number of hours per year that the building is occupied, Item 6.
2. Move vertically upward, stopping at the intersection with the diagonal line labeled "100% Daytime Occupancy."
3. From that point, move horizontally to the right into nomograph segment II-B, stopping at or near the correct diagonal line labeled "Installed Lighting Load", Item 7. If installed lighting load varies within the building, use an area-weighted average of installed watts per square foot (W/ft^2) for each building zone. Include all task lighting as well as general lighting loads.
4. Move down vertically to segment II-C, stopping at the intersection with the diagonal line labeled "100% Control Effectiveness." Note: If some building zones (e.g., conference room, cafeteria) have scheduled occupancies that are less than the occupied hours selected in step 1 above, do not include them in this analysis; treat them instead in a separate analysis using these same procedures.
5. Move horizontally to the left to segment II-D, stopping at the line labeled "100% Daylit Area."
6. Move down vertically from that point to the horizontal scale of segment II-E marked " kWh/ft^2 -yr." The value at this intersection is the average lighting energy consumption in kilowatt-hours per year for each square foot of building. Record this number as Item 18.
7. Continue moving down vertically, stopping at or near the appropriate diagonal line marked "Electricity Cost, $\$/kWh$ ", Item 8. For initial estimates use the average cost per kWh for buildings of similar size and type.
8. From this point move horizontally to the right until intersecting the vertical scale marked "Light Cost/Savings." This value, in $\$/ft^2$ /building-yr, is the annual lighting cost to electrically light each square foot of building. Record it as Item 19.

ENERGY AND COST SAVINGS IN A DAYLIGHTED BUILDING

1. Enter the nomograph at the upper left-hand horizontal scale entitled "Hours/Year Occupancy." Use the number of hours per year the building is occupied.
2. Move upward vertically, stopping at or near the appropriate "Daytime Occupancy, %", Item 12.
3. Move horizontally to the right to segment II-B, stopping at or near the appropriate diagonal line "Installed Lighting Load", Item 7.
4. Move down vertically to segment II-C, stopping at or near the correct line entitled "Control Effectiveness", Item 14.
5. Move horizontally to the left to segment II-D, stopping at or near the appropriate diagonal line marked "Daylit Area, %", Item 13.
6. Move down vertically to the horizontal scale in segment II-E labeled "kWh/ft²-yr." The value at this intersection is the energy saved in kilowatt-hours per year for each square foot of the building. Record this value as Item 20.
7. Continue moving down vertically and stop at or near the correct diagonal line labeled "Electricity Cost, \$/kWh", Item 8.
8. Finally, move horizontally to the right, intersecting the vertical scale labeled "Light Cost/Savings (\$/ft²-yr)". This value represents the annual savings in dollars per square foot of building that a reasonably good daylighting design can provide.
9. To find the potential daylighting energy savings for the entire building, multiply the value above by the building area Item 9. Record the result as Item 22.



LOAD MANAGEMENT WITH DAYLIGHTING

NOMOGRAPH III

Required Preliminary Data: Worksheet Items 3-5, 7, 9-11, 13, 15

Use of the Nomograph

This nomograph is used to determine (1) the contribution a building's lighting system makes to peak electrical load and its associated cost, and (2) the potential load management and cost savings possible from effective use of daylighting strategies.

LIGHTING ELECTRICAL DEMAND AND COST IN A NON-DAYLIGHTED BUILDING

In this case the peak electrical load is estimated without daylighting credits, and the resultant demand charge is calculated. The procedure involves estimating all electrical loads in the building (or zone) and can be repeated for a typical summer and winter month in order to account for seasonal demand charges.

1. Because this is the non-daylighted case, enter the nomograph at the middle left-hand, horizontal scale labeled "Lighting Load (W/ft^2)," just below nomograph segment III-B; use the value from Item 7. Include power consumption for both task and ambient lighting. If the levels differ significantly throughout the building, use an area-weighted average or calculate results separately for each zone.
2. Move down diagonally to the right, following the W/ft^2 value parallel to the broken lines leading to the vertical scale labeled "Building Electrical Load (W/ft^2).". Move down the scale in order to add to this value the net electrical load in watts per square foot that results from all non-lighting electrical use in the building: air conditioning and heating, fans, office equipment and other miscellaneous loads. The specific load selection should be based upon the type of HVAC envisioned and the season being considered.
3. Move horizontally to the right into segment III-C, stopping at or near the appropriate diagonal line marked "Total Building Area (ft^2)" (Item 9). Move up vertically to the intersection with the horizontal scale labeled "KW Peak Demand" and record the value as Item 23. Note: if the total building area is more than $10,000 ft^2$, use a multiplier (e.g., 5, 10, 50) to obtain the correct result. For a $70,000-ft^2$ building, for example, use the " $7000 ft^2$ " line and multiply the final value by 10.
4. Now return to the point on the "Lighting Load" described in step 1. Move down vertically to segment III-D, stopping at or near the appropriate diagonal line labeled "\$/KW-Month Demand Charge" (Item 11). The appropriate demand charge should be obtained from local utility rates based upon the building peak demand determined in the previous step.

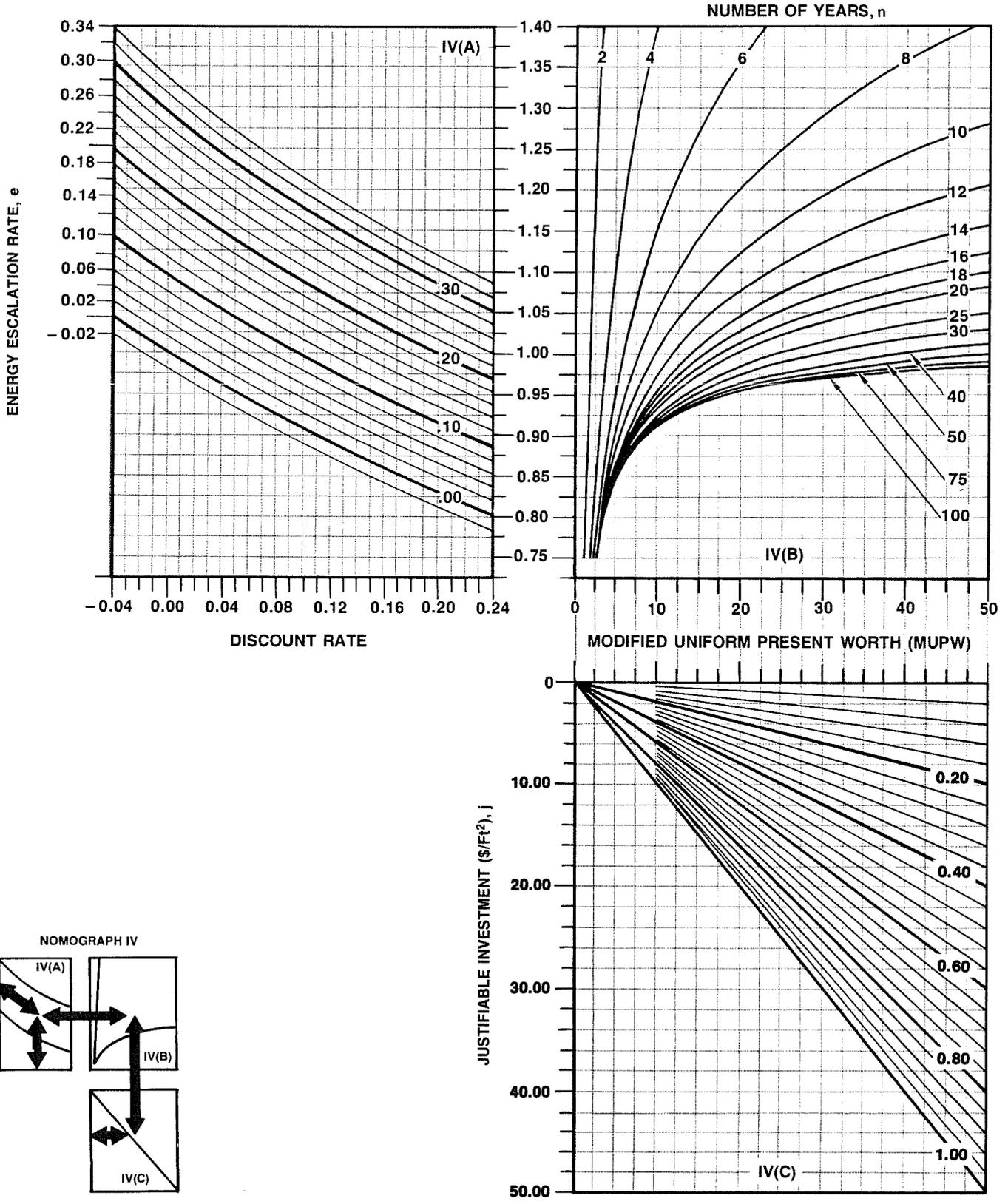
5. Move horizontally to the right until intersecting the first vertical scale marked "\$/ft²-Month." Record this value as Item 24. Continue moving to the right until intersecting the second vertical scale marked "\$/ft²-Year," recording the value as Item 25. These figures are the demand charges for electric lighting per month and per year in the non-daylighted building.

LIGHTING ELECTRIC REDUCTIONS AND COST SAVINGS IN A DAYLIGHTED BUILDING

The procedure is now repeated while incorporating several additional factors to reflect the use of lighting controls in daylighted buildings. Reductions in peak demand and resultant cost savings are calculated.

1. Enter the nomograph at the upper right-hand horizontal scale labeled "Lighting Load (W/ft²)", Item 7.
2. Move down vertically, stopping at or near the appropriate diagonal line marked "Daylit Area (%)", Item 13.
3. Move horizontally to the left to segment III-B, stopping at or near the diagonal line labeled "Dimming Factor (%)", Item 15.
4. Move down vertically to the line intersecting the horizontal scale labeled "Lighting Load", Item 7. Mark this point in order to return to it in step 7 below.
5. Move diagonally down to the right, parallel to the broken lines, until intersecting the vertical scale labeled "Building Electrical Load (W/ft²)."
6. Move horizontally to the right, stopping at or near the correct diagonal line corresponding to the "Total Building Area", Item 9. If the building area is larger than 10,000 ft², use a multiplier as explained in step 3 in the non-daylighted case described above.
7. Move up vertically to the scale marked "KW Peak Demand," and record it as Item 26. This is the peak demand reduction from the daylighting system. Now return to the horizontal scale labeled "Lighting Load" and move to the point marked in step 4 above.
8. Move all the way down vertically to nomograph segment III-D, stopping at or near the diagonal line representing the "\$/KW-Month Demand Charge", Item 11. This is obtained using the peak demand calculated in step 7 and the local utility rate structure.
9. Move to the right horizontally, intersecting the two vertical scales that indicate "\$/ft²-Month" and "\$/ft²-Year," the savings in demand charges per month and per year as a result of daylighting. Record these values as Items 27 and 28, respectively.

Note: The \$/ft²-year scale is simply twelve times the value on the monthly scale. Depending on location and utility rate structures, the monthly peak load savings should only be credited for those months in which the rate applies.



XBL 8211-4945

JUSTIFIABLE INVESTMENT IN DAYLIGHTING STRATEGIES

NOMOGRAPH IV

Required Preliminary Data: Worksheet Items 9, 22, 28, 29

Use of Nomograph

Building designs that maximize use of daylighting will generally require additional investment in lighting and fenestration controls. The purpose of this nomograph is to estimate the justifiable investment in daylighting strategies based upon (1) estimates of costs/savings for electrical energy and peak load as determined from Nomographs II and III, and (2) the investment criteria of the building owner or operator. This nomograph can be used in a number of ways as explained below. Note that non-energy issues may influence the decision: aesthetics, lighting quality, additional rental value of floor space having windows, reduced dependence on mechanical systems and non-renewable energy sources, etc. If an economic value ($\$/\text{ft}^2\text{-yr}$) can be assigned to these factors, they can be accounted for in the nomograph. They can also be considered as a modifier to the results derived from the nomograph. Note also that this analysis does not account for reductions or increases in heating/cooling loads. The notes following discussion of cases provide references for more detailed economic analyses. The total annual savings (Item 29) is the sum of daylighting energy savings (Item 21) and daylighting demand saving (Item 28).

SIMPLE PAYBACK CALCULATION

The simplest decision-making criterion frequently will be the desire for a relatively fast payback of investment (typically two to five years). Determining the justifiable investment in daylighting design then follows quickly from a four-step calculation. (Nomograph IV is not used in this case.)

1. Determine s , total annual savings ($\$/\text{ft}^2$) in energy and demand (Item 29), and any other factors to be considered.
2. Determine the maximum acceptable payback period, n years.
3. Maximum justifiable dollar investment = $(s)(n)$, $\$/\text{ft}^2\text{-building}$.
4. Multiply by the total building area to determine the total justifiable dollar investment. Note that this sum probably will not be spent on the entire building but only in daylighted zones.

OTHER INVESTMENT CRITERIA

A variety of other decision-making criteria and economic factors may be utilized. Electric energy prices will generally escalate with time, increasing the magnitude of future savings. The return on alternative investments, or discount rate, will reduce the present value of apparent future savings. Depending upon the investment criteria, one might calculate (1) savings over the life cycle of a particular investment, (2)

the time required to pay back an investment, or (3) the rate of return on investments in energy conservation. Common to all these calculations is the requirement that future costs or savings be converted to an equivalent present worth. The calculation technique used in this nomograph is based upon a modified uniform present worth factor ("MUPW" or "m").

CASE 1: MAXIMUM JUSTIFIABLE INVESTMENT GIVEN DESIRED PAYBACK PERIOD

This calculation determines the maximum investment, or first cost, that is justifiable based upon projected savings and a given payback period. It includes the discounted value of future savings and the effects of escalating energy costs.

1. Enter the nomograph at the horizontal scale labeled "Discount Rate," nomograph segment IV-A. From the point corresponding to the discount rate, "i," Item 33, move up vertically, stopping at or near the appropriate curve representing "e," energy cost escalation rate, Item 34.
2. From that point of intersection move horizontally to the right into segment IV-B, stopping at or near the curve having a value "n," the desired payback period in years, Item 32.
3. Move down vertically until crossing the horizontal scale labeled "Modified Uniform Present Worth." The value of this factor, when multiplied by the first-year savings, becomes the maximum justifiable investment.
4. Continue to move down vertically from the present worth factor into segment IV-C, stopping at or near the diagonal line that represents the "First-Year Savings ($\$/ft^2$)", Item 31.
5. Move horizontally to the left to intersect the vertical scale "Justifiable Investment ($\$/ft^2$).". Multiply this value by the area of the building, Item 9 to calculate the total justifiable dollar investment, Item 30. Note that this sum generally will not be spent throughout the building but more likely on lighting controls in the perimeter zone and on glare and sun controls for glazed areas.

CASE 2: MINIMUM SAVINGS REQUIRED TO JUSTIFY A GIVEN INVESTMENT

This case is the inverse of Case 1. Here the size of the initial investment in energy conservation is given, and we want to determine the first-year savings necessary to justify that investment.

1. Given a discount rate, energy cost escalation rate, and payback period, follow steps 1-3 described in Case 1 above. Mark that value along the "Modified Uniform Present Worth" scale.
2. Find the value (in $\$/ft^2$) of the initial investment on the left-hand vertical scale of segment IV-C (labeled "Justifiable Investment").

3. Move horizontally to the right from that point and down vertically from the "MUPW" value until the two lines intersect. The point of intersection gives the required value of first-year energy savings by interpolation between the values of the two nearest diagonal lines. Record the value as Item 31.

Case 3: REQUIRED PAYBACK PERIOD GIVEN FIRST-YEAR SAVINGS AND CONSERVATION INVESTMENT

This case is similar to cases 1 and 2. We are given the annual savings and available investment figures and must find the number of years required to pay back that investment.

1. Enter the nomograph at the upper left-hand scale labeled "Discount Rate", Item 33. Move up vertically until intersecting the curve corresponding to the energy escalation rate.
2. From that point move horizontally to the right until intersecting the vertical scale (with the range 0.75 to 1.40). Mark that value, which will be used in step 5 below.
3. Find the value of the initial investment in the vertical "Justifiable Investment" scale Item 30, segment IV-C. Move horizontally to the right, stopping at or near the appropriate diagonal line representing "First-Year Savings", Item 31.
4. Move up vertically to the horizontal scale of segment IV-B, "Modified Uniform Present Worth."
5. Continue to move up vertically from the "MUPW" scale. Find the value from step 2 along the vertical scale, and move horizontally from that point to the right until the two lines intersect in segment IV-B. The required payback period is found by interpolating between the two curved lines nearest the intersection point, Item 32. If the intersection point lies below the lowest curve marked "100," the payback period is greater than 100 years.

CASE 4: RATE OF RETURN ON INVESTMENT

The rate of return on initial investment is equivalent to the discount rate, which was a given in Case 3. This calculation is similar to Case 1 except that we reverse the movement through the nomograph.

1. Follow steps 3 and 4 described in Case 3 above, arriving at a point along the horizontal "Modified Uniform Present Worth" scale.
2. Move up vertically, stopping at the appropriate curve in segment IV-B which represents the given payback period, Item 32.
3. Move horizontally to the left into segment IV-A until intersecting the curve corresponding to the given energy escalation rate, Item 34.

4. Finally, move down vertically to intersect the horizontal scale labeled "Discount Rate." This value is the rate of return on investment, Item 33.

ACKNOWLEDGEMENT

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Energy Research and Development, Building Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098 and the Bonneville Power Administration, Portland, Oregon.

Example Building Specifications

The example building, used to illustrate the four nomographs, has the following specifications. Note that this is the level of detail one needs to make use of the nomographs.

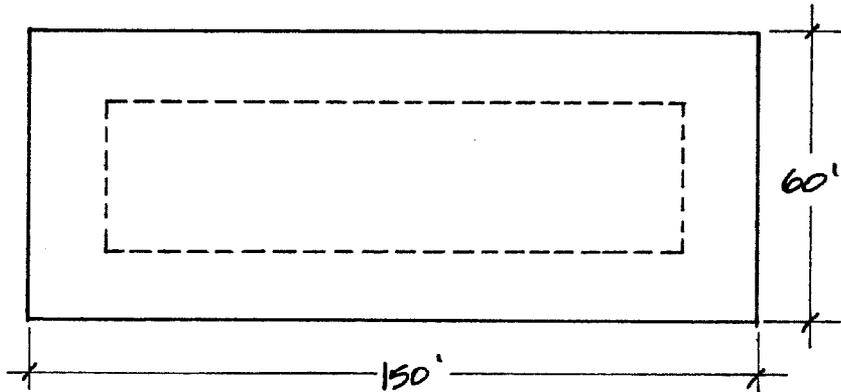
Building type: 45,000 ft² office building.

Annual hours of occupancy: 2500.

Daily occupancy schedule: 8AM - 6PM.

Location: Berkeley, California; 37.5 N. Latitude.

Building shape and dimensions: 5 stories, rectangular; 60' by 150'.



Typical floor-to-ceiling height: 8'-6".

Windows: double-glazing, a horizontal "glass strip" from 3'-0" to 7'-0" above the floor on each level. Glass visible light transmittance is 80%. All four sides of the building have the same type of fenestration.

Lighting controls: continuous dimming is contemplated in the perimeter zone; the maximum dimming factor is 85% reduction in power.

Illumination level: 50 footcandles of general and task lighting.

Installed lighting load: 2.5 watts per square foot.

Non-lighting electrical load: 3.0 watts per square foot.

Electricity cost: average unit cost is \$0.100/kWh.

Peak demand rate: \$1.70/kW-month.

Description of the Example

The following pages illustrate an example of how one uses the worksheet, the supplementary charts (S.1 through S.7) and the nomographs. Under the column marked "Base Case", worksheet Items 1-11 and 15 are taken directly from the building specifications (listed below), or are obtained through a simple calculation. For example, Item 5c, "Side Lighting: Glass Area Fraction" is calculated as follows:

$$\frac{(\text{height of glass})}{(\text{floor ceiling height})} = \frac{4.0 \text{ ft.}}{8.5 \text{ ft.}} = 0.471$$

To find Item 12, use chart S.1 as indicated. Item 13, "Total Daylit Area (%)", can be obtained as shown with chart S.6 for a 15 foot daylight zone depth, or by direct calculation. The value selected for "Control Effectiveness", Item 14, is taken off chart S.4 for "SIDE LIGHTING, CONTINUOUS DIMMING".

A few case studies (Case 1-4) are worked out to show how one can vary design and other parameters and keep track of the results.

Case 1: Variation in the economic analysis used in Nomograph IV, where the maximum justifiable investment is fixed, and the minimum first year saving is determined.

Case 2: Change in the lighting control type from continuous dimming to one-step (on/off) switching.

Case 3: A change back to continuous dimming, and glass changes from clear to reflective, TVIS = .14.

Case 4: Same as Base Case, with the addition uniformly spaced, diffusing dome skylights over the interior zone (previously non-daylighted portion) of the top floor.

These are the kind of variations one might test and compare. Page 2 of the worksheet, placed at the end of the nomograph examples, has each case worked through to the end.

Notice that "Justifiable Investment", Item 30, and "First Year Savings", Item 31, may be expressed in $\$/\text{ft}^2$ or $\$/\text{building}$. On the example worksheet, a slash is used so that these items can be listed both ways. An alternative way of quantifying these items with side lighting is in $\$/\text{linear foot}$ of perimeter wall. Much of the investment attributable to daylighting would be for solar controls and lighting controls, the cost of which may lend itself to $\$/\text{linear foot}$ of window wall.

The worksheet is intended as a guide and as a record of calculations. After a little practice, you may wish to create your own worksheet taking into account your own particular evaluation technique.

Project Title: EXAMPLE BUILDING Date: 1/19/84 Prepared By: M. GABEL

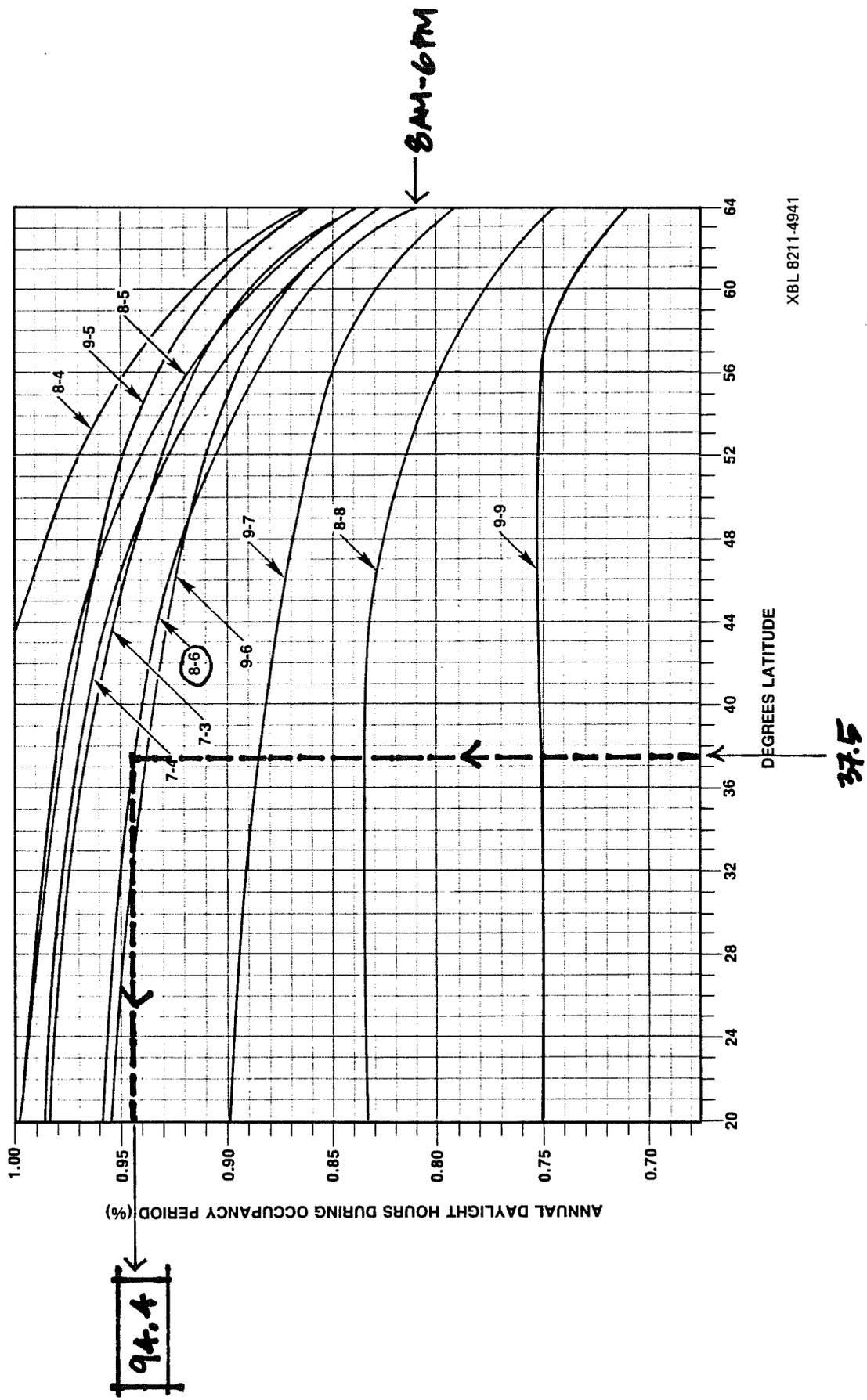
Description of Study / Remarks: 'BASE CASE' (ILLUSTRATED IN EXAMPLE CHARTS & NOMOGRAPHS) AND OTHER CASE STUDIES

Input (i) or output (o) value for the specified nomograph or chart.	Work-sheet Item No.							Description of Worksheet Item	Base Case	Case 1.	Case 2.	Case 3.	Case 4.
	Charts S.1 - S.7	1	2	3	4	5	6						
I	II	III	IV	1	1	1	1	1	MINIMUM 1ST YE-SAVING	ON/OFF	ON/OFF	REFLECTIVE, 5' GLASS	... PLUS SKYLIGHTS
									77.5				
									8AM-6PM				
									9000				
									2.5:1				
									DIMMING	ON/OFF	DIMMING		
									50				
									.471			.588	OF TOP HU INCREASE FACTOR
									(NONE)				.05
									.80			.14	.80
									(NONE)				.56
									2500				
									2.50				
									0.100				
									45000				
									3.00				
									1.70				
									94.4				
									60.0				68.0
									64.0	61.0	38.0		65.9 *
									85				

* WEIGHTED AVERAGE CALCULATION = (.882) (66.5) + (61.0) = (65.9)

(SIDE LIGHTING - CONTROL EFFECTIVENESS FOR TOTAL DAYLIGHTED #) (TVIS = .80, AREA = .588) + (TOP LIGHTING - CONTROL EFFECTIVENESS FOR TOTAL DAYLIGHTED #) (TVIS X WELL FACTOR = .50, AREA = .05)

ANNUAL DAYLIGHT HOURS

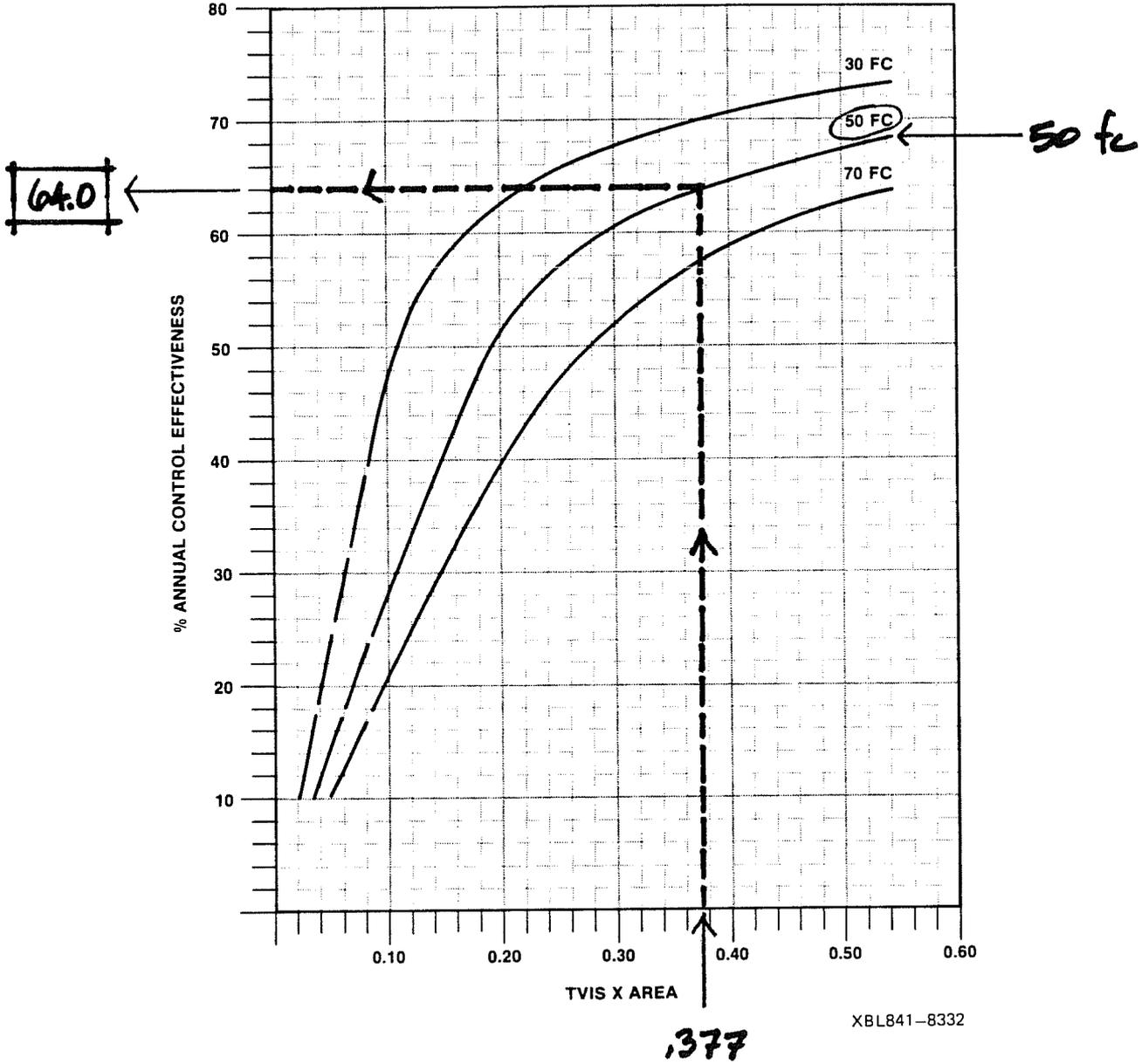


XBL 8211-4941

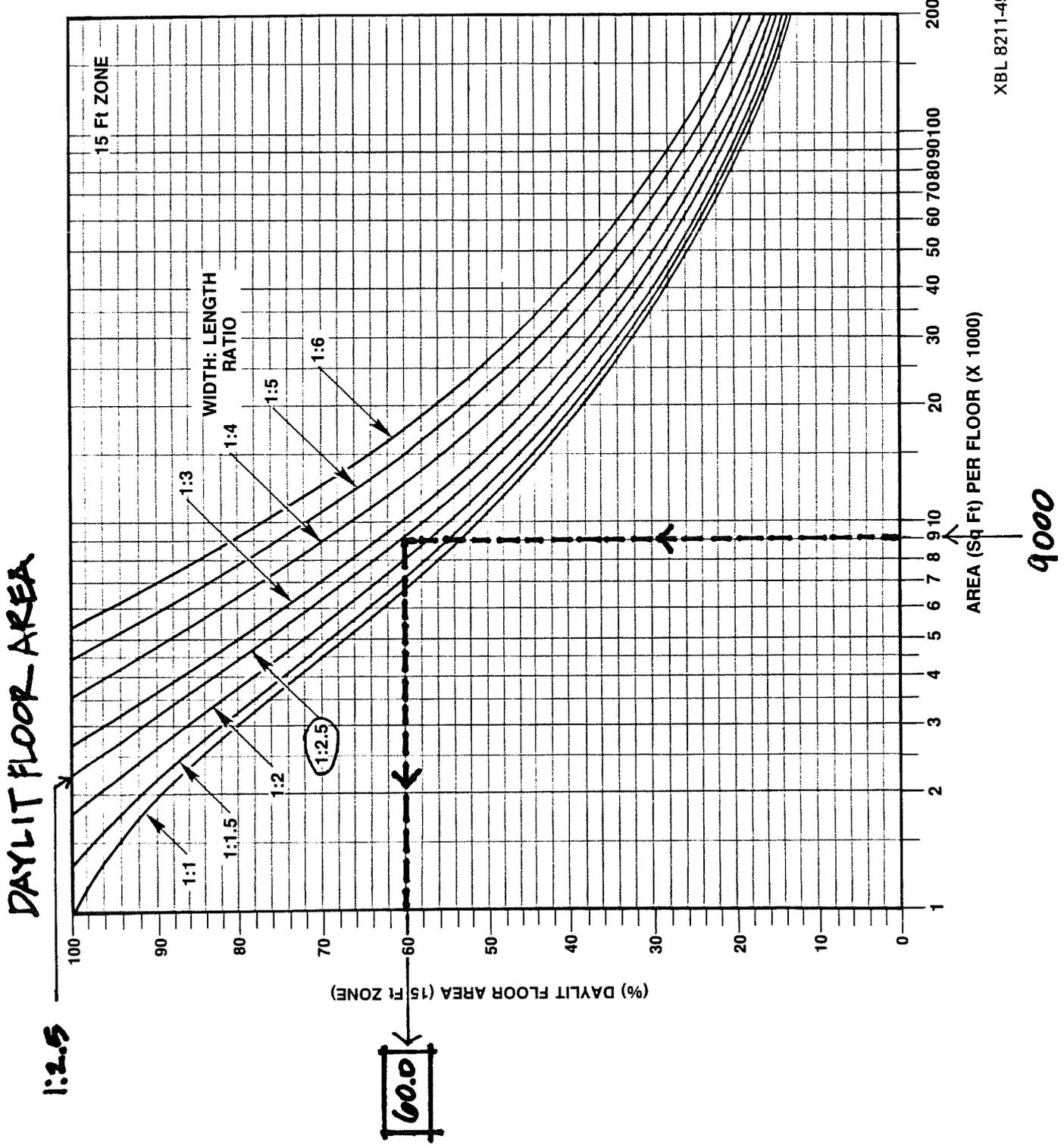
ANNUAL CONTROL EFFECTIVENESS

SIDE LIGHTING

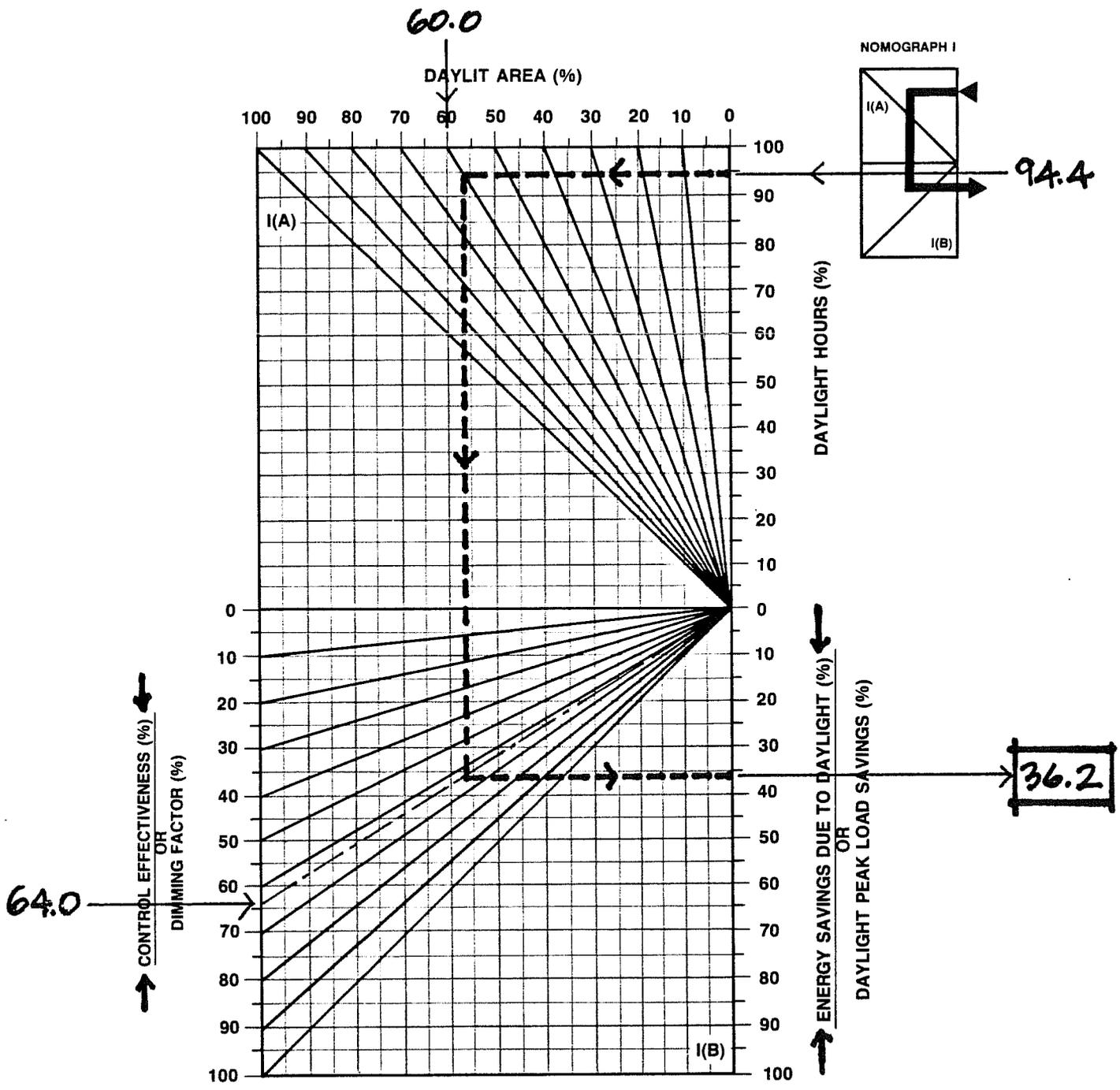
CONTINUOUS DIMMING LIGHTING CONTROL



XBL 8211-4938

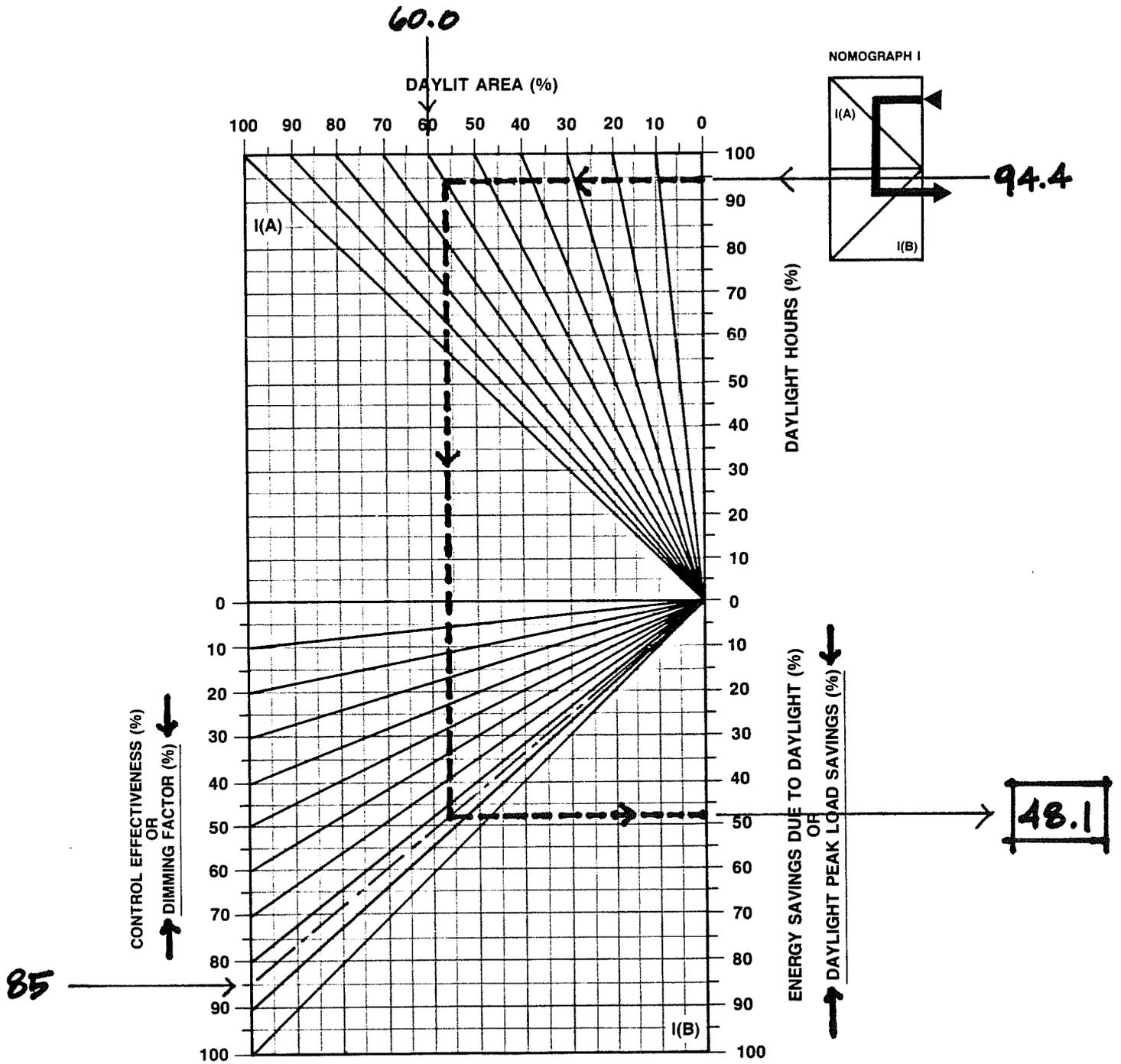


POTENTIAL FRACTIONAL ENERGY SAVINGS



XBL 8211-4948

POTENTIAL FRACTIONAL POWER SAVINGS



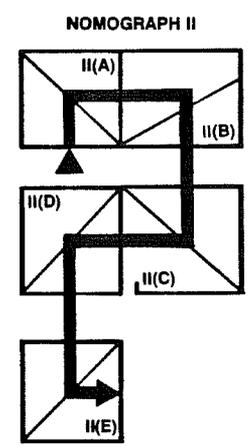
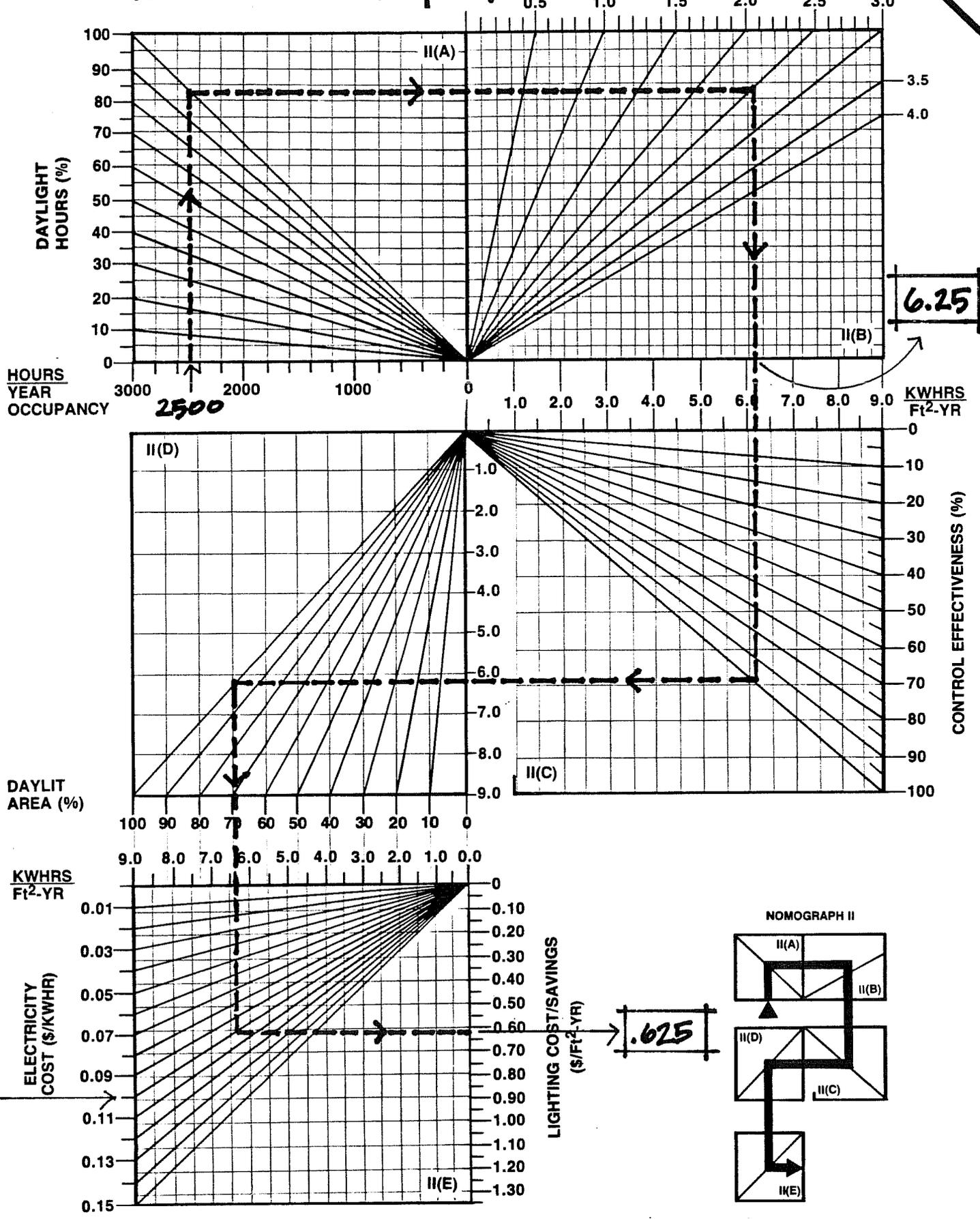
XBL 8211-4948

NON-DAYLIGHTED BUILDING: ANNUAL ENERGY USE & COST

II

2.5

INSTALLED LIGHTING (WATTS/Ft²)



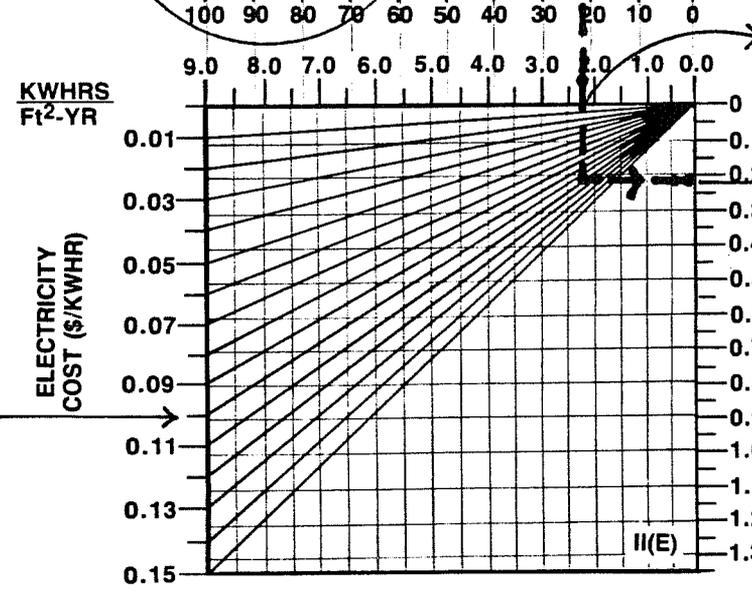
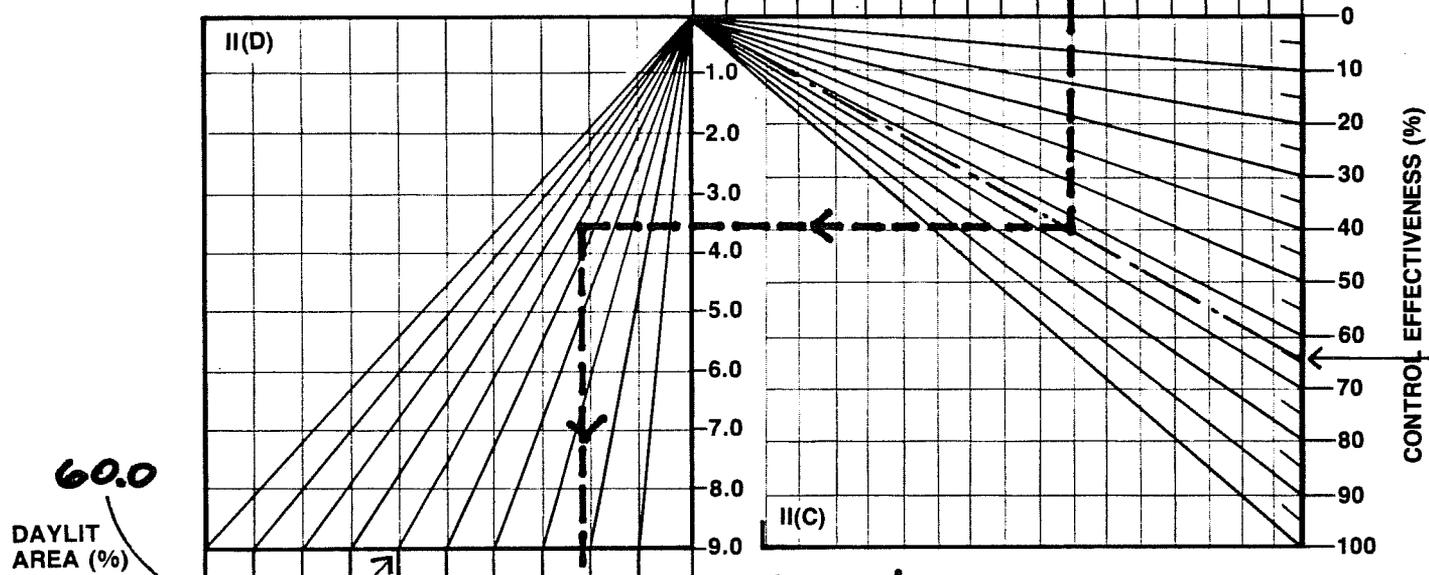
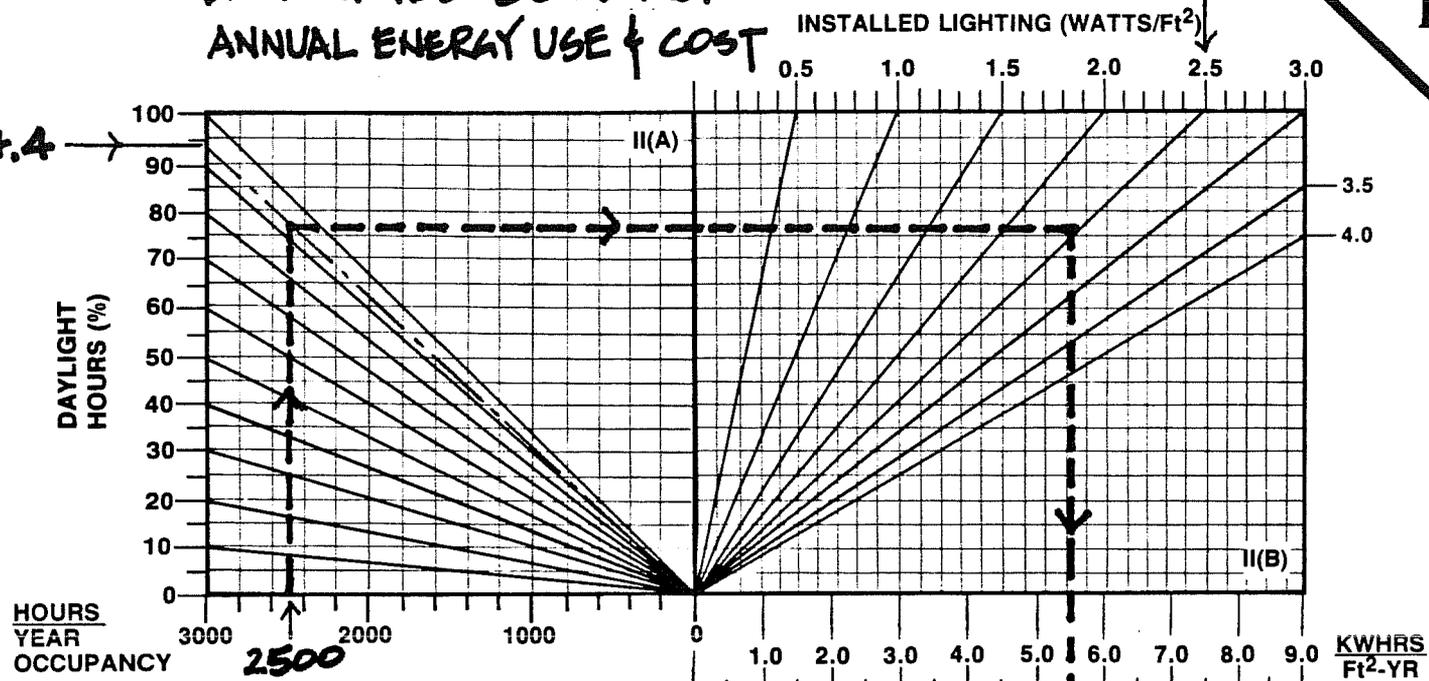
XBL 8211-4947

DAYLIGHTED BUILDING: ANNUAL ENERGY USE & COST

2.5

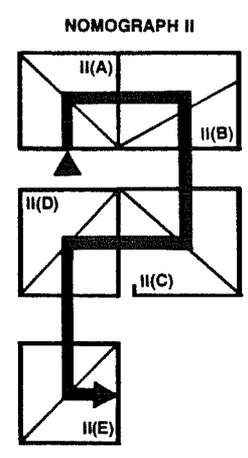
II

94.4



2.27

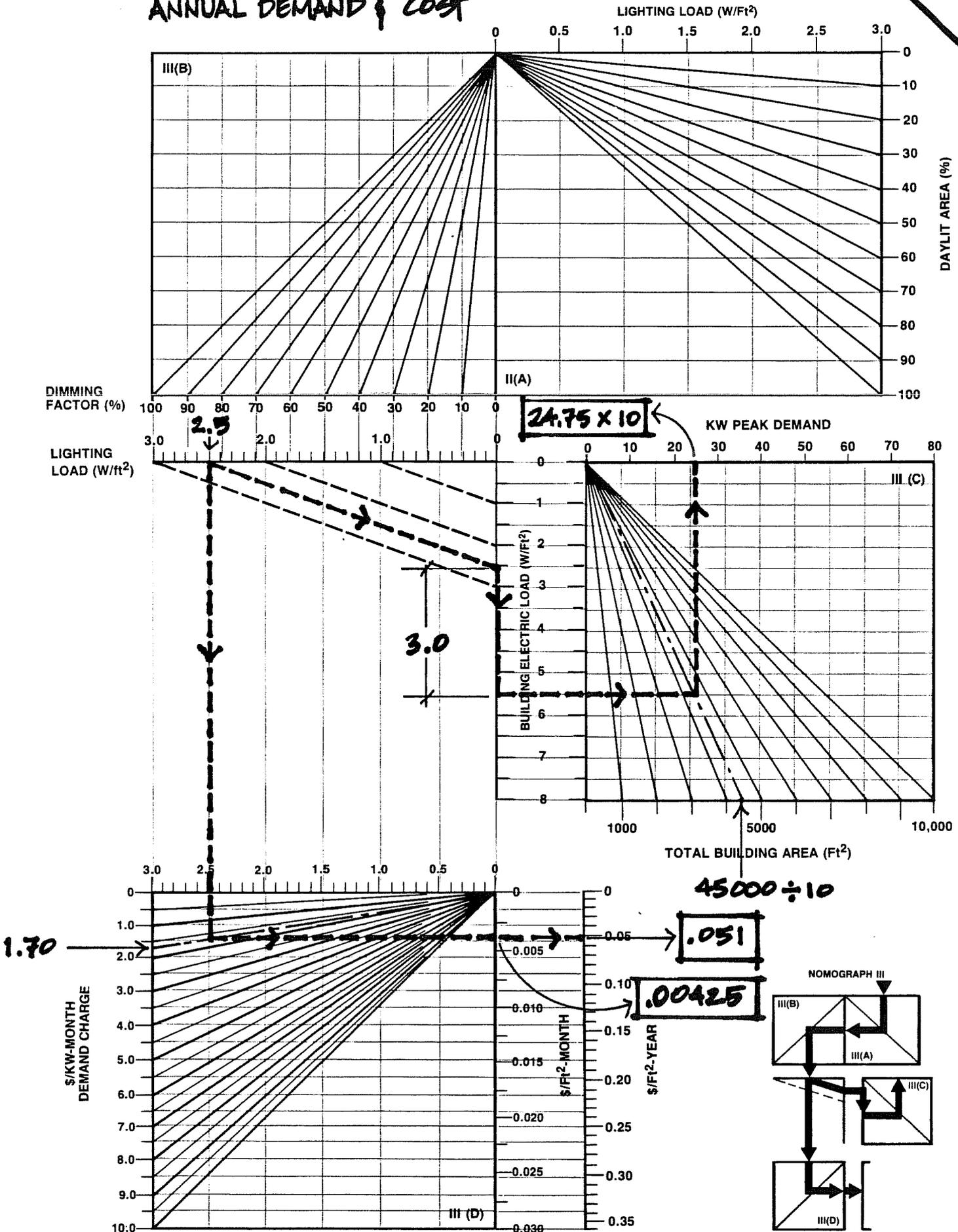
0.227



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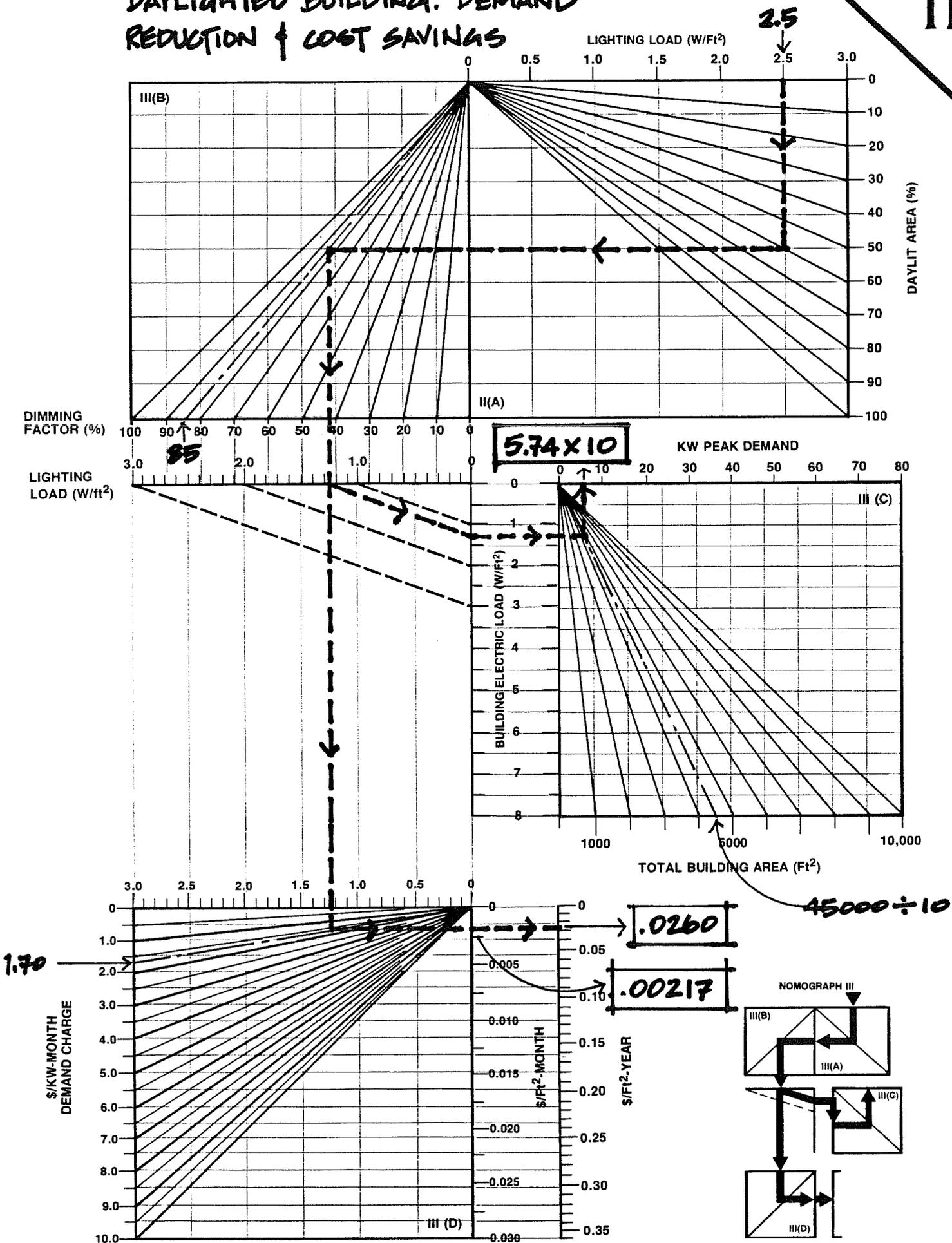
NON-DAYLIGHTED BUILDING: ANNUAL DEMAND & COST

III



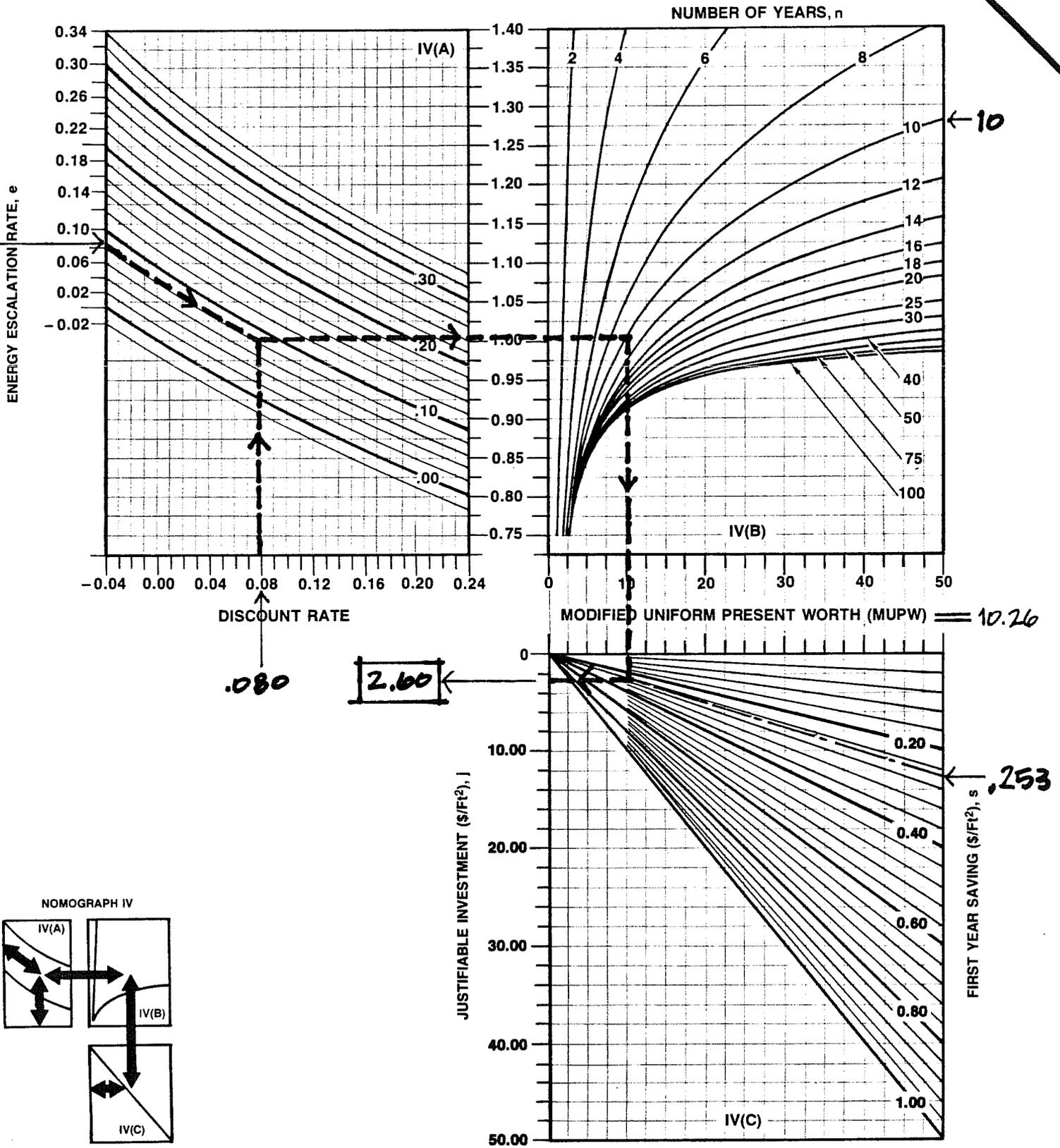
DAYLIGHTED BUILDING: DEMAND REDUCTION & COST SAVINGS

III

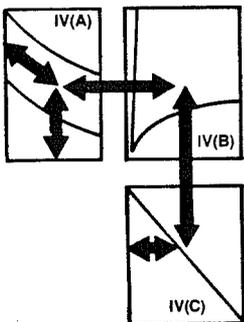


MAXIMUM JUSTIFIABLE INVESTMENT

IV



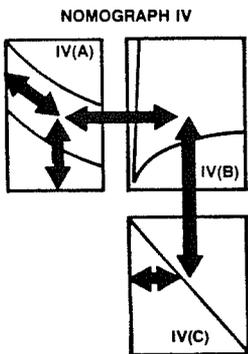
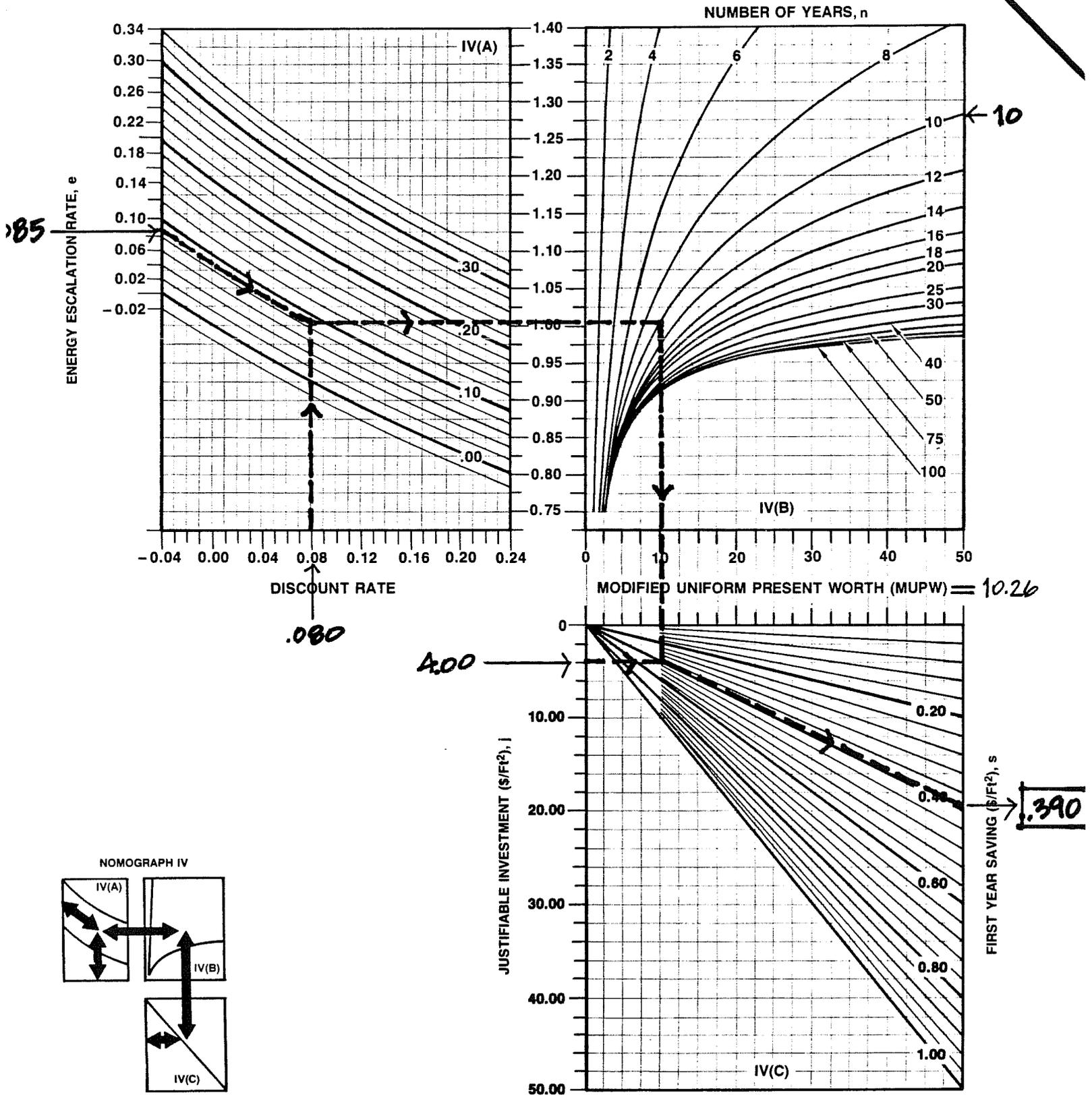
NOMOGRAPH IV



XBL 8211-4945

MINIMUM FIRST YEAR SAVING

IV



XBL 8211-4945

Project Title EXAMPLE BUILDING Date 1/19/84 Prepared By M. GABEL Page 2

Description of Study / Remarks 'BASE CASE'... AND OTHER CASE STUDIES.

Input (i) or output (o) value for the specified nomograph or chart.	Nomographs							Work-sheet Item No.	Description of Worksheet Item	Base Case	Case 1.	Case 2.	Case 3.	Case 4.
	I	II	III	IV	1	2	3							
o								16	Annual Energy Savings Due to Daylight (%)	BASE	MINIMUM 1ST YR. SAVINGS	ON/OFF	REFLECTIVE, 5' GLASS	SKYLIGHTS
o								17	Daylight Peak Load Savings (%)	36.2	→	34.6	21.5	42.3
o								18	Non-Daylit Lighting ₂ Energy Consumption (kWh/ft ² -year)	48.1	→	→	→	54.6
o								19	Non-Daylit Lighting Cost (\$/ft ² -yr)	6.25	→	→	→	→
o								20	Daylighting Energy Consumption Saving (kWh/ft ² -year)	.625	→	→	→	→
o								21	Daylighting Saving (\$/ft ² -year)	2.27	→	2.16	1.34	2.64
o								22	Annual Daylighting Savings (\$/building)	.227	→	.216	.134	.264
o								23	Non-Daylit Peak Demand (kW)	10 200	→	9 700	6 000	11 900
o								24	Non-Daylit Monthly Demand Charge (\$/ft ² -month)	247.5	→	→	→	→
o								25	Non-Daylit Annual Demand Charge (\$/ft ² -year)	.00425	→	→	→	→
o								26	Daylit Peak Demand Saving (kW)	.051	→	→	→	→
o								27	Daylit Monthly Demand Saving (\$/ft ² -month)	57.4	→	→	→	65.0
o								28	Daylit Annual Demand Saving (\$/ft ² -year)	.00217	→	→	→	.00246
o								29	Total Annual Savings (\$/ft ² -year)	.0260	→	→	→	.0295
o								30	Justifiable Investment (\$/ft ² or \$/building), j	2.60	4.00	2.48	1.60	3.02
o								31	First Year Saving (\$/ft ² or \$/building), s	11 700	100 000	112 000	74 000	136 000
o								32	Payback Period (years), n	.253	.390	.242	.160	.294
o								33	Rate of Return on Investment or Discount Rate, i	10	→	→	→	→
o								34	Energy Escalation Rate, e	.080	→	→	→	→
o									Energy Escalation Rate, e	.085	→	→	→	→

Appendix A: Assumptions

1. The curves predicting annual control effectiveness (charts S.3, S.3A, S.4 S.4A) are derived from analysis using DOE-2.1B, a computer program that contains an hour-by-hour daylighting simulation model. The data for side lighting in S.3 and S.4 were calculated for each orientation but are shown in the charts as averages of all orientations. The toplighting results in S.3A and S.4A assume the use of diffusing domed skylights. The assumption of "average orientation" of glazing may appear to be simplistic. However, study of the data indicates the assumption is quite reasonable. At 70 fc, with one-step (on/off) switching, the annual performances of south and north glazing diverge no more than 2-4% from the average annual performance of all four orientations.
2. The results assume that a simple interior shade or blind system is utilized when window glare exceeds specified values or when solar gain creates thermal discomfort for an occupant.
3. The analysis is based on the use of a standard 8 am - 6 pm office occupancy lighting schedule and was generated for a high latitude, predominantly overcast city (Seattle). For most other U.S. locations these values will be conservative.
4. The daylighting model assumes the use of a one-step (on/off) lighting control (chart S.3, S.3A) or continuous dimming system (chart S.4, S.4A). The dimming system operates linearly between 100% light/100% power and 0% light/10% power.
5. The standard office used in the DOE-2 analysis for side lighting was 8'-6" high, 10' wide, and 15' deep; the lighting control (reference) point was located at a depth of 10 from the window wall and work-plane height was 2'-6". Reflectances of internal surfaces are: ceiling, 70%; walls, 50%; floor, 30%.

For top lighting uniformly spaced square diffusing dome skylights, were assumed. The reference point was located at the crossing ("X") of imaginary diagonal lines intersecting the centers between the skylights. The uniform light distribution spacing of skylights should not be wider than 1 1/2 times floor-to-ceiling height.

Charts S.5, S.6 and S.7 provide fractional daylighted areas for zone depths of 10, 15, and 20 feet. Savings in the shallower zone would be greater than those indicated in charts S.3 and S.4, while the deeper zone will have lower savings. Data for the 15-foot-deep zone can be used directly for the 20-foot-deep zone if the ceiling height is increased proportionally to 11'-4". With additional supporting calculations and experience, the nomographs can be used for variable zone depths and for more architecturally sophisticated fenestration solutions.

6. For side lighting, daylight illuminance was calculated assuming that the glazing area was be a single horizontal strip above the work-plane (2'-6"), with a horizontal centerline 5'-6" above the floor.

Maximum size glazing extended from the workplane (2'-6") to the ceiling (8'-6").

These assumptions are reasonable ones for an analysis of this type in which the main focus of the daylighting performance is annual energy use. Analysis of a building design whose parameters vary from the values assumed here is not likely to introduce slightly sources of error. Altering fixed parameters might produce significant differences in illumination levels for an instantaneous daylighting calculation method. However, daylighting performance calculated hourly throughout the whole year (assuming a specific electric lighting control and illuminant level) reduces the magnitude of distinctions obtained in instantaneous calculations.

APPENDIX B: Calculation Procedure

The nomographs serve as a graphic means of obtaining information concerning the potential benefits of daylighting. As such, they are a visual calculation method. The direct calculation of values derived through the use of the nomographs, Worksheet Items 16 through 33, can be done instead on a hand calculator or microcomputer. This appendix presents the formulas that are used to find each Item, as well as verbal descriptions of the algorithms.

$$[16] = [12] [13] [14] / 10^4$$

"Annual Energy Savings Due to Daylight (%)" equals "Daylit Hours (%)" times "Daylit Area (%)" times "Control Effectiveness (%)" divided by 10000 (or 10^4). Because each of the values used is a percent and not a fraction, division by 10^4 is required to keep "Annual Energy Savings" a percent.

$$[17] = [13] [15] / 10^2$$

"Daylight Peak Load Savings (%)" equals "Daylit Area (%)" times "Dimming Factor (%)" divided by 100.

$$[18] = [6] [7] / 10^3$$

"Non-Daylit Lighting Energy Consumption (kWh/ft²-yr)" equals "Annual Hours of Occupancy" times "Installed Lighting Load (W/ft²)" divided by 1000. The division accounts for converting watt-hours to kilowatt-hours.

$$[19] = [18] [8]$$

"Non-Daylit Lighting Cost (\$/ft²)" equals "Non-Daylit Lighting Energy Consumption (kWh/ft²-yr)" times "Electricity Cost (\$/kWh)".

$$[20] = [6] [12] [7] [14] [13] / 10^9$$

"Daylighting Energy Consumption Saving (kWh/ft²-yr)" equals "Annual Hours of Occupancy" times "Daylit Hours (%)" times "Installed Lighting Load (W/ft²)" times "Control Effectiveness (%)" times "Daylit Area (%)" divided by 10^9 . The division accounts for the three values that are expressed as percents and the conversion of watt-hours to kilowatt-hours.

$$[21] = [20] [8]$$

"Daylighting Saving (\$/ft²-yr)" equals "Daylighting Energy Consumption Saving (kWh/ft²-yr)" times "Electricity Cost" (\$/kWh).

$$[22] = [21] [9]$$

"Annual Daylighting Savings (\$/building)" equals "Daylighting Saving (\$/ft²)" times "Gross Total Building Area (ft²)".

$$[23] = ([7] + [10])[9]/10^3$$

"Non-Daylit Peak Demand (kW)" equals the sum of "Installed Lighting Load (W/ft²)" and "Non-Lighting Electrical Loads (W/ft²)" times "Gross Total Building Area (ft²)" divided by 1000.

$$[24] = [7][11]/10^3$$

"Non-Daylit Monthly Demand Charge (\$/ft²-month)" equals "Installed Lighting Load (W/ft²)" times "Peak Demand Rate (\$/kW-month)" divided by 1000.

$$[25] = 12[24]$$

"Non-Daylit Annual Demand Charge (\$/ft²-yr)" equals 12 times "Non-Daylit Monthly Demand Charge (\$/ft²-month)".

$$[26] = [7] [13] [15] [9]/10^7$$

"Daylit Peak Demand Saving (kW)" equals "Installed Lighting Load (W/ft²)" times "Daylit Area (%)" times "Dimming Factor (%)" times "Gross Total Building Area (ft²)" divided by 10⁷.

$$[27] = [26] [11] / [9]$$

"Daylit Monthly Demand Saving (\$/ft²-month)" equals "Daylight Peak Demand Saving (kW)" times "Peak Demand Rate (\$/kW-month)" divided by "Gross Total Building Area (ft²)".

$$[28] = 12[27]$$

"Daylit Annual Demand Saving (\$/ft²-yr)" equals 12 times "Daylit Monthly Demand Saving (\$/ft²-month)."

$$[29] = [21] + [28]$$

"Total Annual Savings (\$/ft²-yr)" equals the sum of "Daylighting Saving (\$/ft²-yr)" and "Daylit Annual Demand Saving (\$/ft²-yr)."

In the following calculations, discount rate = i, energy escalation rate = e, payback period = n, modified uniform present worth = m, first year savings = s, and justifiable investment = j where

$$a = \frac{1 + e}{1 + i} \text{ and } m = \frac{a(a^n - 1)}{a - 1}$$

Justifiable investment, j, and first-year savings, s, may be both expressed as \$/ft² or \$/building.

$$[30] = j = (s)(m) = \frac{(s)(a)(a^n - 1)}{a - 1}$$

$$[31] = s = \frac{j}{m} = \frac{j(a - 1)}{a(a^n - 1)}$$

$$[32] = n = \log \left[\frac{j(a - 1) + (s)(a)}{(s)(a)} \right]$$

$$[33] = i = \left[\frac{e + 1}{a} \right] - 1 \text{ and } j/s = \frac{m a(a^n - 1)}{a - 1}$$

To find "a," no simple closed-form solution exists for all cases of "n." A numerical evaluation of "a" is possible for a given value of "n."

General Note: Throughout the nomographs and the appendices, the unit "\$/ft²" has been used to indicate dollars per square foot of total (or "gross") building area. However, \$/ft² of perimeter (daylit) zone only can be found by setting "Daylit Area (%)", Item 13, equal to 100% wherever it occurs in the calculations.