ENERGY ANALYSIS PROCESS FOR DAYLIGHT UTILIZATION IN OFFICE BUILDINGS

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ENERGY ANALYSIS PROCESS FOR DAYLIGHT

UTILIZATION IN OFFICE BUILDINGS

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PREFACE

This study is concerned with developing an analysis process for estimating the annual energy savings due to daylighting in office buildings. Design variables and their impact on savings potential are discussed at length in the early stages of the process. A sensitivity analysis is performed on several of the detailed daylight design variables to show specifically how they affect annual energy saving. The lumen method is used to calculate interior daylight illumination levels once the design variables are fixed and the annual energy savings is found using a computer summation process. An example project is used to apply the process.

The author wishs to express his appreciation to his major adivser, Dr. Lester L. Boyer, Professor of Architecture and Architectural Engineering, for his guidance and assistance throughout this study. Appreciation is also expressed to Walter T. Grondzik, Assistant Professor of Architecture, for his guidance in formulating and organizing the material. A note of thanks is given to W. George Chamberlain, Professor of Architecture, for his participation as a committee member.

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CHAPTER I

INTRODUCTION

Energy Incentives

Energy consumption for maintaining interior building environments was not normally considered a primary issue before the energy crisis became apparent in the mid-1970's. Often mechanical systems components for buildings were sized in response to a design concept of "architecture" which was not necessarily environmentally compatible. Building environmental systems merely filled a continually widening gap between architectural design and comfort requirements; all because fuels were inexpensive.

> Probably the greatest factor on which the change in design philosophy depended was the development of mechanical components that permitted comfort conditions to be generated almost entirely internally. This shifted the responsibility for interior environmental conditions from the architect to the engineer, and while it presumably freed the architect to pursue new design options, it also stripped him of one of the important historic reasons for the existence of architecture as a profession. Once this path was embarked on, it led rapidly into an almost complete dependence on the sealed building, the undifferentiated facade, and mechanical production of light, conditioned air, internal temperature, and humidity content. It resulted also in a constant escalation of the amount of fuel required to operate buildings.[1]

Since the OPEC oil embargo in the early 1970's, designers have become more aware of the need for energy efficient buildings. As a result, buildings have become more responsive to their local environment, thereby reducing the energy gap between system loads and occupant comfort. Today, the overall incentive seems to be one of energy efficiency coupled with more lenient comfort standards, which is better at allowing greater design freedom.

Almost 40 percent of the energy consumed in the United States falls into the professional jurisdiction of the architect or engineer.[2] Opportunities for these professionals to implement conservation practices have never before been so important. Daylight utilization as a conservation strategy can reduce building lighting wattage requirements, but may have subsequent effects on ventilation and space conditioning loads. Heat gain reductions resulting from lights not in use can reduce the internal heat load, but additional glazing for optimizing daylight potential can add perimeter heating, ventilating and air-conditioning (HVAC) loads. Understanding the relationship between these systems is the key to maximizing energy conservation through the use of daylighting.

Windows have been around as long as buildings, but their efficiency as a subsystem has been overlooked. As noted by Hopkinson:

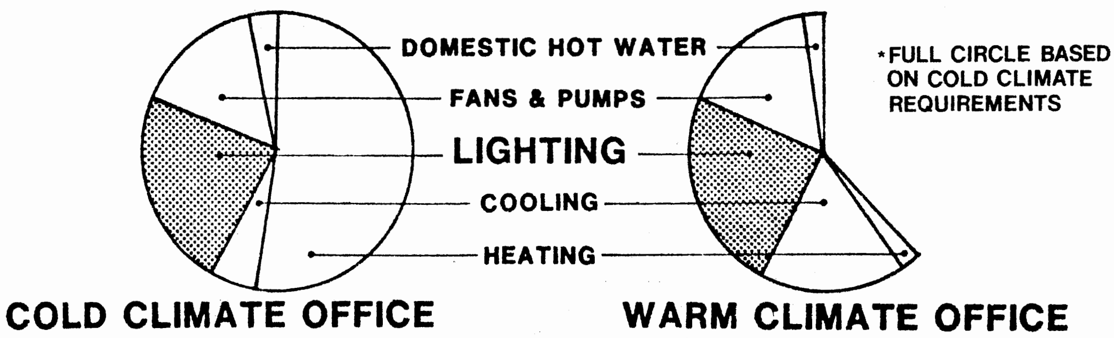
> Windows have always been of major importance in determining the form and character of buildings. From the unglazed 'window-eye' in a medieval castle, to the curtain walls of today. At each period window design has been determined by social, economic and technical considerations in addition to strictly lighting requirements. From time to time the needs of security, limitation of structure, and the size of available glass panes, have all played a part.[3]

In the past, designers have tended to reduce window areas because heat transfer through them is greater than through insulated walls. Lighting engineers also argued for smaller fenestration because glass has a low interior reflectivity and they sized equipment for maximum output during nighttime use.[4] They also considered not having to worry about glare control with smaller windows. Actually the reverse of these approaches can be shown to be beneficial, and they can be energy efficient if these window systems do not evolve independently from the total building concept.

Office Building Application

Building designers and engineers have a substantial opportunity to conserve lighting energy in office buildings. These opportunities are characterized by: daytime use patterns, long hours of lighting use, relatively high lighting levels, and a high density of installed luminaires. Lighting is thus a significant energy consumption factor in most office buildings and represents a large fraction of total building utility costs.[5] Figure 1 shows typical building energy use components for both warm and cold climates. This figure illustrates that at least one-fourth of the energy consumed in commercial office buildings goes for lighting. Substituting daylight can reduce the lighting and cooling components, but could increase the heating component. The components of lighting, fans and pumps make up the bulk of the electrical energy used in contemporary office buildings. Daylighting can also reduce peak load requirement, component sizes in the distribution system, and daily electrical usage.

Daylighting can become a major design determinant when energy savings are important. Building design forms begin to take on characteristics that are environmentally responsive rather than simply sculpted buildings blocks. Perimeter surface areas become greater and different orientations take on different characteristics. The daylighted building takes on a dynamic environment and begins to shed its total dependence on mechanical and electrical systems.



Source: D. Baker, "Daylight Design for a New State Office Building in San Jose, California," Proceedings of 4th National Passive Solar Conference, AS/ISES (Kansas City, Missouri, October, 1979), p. 411.

Figure 1. Typical Office Building Energy Use Components For Warm and Cold Climates

Commercial buildings are normally characterized by their large internal heat load compared to the perimeter skin load of the building. People, equipment and, of course, electric lights combine to produce heating benefits to buildings in colder climates, but tax mechanical cooling systems for buildings in warm climates. With proper integration of daylight and electric systems, electric energy is saved with daylight schemes, however, such heat gain reductions may not be energy conserving in colder climates. If a building in a cooler climate is dependent on internal gains for heating then there might be thermal and illumination tradeoffs. However, for buildings in warm climates, heat gains are not usually desired, so conservation is accomplished in two ways. Again, the climate and the total building systems approach is the key to determining the conservation potential of daylighting.

Lighting accounts for about 20 percent of the total electric energy consumed in the United States.[6] With increasing concern for power generation capacity, utility companies have penalized commercial consumers with a demand charge. The so-called peak power measurement determines a power company's generating capacity, so businesses are charged extra for excessive peak power consumption. Daylighting for office buildings can reduce peak power requirements, which not only reduces the consumer bill but also helps remove the burden from the utility companies.

Daylight Integration Problems

Because of the dominance of artifical lighting in the past 25 years, the lack of daylight utilization has allowed designers to overlook integration strategies in contemporary buildings. Historically, prominent architects were usually recognized by good daylight utilization, but that is not necessarily the case today. Electric lighting has produced buildings which maximize space utilization, which is fine for optimizing work output, but a great dependence on electric sources has developed as a result. The consequences of power blackouts in recent years are well known. Reducing the electrical dependence is a step in the right direction, but some of the problems have been expressed by Selkowitz:

> Although the potential energy savings are significant, effective daylighting requires the solution of a series of problems which currently act as obstacles to widespread implementation. Four major issues are: 1) analysis and design techniques, and daylighting availability data, 2) thermal/illumination tradeoffs, 3) sun and glare control, and 4) lighting controls.[7]

A standard method for determining available daylight for interior spaces does not exist. Several approaches exist but all have shortcomings. The absence of detailed daylight data for many locations in the United States further inhibates the establishment of accurate daylight availability information.

Thermal tradeoffs for commercial buildings, as pointed out earlier, are another problem. Optimizing daylighting will, of course, affect solar heating inputs to the building. Designing for an appropriate balance between illumination and thermal performance by anticipating climate and, more importantly, occupant response, is difficult.

Direct sunlight penetration is not usually desired for lighting, but might be desired for passive heat gain in smaller buildings. Architectural elements are available to control direct sunlight, but resulting effects on occupant comfort must also be considered. If a person is bothered by glare, however, he should have an opportunity to make adjustments with shading devices without sacrificing the daylight scheme. A varying solar climate and varying occupant response modes make sun and glare control an important issue.

With the evolution of electronic technology, light switching for daylight schemes contributes a significant input to energy savings, but poses the most questions. How sophisticated should the controls be, and how much control does the occupant have? Again Selkowitz points out:

> To address the question of actual energy savings, one must know whether the lights are controlled in an on-off mode or a dimming mode, whether that control is automatic or manually operated, how user control of window shading devices affects daylighting levels in the room, how the users will respond to solar gain and glare conditions of the room, or how control strategies to maximize winter solar gain will affect daylighting savings. At the present time, we do not have a comprehensive understanding of these issues.[8]

Another important point is the difference in the first cost of installing lighting in a work area and the annual benefits of worker productivity. Selkowitz points out that the cost of lighting is insignificant when compared to the cost of worker productivity.[9] This points out the need for a quality lighting environment which results from an accurate analysis process.

FOOTNOTES

[1]R. G. Stein, Architecture and Energy, Chalmers Institute of Technology (Goteborg, Sweden, March, 1979).

[2]F. Dubin, "Energy for Architects," Architecture Plus (July, 1973), p. 38.

[3]R. G. Hopkinson, The Lighting of Buildings (New York, 1969), p. 32

[4]R. N. Helms, Illumination Engineering for Energy Efficient Luminous Environments (Englewood Cliffs, N.J., 1980), p. 275.

[5]S. Selkowitz, "Effective Daylighting in Buildings - Part 1," Lighting Design and Application (February, 1979), p. 6.

[6]Ibid., p. 6.

[7]S. Selkowitz, " Daylighting and Passive Solar Buildings," Proceedings of 3rd National Passive Solar Conference, AS/ISES, (San Jose, California, January, 1979) p. 273.

[8]Ibid., p. 274.

[9]Ibid., p. 278.

CHAPTER II

PROBLEM STATEMENT

Approach

The first step this study involves formulating and developing an overall process that will consider all energy inputs to a daylighting scheme. Next, the process will be broken down into major sections, where variables in each can be analyzed and discussed. A detailed inspection of these variables is important to determine their relative impact on the outcome of the total process.

The second major portion of this study deals with developing a sensitivity analysis. Specific daylight design variables will be varied over their potential range one at a time while all others are held at a constant "typical" value. The relative effect of the range of a variable on annual savings will be plotted and discussed.

The final part of this study deals with application of the developed process model to a specific building project. "California State Office Building" in Sacramento will be utilized because its daylighting design has been shown to be energy effective.[1] The results of the present detailed examination will be compared to the results of the original project study. The comparative study results will be utilized to assess the appropriateness and validity of this particular daylight analysis process model.

Purpose

The determination of expected annual energy savings due to daylighting has not generally been considered to be a well-defined task during the design phase of a building project.[2] It has become evident that most commercial buildings would perform better and more economically if daylighting were properly incorporated into their design, but many buildings do not incorporate such potential advantages. A simplified manual process is needed to allow designers to make an easier determination of whether a daylighting scheme satisfies energy design objectives.

> Viable alternative environmental systems, composed of a multiplicity of subsystems, must be evaluated in terms of resource costs and goal effectiveness. This is done by collecting data and constructing models synthesizing real life cause-and-effect relations pertinent to the total expected life of the systems. The cost is then evaluated in terms of objective satisfaction.[3]

This process, or portions of this process, could be converted to an interactive computer process available for design optimization on future projects. A rapid computer model could show how changing certain design options affects internal daylight utilization and subsequent operation costs. Post-occupancy performance studies can also be utilized to increase public acceptance of daylighting schemes. The findings would show that alternatives exist which reduce energy requirements while providing a comfortable and even stimulating working environment.

Specific Objectives

The main objectives of this study are to develop an energy analysis process for determining optimum daylight utilization in commercial office buildings and then to apply it to an example project. Specific objectives are as follows:

1. Research existing procedures for calculating energy savings due to daylighting systems.
2. Establish and examine daylight variables which affect the economic operational performance of a building.
3. Develop an energy analysis model for daylighting performance and construct a flow chart of the overall process.
4. Develop a sensitivity analysis for daylight design variables by using annual savings as a comparative measure.
5. Develop a computer program for portions of the flow chart needed for the sensitivity analysis.
6. Use a California State Office project as an example for the daylight analysis model; also a simplified hypothetical illustration.
7. Make comparisons of example results to original study results and then make final conclusions about the utility and accuracy of this model.

Scope and Limitations

Developing an evaluation process involves establishing quantitative, as well as qualitative, requirements which the design should meet. Human response is difficult to pin-point for qualitative variables, such as glare, so most energy analysis processes are based on footcandle quantity measurements. This process will be no different, especially since it is a manual process established for preliminary design stages. Certain quality measures will, however, be discussed and their use will be stressed.

Since the exact duplication of natural phenomena is difficult to achieve, there should be a certain degree of conservatism built into this process. The user will be allowed to pick a degree of conservatism which should give him more confidence in his utilization of the daylight analysis process. The type of preliminary assumptions made by the user help establish this conservatism, which will account for any over-estimation.

Establishing an "energy balance process" for daylight schemes involves identifying energy flows relevant to the daylight scheme over a period of one "typical" year. By summing the energy flows of a given scheme, and then comparing it to the performance of the building design without the daylighting, annual energy savings can be determined. This, however, is only part of the picture, since psychological benefits, as well as life cycle cost implications, should be included as noted by Griffith:

> Daylight is a by-product of passive solar systems, and proper evaluaton of the costs and benefits (heat and daylight) of the total system over its expected life could prove energy conserving. Life-cycle cost-benefit analysis allows tradeoffs of human productivity and energy costs. Passive solar systems use nondepletable energy sources and should be a part of every design study of alternative building systems to determine their economic desirability.[4]

Establishing a dollar value for psychological benefits that affect human productivity and are dependent on daylight quality variables is a difficult task. This study will address these points, but will not include them quantitatively in this process, since it is based only on annual building energy savings.

The sensitivity analysis is based on the lumen method or Libbey-Owens-Ford (LOF) method.[5] The design variables and their average values will be established from this method, and all other basic design values will be assumed at fixed levels. This should provide some conclusion about how varying a lumen (LOF) variable can affect annual savings.

Only one hypothetical and one constructed example project will be tested using the daylight analysis process. If the process were to be accurately checked, more examples would have to be studied. This would allow possible discrepancies to be uncovered beyond those indicated in this study example, which is an excellent project showing daylight utilization in commercial open plan office buildings.

FOOTNOTES

[1]B. V. Setty, "The Nation's Most Energy-Efficient Office Building," ASHRAE Journal (November, 1979), p. 31.

[2]L. L. Boyer, "Evaluation of Energy Savings Due to Daylighting," Proceedings of International Passive and Hybrid Cooling Conference, AS/ISES (Miami Beach, Florida, November, 1981), p. 343.

[3]J. W. Griffith, "Benefits of Daylighting - Cost and Energy Savings," ASHRAE Journal (January, 1978), p. 53.

[4]Ibid.

[5]How to Predict Interior Daylight Illumination, (Toledo, Ohio, 1976).

CHAPTER III

PROCEDURE

Establishing a detailed daylight design approach is essential for implementing effective energy solutions without sacrificing other design priorities. The initial step in this daylight analysis process begins when the preliminary building design concept has been tentatively established. Although the main design determinant may not be daylighting, certain variables related to the building design and its daylighting efficiency are fixed. From this point, the process allows all design assumptions concerning the remaining daylight variables to be made. Since the process does allow for refinement of window and reflectance design, these initial assumptions could be later modified to better enhance energy savings. The next step of the design approach involves establishing basic lighting requirements for a given building. The lighting criteria can be specified in terms of quantity and quality. Later, when available daylight distribution is calculated, it can be checked against these criteria and the design can be modified if needed.

The next major step involves investigating characteristics for both the electric and daylighting schemes. When these characteristics meet criteria standards and improve building efficiency, then they can be incorporated into the design. The procedure for determining an electrical lighting scheme is the same for a daylighted building as for any other. Since no daylight benefits can be given to the interior core regions, functions in this area are electically lighted. Electric lighting luminaires for perimeter areas provide the same amount of light as in the core, so that optimum output can be provided during nighttime hours. The key to energy savings is special switching circuitry and dimming for daytime reduction of energy use in the perimeter zone. The daylighting scheme, which is already partially determined by the basic building form, is now refined to its full potential by iterating through the next step in the process and adjusting window, penetration, and occupancy variables.

With the preliminary establishment of variables, the process of determining the amount of daylight available to the preliminary design can be pursued. First, by deciding to use the lumen or Libbey-Owens-Ford (LOF) prediction method, the variables are established.[1] Since this portion of the process is iterative, the examination of these variables with a sensitivity analysis for savings improvements is necessary to minimize the number of design changes. If savings opportunities are evident at this point, changes in the design should be made.

The calculated result is dependent on solar altitude, which of course varies both daily and seasonally. At this point, time segments must be established for both daily and seasonal time variables. Calculating available daylight for each hour of the day, every day of the year, is possible for accuracy, but is not encouraged for a manual process. In preliminary design cases, comparative performance levels should be sought rather than absolute quantitative results. Hour-by-hour increments for each seasonal design day can be established for each of the three main seasons; summer, winter, and intermediate. The calculation is completed for each typical office space orientation and yields daylight levels at three distances away from the window. From these calculations, daylight level contours can be drawn and daylight distribution patterns between the core and perimeter zones can thus be established.

After determining the lighting level increments produced by daylight, the final integration of both the electric and daylight schemes can begin. As stated earlier, electric lighting is installed throughout the building, but switching options are available and these are dependent on the selection of the luminaire type. For example, the luminaires could be multi-lamped units that can which switch off a given number of lamps, depending on how far they are from the window or upon changes in the outside sky conditions. The system could also be a dimmable one that has photo-electric cells to modulate the amount of additional light needed at a given perimeter location. Perhaps the simplest concept would be to have an on-off switch that an office occupant could operate according to how he perceived the daylight level. If the daylight is sufficient, he turns off the lights. There could, however, be a severe penalty for only manual operated system. Whatever system is installed, the type of control, whether it is manual or automatic, and how much occupant interaction is available or desired must be decided upon.

The percentage of annual savings can be determined after the lighting scheme is established and the consumption level of the lights is known. This includes the amount the lights are reduced, and how long they are reduced. A calculation of the total building light-related energy use must be made assuming both daylight utilization and no daylight utilization. First, an annual adjustment must be made in the length of time the lights are used. Next, climatic assumptions must be made using existing weather data to predict a percentage of annual cloud cover and to determine whether all seasonal solar angles provide useful daylighting. These assumptions are applied only to the daylight scheme. Annual building electrical usage is then calculated for both a day-lighted and a non-daylighted design. The additional heat energy produced by the electric lights and the impact it has on the seasonal heating or cooling load must also be calculated for both designs. The percent annual savings of the daylight scheme is then expressed by:

$$\frac{\text{Annual building lighting energy + total HVAC energy WITH daylight}}{\text{Annual building lighting energy + total HVAC energy WITHOUT daylight}}$$

Once the savings are predicted, refinements can be made depending on the outcome. Since the basic building form is established, only the Lumen (LOF) prediction variables can be modified. These variables include window area, glass transmittance, ground reflectance, room dimensions, wall reflectances, and shading characteristics. If a process run can be executed using constant average values for all Lumen (LOF) variables, except one, then a sensitivity analysis approach can be adopted. By determining a range for each variable and holding the others to a typical reference value, each variable impacts annual savings can be shown. Once this is done for each variables the designer, will have a valuable tool to refine his final daylight design.

A hypothetical example will first be examined with the analysis process. Then an actual example project will be analyzed, including the examination of refinement opportunities. The constructed project selected is a design by Benham-Blair and Affiliates of Oklahoma City, which in 1977 won a national energy design competition for a state office building in Sacramento, California.[2,3] It was designed to optimize the use of daylight and the prediction calculations have been made available.[4] By analyzing this project, evaluations about this analysis process and how it was designed can be made and analyzed.

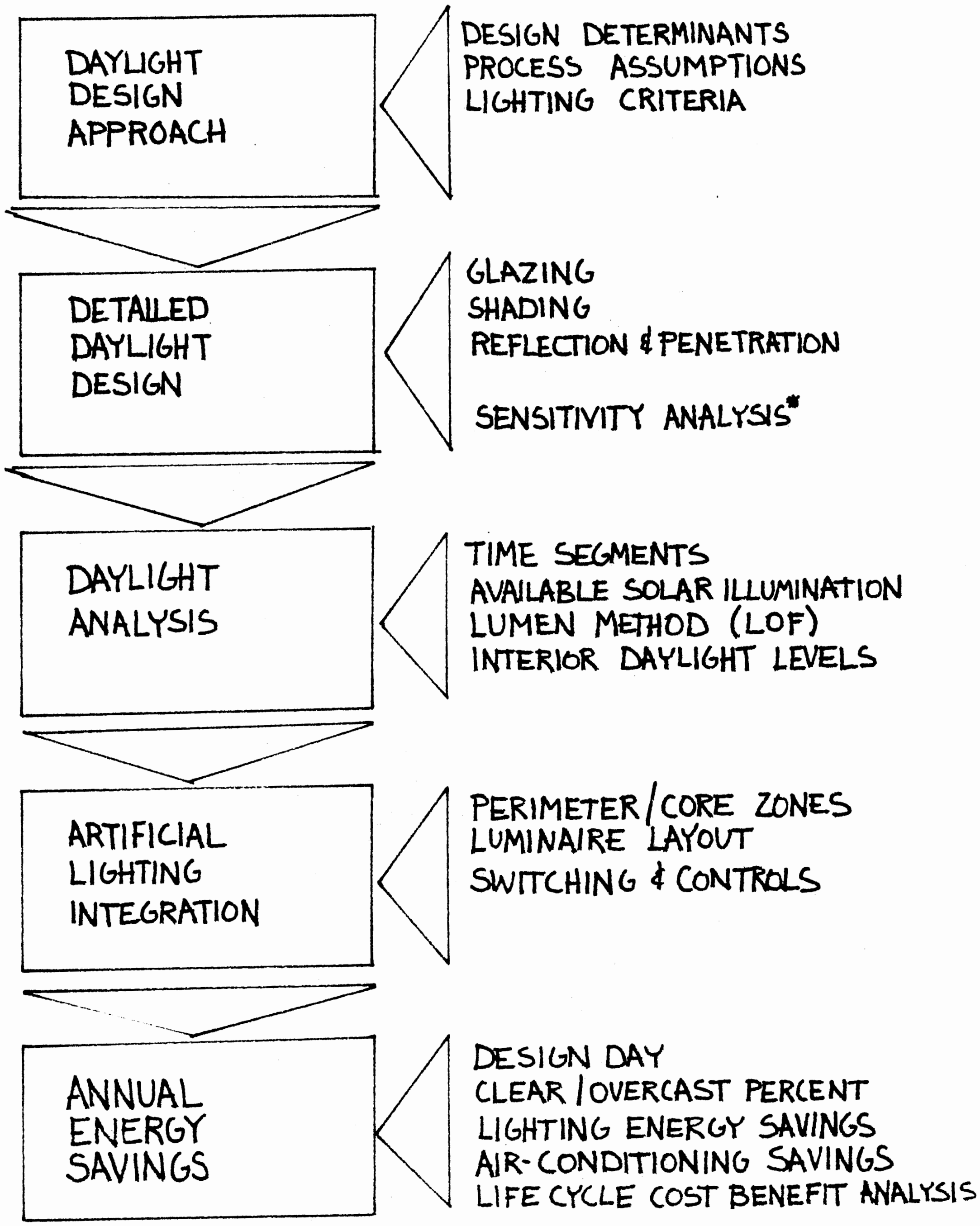


Figure 2. General Energy Analysis Flow Chart for Daylight Utilization

FOOTNOTES

[1]How to Predict Interior Daylight Illumination (Toledo, Ohio, 1976).

[2]"California State Office Building Competition: Practicing What They Preach," Progressive Architecture (February, 1978), p. 70.

[3]L.L. Boyer, "Underground California Office Building Wins National Energy Design Competition," Proceedings of Earth Covered Settlements Conference, Arlington, Texas, U.S. Department of Energy, Vol. 2, F.L. Moreland (Ed.), 1979, p. 241.

[4]L. L. Boyer, "Evaluation of Energy Savings Due to Daylighting," Proceedings of International Passive and Hybrid Cooling Conference, AS/ISES (Miami Beach, Florida, November, 1981), p. 343.

CHAPTER IV

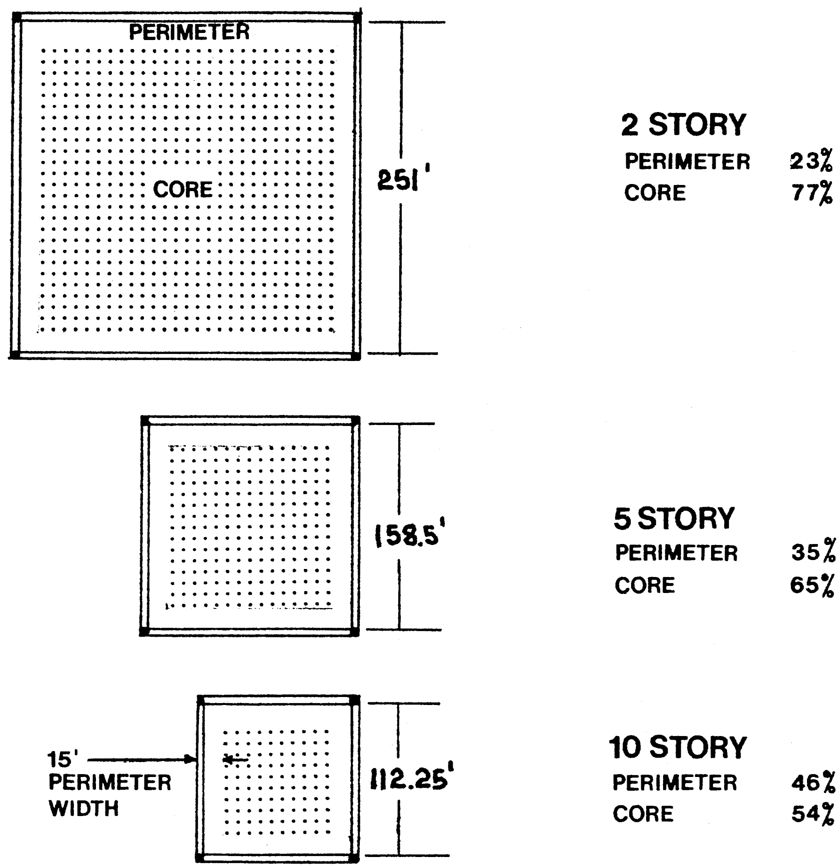
DAYLIGHT DESIGN APPROACH

Basic Design Considerations

Daylighting incorporated in commercial office buildings for energy conservation influences the design approach in a particular way. Traditionally, office buildings have been multi-level structures designed as rectangular affairs suitable to fill an urban city block. Selkowitz notes:

> Centralized, compact forms have been generated by the pressures of high urban land costs, increasing building material costs, business organizational requirements, and in part, more recently, by perscriptive building codes designed to promote energy conservation.[1]

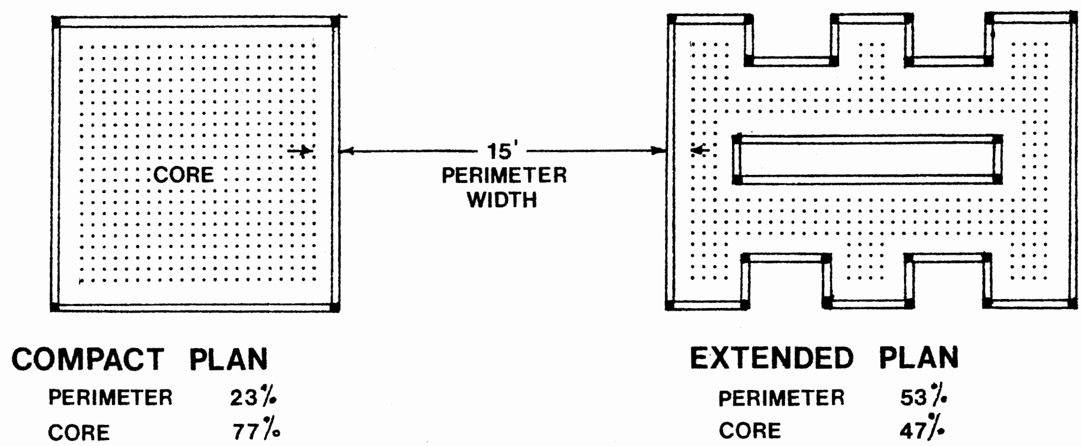
The evolution of this building form is not based on environmental compatibility with daylight, yet it is an acceptable form if daylight is utilized. Large perimeter floor areas, suitable for daylight, are generated by high rise building designs through repetition of floor levels as shown in Figure 3. This figure illustrates how increasing the number of floor levels of a square plan with a fixed total square footage will increase the relative fraction of perimeter floor area. Of course, this could provide more savings due to daylight, but could reach a tradeoff point when other systems would use more energy because of higher vertical lift distances. Nevertheless, the increased perimeter area fraction encourages the use of daylight integration in typical urban high rise buildings. The effective horizontal distribution of light in such vertical high rise light shells is, however, a difficult technical problem to solve and there are psychological implications as well.



Source: F. Dubin, "Energy for Architects," Architecture Plus, Vol. 68, No. 7, (July, 1973), p. 46.

Figure 3. Perimeter Area Percent for Varying Heights of a Fixed Floor Area

Designs which deviate from a square plan to a rectangular or even an extended irregular plan can achieve even higher percentages of perimeter floor area. At this point daylighting becomes a strong design determinant and the building form evolves accordingly. Figure 4 shows two building floor plans with the same gross floor area having a two-to-one difference in the perimeter area fraction.



Source: S. Selkowitz, "Daylighting and Passive Solar Buildings," Proceedings of 3rd National Passive Solar Conference, AS/ISES, (San Jose, California, January, 1979), p. 280.

Figure 4. Perimeter Area Percent for Varying Plan Types of a Fixed Floor Area

There are several conditions that must be met to insure the savings potential of this type of extended floor plan. Obviously, a sprawling form will take more land area, so the site must be large enough to accommodate it. Also, the increase of the building's outside surface area will increase initial building costs and the building's thermal loads. This means local climate conditions must be checked to determine environmental conditioning impacts. With a warm climate, possibly no modifications to increase thermal resistance need to be made on the envelope perimeter. However, in cooler climates, more resistant envelope insulating materials and construction methods will insure a total savings benefit with the increased surface area. With newly evolving code requirements, such energy design measures will already be considered.

Another basic building design variable is the amount of glass opening at the building perimeter. In general, the more glass area present, the more light there is available to reach into the space. This is good for a daylight design, especially since larger windows tend to reduce brightness contrasts when looking at a window wall.[2] One problem, however, is the fact that glazing is less resistant to outside thermal variations than typical opaque wall materials, so the glazing may need thermal resistance improvement to maintain overall energy savings.

A rule-of-thumb for daylighting office areas is that useable light will penetrate into the space to a distance of about twice the window height.[3] This means that if the story height is increased, more usable daylighted area will result. There is, however, a tradeoff point as to how far the design can be modified to increase daylighting and still keep the building in scale. For a low rise building, such story height modifications could be beneficial, but for a high rise, the additional height can add up quickly to burden building lift systems and overall construction costs, thereby offsetting potential savings. Also, for a fixed building height, considerably less floors means less rental area. Typical floor-to-ceiling heights produce useful daylighting areas roughly 15 feet back from the window wall.

A key to utilizing daylight effectively is to increase penetration into the space. This can be accomplished at the perimeter of the building by using special devices such as light shelves or more elaborate optical systems.[4,5] These systems have been shown to improve penetration, but have not been widely utilized because of high first cost.

The interior location of partitions and furniture is also important for optimizing penetration. Walls located parallel to the window wall should be kept to a minimum, especially if they are closer than 20 feet away. Walls perpendicular to the window wall are not as critical, but their number should be reduced to prevent excessive compartmentation, which reduces the horizontal view angle of incoming light. All partitions should help promote penetration by having surfaces which induce secondary reflections. Partial height units or even translucent partitions could be effectively utilized. Office furniture layouts should be arranged so as not to block incoming light.

The established building form and the degree of required privacy for office functions will strongly influence the interior layout. Open plan spaces, which require less visual and acoustic privacy are quite appropriate for utilizing potential daylight savings. Also, an improvement in lighting quality often occurs with open plans which usually have light arriving from more than one direction. Compartmented office plans can also be effective if the amount of interior core area is kept to a minimum. Double loaded corridors with daylight arriving from each side of the corridor can be effective.

Vertical penetration of daylight can be a problem in high rise buildings with an interior courtyard or atrium. Normally these spaces are designed as entrance lobbies where the light is used for psychological effect rather than working tasks. Funneling light into a vertical shaft and then distributing it horizontally to individual levels is a problem that requires generous atrium spaces or ceiling plenums. For this approach to be successful, daylighting must be a very strong design determinate as exhibited by the proposed Tennessee Valley Authority (TVA) building in Chattanooga.[6] Most atrium buildings designed for daylight are not this elaborate and, consequently, are designed with very few levels to avoid penetration problems.

Building orientation is a basic design variable needs special consideration because each facade receives different light levels at different times of the day. It has been generally accepted that north light provides the best lighting for working task areas.[7] Utilizing this orientation facilitates the design of sunlight control because direct rays rarely need to be excluded with shading devices. Even though northerly directions are the optimum orientation for daylighting, thermal tradeoffs in cooler winter regions are more critical for this orientation, so consideration must be given to the area of glass that could be used. Usable daylight for east and west orientations, in contrast, are the most difficult to control. A rising or setting sun produces low angle direct sunlight penetration problems. This situation can be especially severe in the winter months when the angle is lowest during early and late working hours. Shading devices for these orientations have to be extensive and interior blinds almost invariably must be used. Considering the disadvantages presented, one might think to avoid the extensive use of these orientations, but they can be effective for most of the day when the sun is on the opposite side. Southern orientations also have seasonal variations in solar altitude but direct sun control is easier with horizontal louvers and overhangs. Utilizing daylight for this orientation is more common because of the ease of seasonal control and the integration of passive solar heat control, desirable for some building designs. The key for all orientations is to increase the input of diffused light and to decrease the input of direct light, unless passive solar heating is desirable. Table I shows the solar angles variations for different latitudes, hours of the day and seasons.

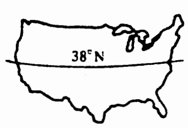
All of the previously mentioned basic building design variables should be established at the preliminary design phase and the beginning of the lighting analysis process. Other variables which can be manipulated, such as window area, glass type, room dimensions, and reflectances, will be discussed later in Chapter V; Detailed Daylight. At that point, this process can begin and refinements on the actual daylight design details can be initiated. It is assumed the analyst is involved at the preliminary stage of design and the discussion of these variables helps keep the project on proper course. The analyst should now be able to apply the process to the basic building design to determine the annual energy savings potential.

Process Assumptions

In any design process that intergrates to a solution certain variables must be assumed at early stages in order to see how they impact the final product. In this process there are a large number of options available so this means a large number of variables will have to be resolved. Some of the variables can be established at an early state and these are fixed in the basic building design and they include: site location, number of levels, building plan, and orientations. Usually,

TABLE I

INCIDENT SOLAR ANGLE VARIATIONS FOR DIFFERENT LATITUDES, SEASONS AND HOURS OF THE DAY

Latitude		Date	AM: 6 / PM: 6	AM: 7 / PM: 5	AM: 8 / PM: 4	AM: 9 / PM: 3	AM: 10 / PM: 2	AM: 11 / PM: 1	Noon
	ALTITUDE	June 21	12	24	37	50	63	75	83
		Mar.-Sept. 21	–	13	26	38	49	57	60
		Dec. 21	–	–	12	21	29	35	37
	AZIMUTH	June 21	111	104	99	92	84	67	0
		Mar.-Sept 21	90	83	74	64	49	28	0
		Dec. 21	–	60	54	44	32	17	0
	ALTITUDE	June 21	13	25	37	50	62	74	79
		Mar.-Sept. 21	–	12	25	36	46	53	56
		Dec. 21	–	–	9	18	26	31	33
	AZIMUTH	June 21	110	103	95	90	78	58	0
		Mar.-Sept 21	90	82	72	61	46	26	0
		Dec. 21	–	–	54	43	30	16	0
	ALTITUDE	June 21	14	26	37	49	61	71	75
		Mar.-Sept. 21	–	12	23	34	43	50	52
		Dec. 21	–	–	7	16	23	27	28
	AZIMUTH	June 21	109	101	90	83	70	46	0
		Mar.-Sept. 21	90	81	71	58	43	24	0
		Dec. 21	–	–	54	43	30	16	0
	ALTITUDE	June 21	16	26	38	49	60	68	71
		Mar.-Sept. 21	–	11	22	32	40	46	48
		Dec. 21	–	–	4	13	19	23	25
	AZIMUTH	June 21	108	99	89	78	63	39	0
		Mar.-Sept. 21	90	80	69	56	41	22	0
		Dec. 21	–	–	53	42	29	15	0
	ALTITUDE	June 21	17	27	37	48	57	65	67
		Mar.-Sept 21	–	10	20	30	37	42	44
		Dec. 21	–	–	2	10	15	20	21
	AZIMUTH	June 21	107	97	88	74	58	34	0
		Mar.-Sept 21	90	79	67	54	39	21	0
		Dec. 21	–	–	52	41	28	14	0

Solar Time

Source: R.N. Helms, Illumination Engineering for Energy Efficient Luminous Environments (Englewood Cliffs, New Jersey, 1980), p. 259.

more detail design variables are not established in early stages and these could included characteristics of glazing, shading and reflection. In this process the variables must be assumed to some value and then tested as an overall design. If the results meet the required criteria then the variable become fixed to the design, but if they are not adequate then they can be modified. The idea is to fill in the holes by making a best guess until the actual design can be finalized. These assumptions are related to detailed daylight design section of this process but other assumptions could be required throughout the process if an uncertain direction is encountered. All assumptions in this study will be expressed when needed and the last chapters will have specific assumptions needed to excute the computer programs.

Lighting Criteria

When assumptions have been made regarding how this process will be approached and how the project will be analyzed then the next step is to establish lighting criteria standards which must be satisfied. These standards have been established by the Illuminating Engineering Society (IES).[8]

> Office lighting should be evaluated in terms of its effect on people and their performance. A great deal is known about the human performance. A great deal is known about the human response to light and more knowledge is being gained through both vision research and experience with lighting installations. Specifically, lighting will affect:
>
> 1. Ability to see visual tasks with speed and accuracy.
> 2. Visual comfort.
> 3. Visual environment or the pleasantness of a space in which one lives and works.
>
> All of these are needed to achieve the best performance. It is convenient to organize lighting criteria into two basic considerations: (1) quality and (2) quantity. However, they are not independent considerations, and both must be taken into account in any lighting design.[9]

Establishing the quantity of light needed in an office environment involves several factors. Knowledge of the visual tasks expected and their importance in the operation of the office is critical to the appropriate selction of lighting levels. Similarly, consideration must be given to the occupants, their expected performance, and their desired reaction to the office environment.[10] Utilization of daylight does not affect the quantity of light needed for the space.

The process for identifying task level lighting requirements is outlined in Section 2 of the Illuminating Engineering Society (IES) Handbook. In the past,the IES Handbook would identify a single light level for a given task, but the latest edition provides suggested ranges of illuminances. It is intended that this new procedure will accommodate a need for flexibility in determining illumination levels so that lighting designers can tailor lighting systems to specific needs, especially in an energy conscious era.[11] For most of the more critical office related tasks, the IES Handbook sets a 50-75-100 equivalent sphere illumination (ESI) footcandle range. For less critical tasks, such as reception and duplicating areas, a range of 20-30-50 (ESI) footcandles is given. The Asher Standard 90-75 reinforces the approach of recommended ranges of light levels for task, general and non-critical adjacent to task areas are roughly one-third the level and non-critical areas adjacent to general areas adjacent to task are roughly one-third level.

Deciding upon an average level of light intensity is the next step in establishing the character of the overall lighting system. Specific task locations could be fitted with task lighting if detailed locations are known. This process, however, is based on office buildings, which are speculative in nature. In these building types, most task lighting requirements are considered to be similar, so a general lighting system provides flexibility to the office layout. This allows rearrangement of luminaires for new work stations locations, overall energy consumption remains the same. Task levels can be maintained at specific work locations while adjacent areas and circulation spaces can float at somewhat lower levels.

Previous lighting concepts for offices in the 1960s and 1970s often distributed the required task level to every square foot of the building; which by modern terms, is considered wasteful. Today, however, this task and ambient approach to lighting is being used more frequently, and is discussed in the IES Handbook.[12] This concept produces an average footcandle level somewhat lower than the task requirement and enhances energy savings. An example of this approach is noted by Boyer:

> Light levels must be sufficient for expected tasks, conducive to energy efficiency, and adaptable to change. Depending on the space layout, different lighting schemes may be appropriate. For example, in individual private offices an average level throughout the room should be about 50 footcandles with the work plane immediately beneath the luminaries somewhat higher. In open plan areas, the average may again be about 50 (fc), but circulation areas can be 10 to 20, while the task levels may be on the order of 70 or above, and immediate surroundings perhaps 30 to 40 (fc).[13]
>
> The second major consideration with regard to lighting criteria involves the quality of light provided by the system. Quality relates to characteristics of lighting that make seeing easier. Some of these characteristics are interrelated, so that deficiencies in one can be offset by improvements in another. If the quality of lighting is optional for a particular task, the quantity of light needed is likely to be less, saving energy and cost.[14]

The utilization of daylight has been shown to create special quality problems, but if properly handled it can also provide benefits. Electric light schemes are not normally as sensitive to quality characteristics because of their overhead location, multiplicity of evenly distributed units, and lower individual intensities. These characteristics, nevertheless, apply similarly to both schemes. The meaning of lighting quality is easier to understand when the components are subdivided into separate categories. The IES Handbook states:

> There are three main elements to be considered in providing quality in office lighting, namely: visual comfort or the level and extent of the luminances in the normal field of view, luminance ratios in the normal field of view, and veiling reflections present on the seeing task.[15]

The first characteristic, described as visual comfort, relates to the amount of discomfort associated with eye stress produced by long periods of activity or high levels of luminance. By literal interpretation this factor could be applied to all the other quality variables since comfort is closely related to each. This term, however, is specifically aimed at light brightness or the amount of light in the field of view. From an artificial lighting perspective, problems could arise in open plan spaces where there is a large angle of view, or in areas where higher than normal light levels exist. These two factors rarely exist together in newer designs, so open plan spaces are still popular. When these large work areas are used, work stations are broken into task and ambient zones. This subdivision helps to reduce the overall quantity of light seen in a normal glance. For additional help with light quality there is a rating system known as the Visual Comfort Probability (VCP) which predicts occupant response for several lighting system types.[16]

Examination of visual comfort for the daylighting scheme is considered differently than with electrical lighting because intensities are variable and unpredictable. If a work station is not in a daylight area, but has visual access to the outdoors, then the area and luminous intensity of the window wall must be considered for clear days. If a work station is in a daylight zone, then the building design must not allow excessive footcandle levels and, above all, no direct sunlight. One positive aspect for daylight and visual comfort is the continual daylight variation that is sometimes believed to be undesirable for indoor working environments. There is strong evidence to suggest that people value and even prefer the changes and variability introduced by daylight in a room over uniform lighting conditions.[17]

The next major characteristics introduced by the IES Handbook are luminance of the task and the remainder of the field of vision.[18] Low ratios of light are recommended to allow the eyes to adapt when they move from one luminance level to another, and to prevent glare sources in the line of sight. For artificial light systems in offices, this is not usually a problem with quality luminaires, but with the reflectance interior surfaces. Surface brightnesses are partially dependent on surface reflectances; a recommended list of these percentages for office environments is given in Table II.

Brightness ratios in daylight applications can become quite a problem because of the difference in interior and exterior light levels, especially on clear days. In daylighting, the primary concern with regard to luminance ratios is the luminance of the window and its immediate surrounding areas of walls or mullions.[19] Consideration of work station layout should keep the primary view away from the window wall. The placement of external visual elements should be considered so as to help redirect light into the space in a soft and diffused manner.

Daylight contribution component should be optimized by the use of shading devices and surfaces should be kept as light and reflective as possible. Table III shows recommended brightness ratio criteria.

TABLE II

RECOMMENDED SURFACE RELECTANCES FOR OFFICE ENVIRONMENTS

Ceiling	80%(80-92%)
Walls	50%(40-60%)
Furniture	35%(26-44%)
Office Machines	35%(26-44%)
Floor	30%(21-39%)

Source: W.J. McGuinness and B. Stein, Mechanical and Electrical Equipment for Buildings Edition (New York, 1971), p. 688.

Another possible adverse element of lighting quality is veiling reflection, which can occur when an image of the luminaire source happens to be reflected in the details of the task and these details assume some of the luminaire surface brightness.[20] These mirror-like reflections are related to the incident angle and kind of light on the task surface. There may be more problems of this type with artificial systems than with incoming daylight. In private offices, luminaires can be properly placed, but in open office areas, one worker's quality lighting might be another worker's veiling reflection. Luminaire location must, therefore, be considered in the office layout scheme. Research has shown that office tasks are viewed most often at about 25 degrees from vertical.[21] Recommendations are, therefore, made that luminaires be placed at an angle of more than 25 degrees, but less than 60 degrees from vertical.[22]

TABLE III

RECOMMENDED BRIGHTNESS RATIOS FOR OFFICE ENVIRONMENTS

1 to 1/3	Between task and adjacent surroundings
1 to 1/10	Between task and more remote darker surfaces
1 to 10	Between task and more remote lighter surfaces
20 to 1	Between luminaires (or fenestration) and surfaces adjacent to them
40 to 1	Anywhere within the normal field of view

Source: W.J. McGuinness and B. Stein, Mechanical and Electrical Equipment for Buildings Edition (New York, 1971), p. 689.

Veiling reflections from daylight appear to be less of a problem than from artificial systems. Daylight coming in from one side direction allows the designer to locate the task with respect to the source. It is generally accepted that effective sidelighting provides less veiling reflection, improved contrast, and thus greater visibility than equivalent footcandles from most overhead lighting systems.[23] This is one aspect where daylight really outdoes its artificial counterpart, as shown in Figure 5.

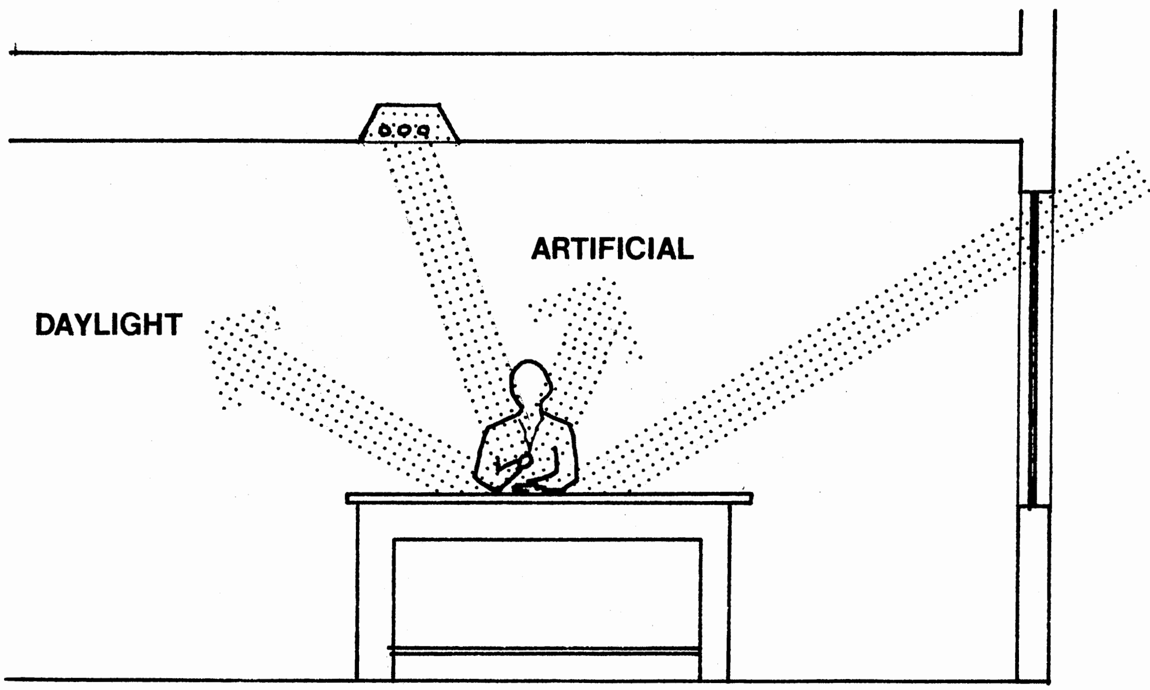


Figure 5. Comparison of Veiling Reflections for Overhead Artficial Systems and Sidelighting With Daylight

Reflected glare is a quality characteristic similar to veiling reflection in the way it is produced, but instead of reducing the contrast of written or typed words on dull paper finishes, it is a direct glare reflected from surfaces, such as polished wood or a glass covered desk top.[24] The light source location is still the problem, but instead of hiding the task, it produces glare in the direct line of vision. Using the luminaire placement methodology described for veiling reflections is one way to handle the problem. Other methods include reduction of the number of reflective surfaces, reduction of luminaire brightnesses, or increase overall illumination to wash out the reflection.

The final quality characteristic which can be detrimental to effective light utilization is of shadows. Shadows cast on the visual task reduce the luminance of the task and may impair effective seeing.[25] For electric systems in office areas, this is not normally a problem because of the large area of a luminaire and because of the number of luminaires supplying light from many directions. Wide light distribution systems are encouraged over concentrating downlight systems which produce pronounced shadows.

Daylighting can produce shadow problems if light is only coming from one direction. If daylight cannot be introduced from more than one direction, then supplemental artificial lighting should be located to soften the shadows in the perimeter zone. Reflective room finishes are encouraged to enhance incoming daylight penetration and should be maintained throughout because they will also help reduce shadowing by reflecting diffused daylight, as well as artificial light, into shadow areas.

FOOTNOTES

[1]S. Selkowitz, "Daylighting and Passive Solar Buildings," Proceedings of 3rd National Passive Solar Conference, AS/ISES (San Jose, California, January 1979), p. 278.

[2]How To Predict Interior Daylight Illumination, (Toledo, Ohio, 1976).

[3]L. L. Boyer, "Subterranean Designs Need Daylight," Earth Shelter Digest (July/August, 1979), p. 32.

[4]C. Dunkerley, N. C. Rodgers, and J. A. Ballinger, "Analysis of Innovative Methods in Natural Lighting," Architectural Science Review (June, 1979), p. 44.

[5]D. Bennett and P. A. Eijadi, "Solar Optics: Projecting Light into Buildings," AIA Journal (September, 1979), p. 86.

[6]S. Matthews and P. Calthorpe, "Daylighting as a Central Determinant of Design," AIA Journal (September, 1978), p. 86.

[7]M. Villecco, S. Selkowitz, and J. W. Griffith, "Strategies of Daylight Design," AIA Journal (September, 1979), p. 68.

[8]J. E. Kaufman, ed., IES Lighting Handbook, Application Volume (New York, 1981).

[9]Ibid., p. 5-2.

[10]Ibid., p. 5-2.

[11]Ibid., p. 2-3.

[12]Ibid.

[13]L. L. Boyer, "Evaluation of Energy Savings Due to Daylighting," Proceedings of International Passive and Hybrid Cooling Conference, AS/ISES (Miami Beach, Florida, November, 1981), p. 343.

[14]How to Predict Interior Daylight Illumination, p. 4.

[15]Kaufman, p. 5-2.

[16]Ibid., p. 5-3.

[17]Selkowitz, p. 279.

[18]Kaufman, p. 5-2.

[19]How to Predict Interior Daylight Illumination, p. 4.

[20]Kaufman, p. 5-3.

[21]C. L. Crouch and L. J. Buttolph, "Visual Relationships in Office Tasks," Lighting Design and Application (May, 1973), p. 23.

[22]Kaufman, p. 5-3.

[23]Selkowitz, p. 278.

[24]Kaufman, p. 5-3.

[25]Ibid., p. 5-4.

CHAPTER V

DETAILED DAYLIGHT CONSIDERATIONS

Glazing

This section deals with the specific nature of the design details for the daylight schemes. There is a certain amount of integration in the utilization of daylight with the artificial lighting, and this discussion approaches it with the idea of increasing the amount of incoming daylight without sacrificing quality. The artificial light scheme will be addressed later in Chapter VII with regard to its integration with daylight, as well as its use without daylight. This discussion delineates characteristics daylighting variable which will be demonstrated later in the sensitivity analysis.

As stated earlier, the optimization of incoming daylight characteristics can be considered after a basic floor plan has been established. At this point strategies for the exterior, building envelope, and interior must be considered or examined for quality daylighting. These include examining glazing, shading, penetration, and reflection characteristics. Strategies for occupant interaction with these daylight characteristics are also considered.

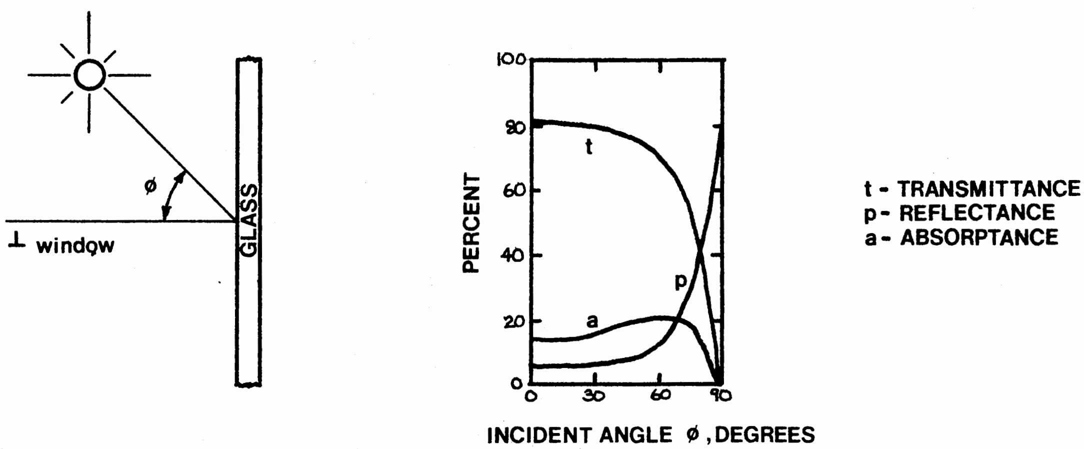
Glass provides the interface between the interior and exterior environment by allowing the passage of light and reducing the thermal impact. As a building material, it gives the occupant more interaction with the outdoors, and, with proper utilization, it can allow for a natural luminous environment for a portion of the floor area. Specifically, dimension, location, placement angle, and transmittance characteristics affect the amount of daylight that can be utilized for office tasks.

Dimensioning glass to maximze incoming daylight is accomplished by using the full window wall area. Floor-to-ceiling glazing allows as much light as is available to enter the space and, at the same time, reduces glare caused with smaller windows. There is, however, some tradeoff with thermal impacts because of the poor thermal resistance of glass. The extremity of the climate will help prescribe the optimum area of glass since it has been shown that reduction of glazing is equal to a reduction in heat loss or gain. Daylight, however, is not reduced in an equal fashion when area is reduced. If the amount of glass planned for a building is cut by one-third, the natural illumination is cut by only one-fourth; the result in a heated building would be proportionately more light and less heat loss.[1] Knowing the climate and the thermal properties of the glass will determine the area of glass to be used.

Glazing location on the window wall is a major daylight variable to be considered if full floor-to-ceiling glazing is not used. Location is mostly dependent on the occupant's outdoor visual access, mean radiant temperature (MRT) comfort effects, the relationship of incoming daylight and space utilization, and the possibility of avoiding glare from external surface reflections. Glazing location can also be affected by radiation from nearby external surfaces, so attention must be given to this detail.

As stated before, the higher the glass is located the deeper the light will penetrate the space. This means glazing should extend to the ceiling to increase daylight usage. Glass to the floor, however, is not critical to overall utilization since the area below task or desk height cannot be directly utilized. Only if the floor surface is a good reflector can the secondary reflections of light coming from outdoors be utilized. This allows the bottom of the window to stop at desk height for normal design, which is compatible with thermal and MRT considerations, especially in cooler climates. Also, the considerable use of carpeting, a poor reflector of light, discourages the use of glass below task height. Glass width, similar to height, increases incoming light quantity and penetration if it occupies the total dimension of the space. The lumen or Libbey-Owens-Ford (LOF) prediction method, developed by the Illuminating Engineering Society (IES), is based on an area of glass from the desk top to ceiling height and spans the full width of the space.[2]

Another design characteristic of glass, which affects the amount of light that is able to penetrate the material, is the angle of the glass with respect to the direct incoming light rays. The amount of transmitted light will change as the source angle changes. Normally, less light will be transmitted as the source direction becomes more parallel with the window because the light has a better opportunity to be reflected. If direct sun is avoided, then the glazing should be as perpendicular as possible to the primary source or reflected source component, or be vertical to allow maximum diffuse sky component. Glass at a fixed angle does not always allow total penetration because of daily and seasonal variations, but an average placement angle should be considered since it could be more efficient than the normal vertical installation. Figure 6 shows the transmittance of quarter-inch plate glass as a function of the incident angle of direct sun. An important observation is the lack of deviation in transmittance until the incident angle becomes greater than 60 degrees. If direct sun shading is assumed, then daylight transmittance efficiency with a diffuse sky is not drastically affected by angle placement for a quarter-inch type glazing.



Source: R. N. Helms, Illumination Engineering for Energy Efficient Luminous Environments (Englewood Cliffs, New Jersey, 1980), p. 280.

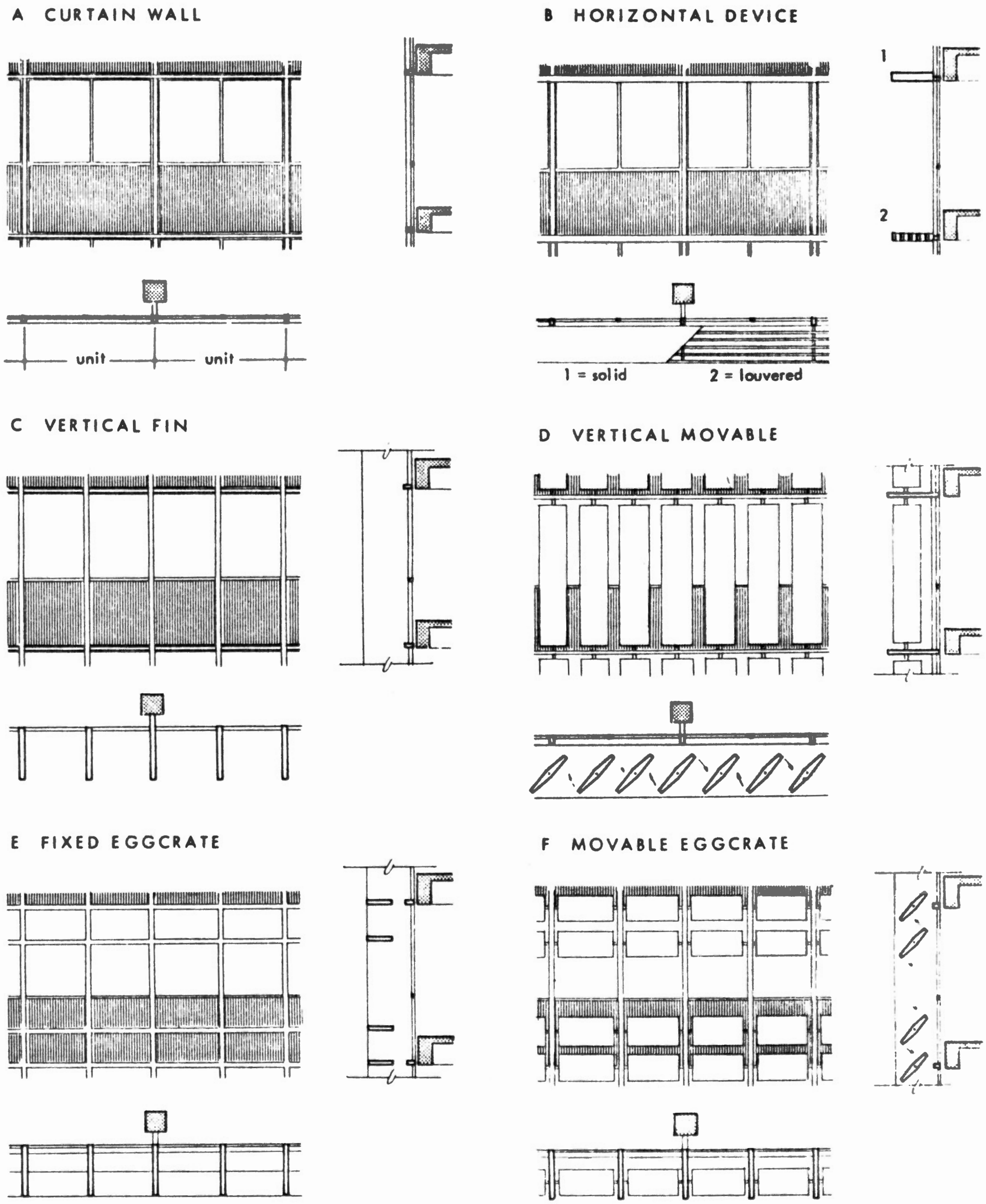
Figure 6. Optical Properties for Typical Quarter-Inch Plate Glass

Other transmittance properties of glass are of interest besides angle placement. These properties are characteristic of the way the glass is manufactured, and the design effectiveness is dependent on the glazing type selected. These characteristics include thickness, number of glazings, tint additives, and reflective coatings. Normally, an increase in any of these characteristics will reduce the amount of daylight reaching the space. There are other important considerations which may dictate a need for an increase in these characteristics, such as double glazing to reduce thermal impact. Because of its importance in its contribution to the building design, more research is being conducted on glass to improve visible sight transmission while reducing thermal transmission.[3] Selective coatings are also being considered for use under a variety of climatic conditions.[4] Hopefully, as daylight utilization is increased, the overall performance of glass and its utilization will also increase.

Shading

The second major consideration for a daylight scheme involves direct sunlight control with shading devices. A large array of sun control devices is available to the building designer.[5] They include exterior architectural appendages; screens, shutters, blinds, awnings and overhangs; hangs; and interior solar absorbing and reflecting glass.[6] All of these devices are utilized to prevent the direct transmission of sunlight, to reduce glare, and to reduce heat gain and heat loss.[7]

Figure 7 shows standard types of external shading devices. This type of solar control device is most effective if properly designed to accommodate different orientations for all annual solar variations. Fixed devices offer maintenance-free permanent control, but if incoming light is to be maintained on cloudy days, then these devices become excessively restrictive. Overcast sky sensing controls integrated with moveable devices offer more flexibility. East and west orientations,



Source: V. Olgyay, Design With Climate (Princeton, New Jersey, 1963), p. 73.

Figure 7. Standard Types of External Shading Devices

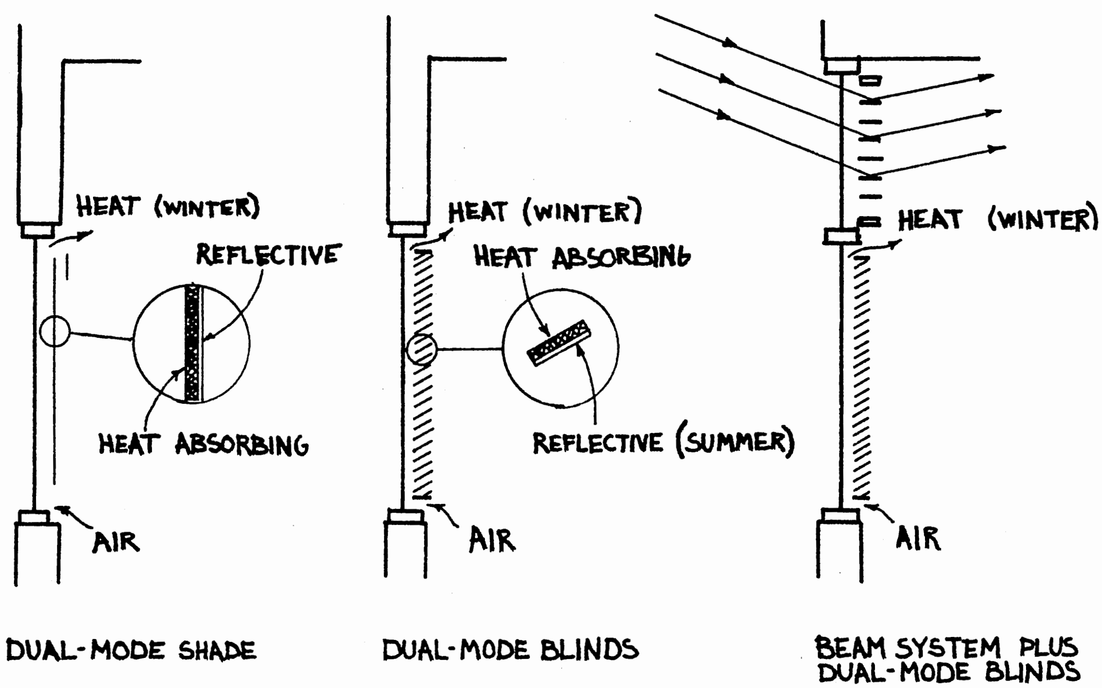
which have a year-round control problem, require massive fixed devices for total control of harsh early morning and late afternoon solar altitudes, but the other portion of the day they require no shading at all. This makes flexible controls more desirable on these orientations. Southern exposures have more of a seasonal problem and can be fairly well controlled with properly sized overhangs, or horizontal louvers. Northern orientations have no real need for shading because normal office hours do not typically coincide with the times when sunlight will penetrate this exposure.

The interaction of external shading devices to control sunlight and solar heat gain can have a varying effect and is dependent on the design. If summer sun is depleted before it reaches the space, then it does not appreciably contribute to the building load. If winter sun is desired for passive heating, then the devices can be designed appropriately, but this may interfere with the daylight quality. The shading design must be carefully weighed to determine the tradeoff between these two considerations. Use of external devices may not be justified for daylighting only, but may be if passive solar control of direct heat gain is desired. Maintaining these two concepts through the entire design of the building is essential to justify the large initial building cost of total exterior sunlight control. For only daylight control, probably a partial external scheme integrated with an interior control scheme would be more flexible, efficient and less expensive.

Interior solar control devices are used more than exterior devices because of initial cost savings, and the accessibility and control they offer the occupant.[8] Interior devices are generally installed because no external control devices exist, because they are supplementing partial exterior control, or because a personal comfort control device is needed. As far as the occupant is concerned, these devices control not only direct sun, but accompanying heat gain and glare. Manual interior controls are more desirable to an occupant because he feels more in control of the space, but there are a couple of problems which affect the overall building efficiency. Interior shading schemes allow the penetration of radiant energy into the space, which will be converted to heat and result in a heat gain due to the greenhouse effect.[9] Also, adequate glare control measures may result in excessive loss in luminous energy entering the space, causing a reduction in effectiveness of the window as a light source.[10] These problems are receiving more attention as daylighting becomes more widely utilized.

To reduce heat gain with interior shading schemes and still maintain light levels, a selective material is needed that will allow light energy to pass but will reflect heat energy. This type of product is currently being developed for glass rather than for blinds. Interior devices have developed more toward a dual mode shading that either reflects or absorbs heat while maintaining light control. Rosenfeld has suggested a venetian blind constructed of low light transmitting gray plastic with a metallic reflective coating on one side.[11] It can be adjusted to absorb or reflect direct sun and still allow penetration of daylight. Another type of device, developed by Silverstein, consists of a reversible roller shade that has a dark absorbing side and a reflecting side.[12] This system, like the other, can influence seasonal solar gain and still allow the passage of light. These two devices are illustrated in Figure 8.

Effective control of daylight glare without infringing on penetration efficiency is another problem. Occupant response and subsequent shade adjustment is a difficult prediction. If manual blinds are installed, an occupant can reduce the daylight effectiveness. Automatic controls with no manual override maintain a scheme's efficiency, but these systems have been deemed complex and costly.[13] A better approach to reducing glare has been to use manual blinds that only partially cover the window in conjunction with partial outdoor shading. This type scheme does not allow the interior shades to carry the full burden of solar control but does allow the occupant to make some individual adjustments without impairing the daylight utilization.



Source: R.N. Helms, Illumination Engineering for Energy Efficient Luminous Environments (Englewood Cliffs, New Jersey, 1980), p. 285.

Figure 8. Internal Daylight and Heat Control Devices

The underlying fact of importance with interior devices is the occupant's desire for manual control of his space. It seems likely that office occupants will close blinds to control thermal or visual comfort, but it is not clear that they can be effectively motivated to operate these devices to achieve energy savings.[14] Recent work with venetian blinds indicates that office occupants will manage those blinds in a manner that distinguishes seasonal differences and differences in orientations.[15] This leaves some hope that occupants can use blinds effectively if the blinds do not have to carry the total burden of solar control and if the occupants are aware of their interaction influences.

The last technique for solar control involves the built-in shading characteristics of the glass itself. This type of shading was mentioned indirectly in the discussion of glass transmission properties. Increasing light penetration through the glass is desired for daylighting, but recent developments in the glazing industry have produced new reflectance and transmittance properties.[16] Again, the key to efficient daylighting is to allow entry of the visible portion of reflected sunlight and sky effects, but to reflect short wave radiation associated with direct heat gain. Programs are being supported to develop selective solar coatings for windows.[17] Also, there has been the suggestion of glass that acts as its own optical shutter, much as today's light sensitive photo-gray eyeglass lenses which darken in bright sunlight but become clear in lower light levels. There are, however, problems of production cost, life expectancy, and durability.

Penetration and Reflection

The third major consideration for a daylight scheme involves increasing penetration of daylight through the use of reflective surfaces in the design scheme. Reflectivity is a relatively simple phenomenon since the angle of incoming light is reflected off a surface at the same angle. The quantity of light reflected is also dependent on the surface material used. Reflections from mirrored or polished surfaces are utilized when the distances of penetration are great and high light levels need to be maintained. Delivery of this reflected light should occur overhead so as not to interfere with the occupant's vision zone, because of lights tendency to be a glare source. White or light colored surfaces are used to diffuse and reflect light directly down from overhead light plenums into work areas. Placement of a reflection device can be internal or external and the device can have varying degrees of sophistication.

External reflections can take many forms and one common one is the simple ground reflection. Control of this reflected light component is possible by the selected use of ground cover. For instance, white stones or concrete diffuse light, water or snow will reflect light and most vegetation will absorb light. A simple technique for increasing penetration is to have a reflective surface on the underside of an overhang that will redirect light from a reflective ground cover near the building. However, the application of ground reflection techniques is limited to low rise buildings. Reflectance values of common ground surfaces are shown in Table IV.

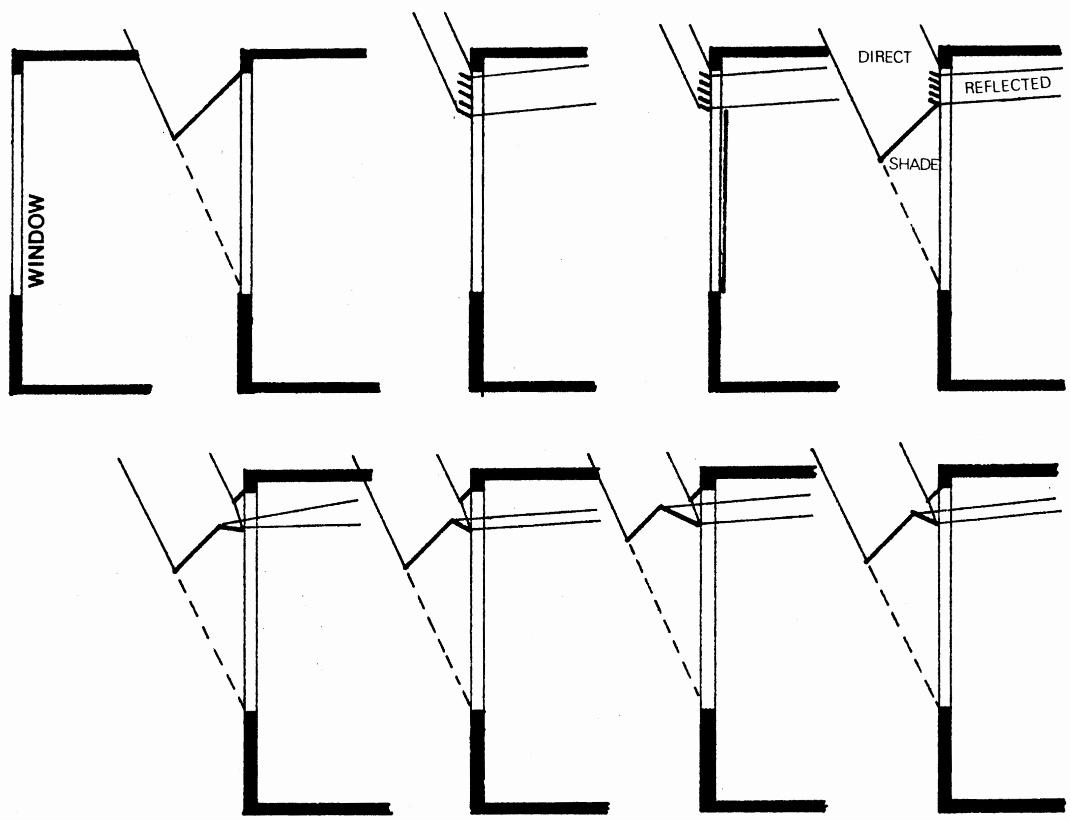
Other buildings or elements of the same building, such as opposing walls, parapets, or external stairwells, can also be utilized for reflection, especially if properly placed with respect to a given direct solar angle. More efficient devices, such as light shelves placed on the perimeter, can capture direct sunlight before it reaches the space and reflect it deeper into the space above the occupants. The ceiling can then act as a diffuser and reflect light down to desk tops. Figure 9 shows how this system works and how variations on the design have been analyzed by Rodgers.[18] More sophisticated optical systems employing collectors, lenses, and diffusers can increase penetration and daylighting efficiency immensely, but can also be quite costly. This methodology of solar optics is discussed by Bennett.[19]

TABLE IV

REFLECTANCE VALUES OF COMMON GROUND SURFACES

Grass fields, lawns	6%
Snow, fresh	74%
Snow, old	64%
Wild fields	25%
Concrete	55%
Macadam	18%
Gravel	13%
Bare earth	7%

Source: <u>How to Predict Interior Daylight Illumination</u>, (Toledo, Ohio, 1976), p. 11.



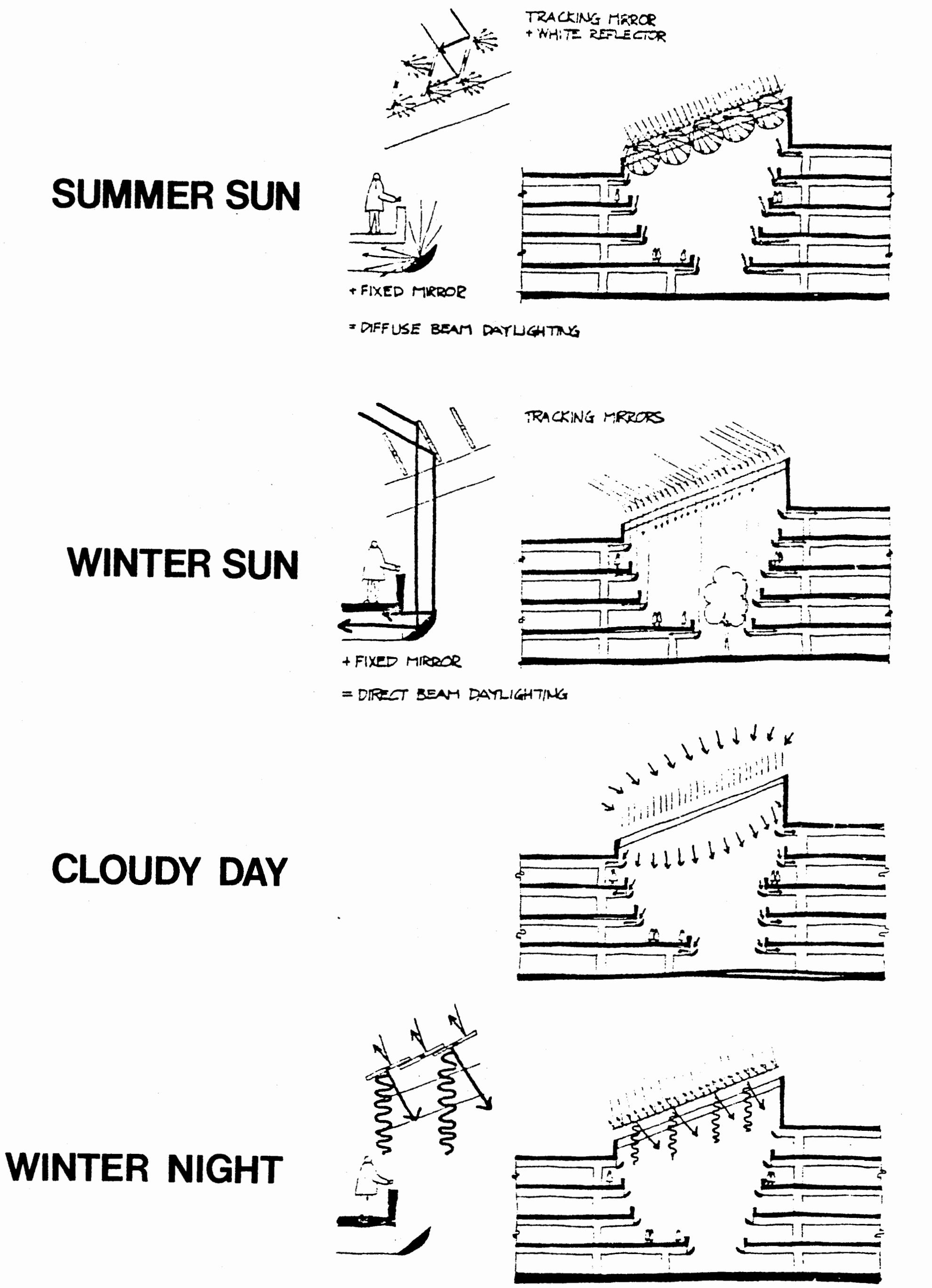
Source: C. Dunkerley, N.C. Rodgers and J.A. Ballinger, "Analysis of Innovative Methods in Natural Lighting," Architectural Science Review, Vol. 22, No. 2 (June, 1979), p. 44.

Figure 9. Light Shelf Design Techniques

One project worth investigating because of its planned extensive use of daylight is a new office bulding for the Tennessee Valley Authority (TVA).[20,21] This state-of-the-art building was designed to employ several of the daylighting techniques already discussed. The design utilizes automatic tracking mirrors that adjust to changes in the sun angle and also to changing cloud cover conditions. The mirrors reflect light to a central atrium space that funnels light down to ground level for the entire length of the building. Figure 10 shows how a louver system for this project can reflect summer sun from the front of one mirrored side to the white back side of its neighboring louver and then into the atrium. This allows for diffused daylighting while excluding direct rays of solar input. Winter sun is reflected directly into the atrium to allow direct beam daylighting for offices and passive solar heat gainfor the atrium. Cloudy day operation allows full opening of the louvers, and on winter nights, the louvers can be completely closed to reduce heat loss. Once light reaches the central atrium, it is then redirected to the open work areas at each offset level with a curved mirror along the ceiling light plenum.

Interior building characteristics which increase daylight penetration are usually simpler than outside devices. As pointed out earlier, a higher ceiling with full glazing will facilitate greater penetration depth than lower ceiling heights. Also, the use of reflective floor, ceiling, and wall surfaces is mandatory in daylight design. Walls parallel to the window wall should be discouraged so as not to dam-up incoming daylight. If these walls are are necessary for privacy, a translucent material should be used to maintain increased penetration depth. Partitions perpendicular to the window wall should be kept to a minimum, and open plan schemes with daylight arriving from more than one direction are encouraged. Many of these daylight design issues have been discussed and they should be studied and considered.[22]

These are some of the many considerations which must be made when the designer begins to think about the efficient daylighting of a building. This section of the process shows available options the designer can utilize before the actual daylight energy analysis is performed.



Source: S. Matthews and P. Calthorpe, "Daylighting as a Central Determinant of Design," AIA Journal, Vol. 68, No. 11 (September, 1979), p. 89.

Figure 10. Operation of Louver System for TVA Building

Once the daylight distribution is computed, then the final integration of artificial light with the daylight can be determined and the annual energy savings can be found.

FOOTNOTES

[1]F. Dubin, "Energy for Architects," Architecture Plus (July, 1973), p. 39.

[2]How to Predict Interior Daylight Illumination (Toledo, Ohio, 1976), p. 14.

[3]W. King, High Performance Solar Control Office Windows, Lawrence Berkeley Laboratory Report No. 7825 (Berkeley, California, 1977).

[4]R. N. Helms, Illumination Engineering For Energy Efficient Luminous Environments (Englewood Cliffs, N. J., 1980), p. 284.

[5]A. Olgyay and V. Olgyay, Solar Control and Shading Devices (Princeton, N. J., 1976).

[6]S. Selkowitz, "Daylighting and Passive Solar Buildings," Proceedings of 3rd National Passive Solar Conference, AS/ISES (San Jose, California, January 1979), p. 274.

[7]Helms, p. 284.

[8]Ibid.

[9]Ibid.

[10]Ibid.

[11]A. H. Rosenfeld, Some Comments on Dual Solar-Control Venetian Blinds, Lawrence Berkeley Laboratory, Dept. of Physics, University of California (Berkeley, California, 1976).

[12]S. D. Silverstein, "Efficient Energy Utilization in Buildings: The Architectural Window," Proceedings of 10th Intersociety Energy Conservation Engineering Conference (1973), p. 685.

[13]Selkowitz, p. 274.

[14]Ibid.

[15]A. Rubin, B. Collins, and R. Tibbot, Window Blinds as a Potential Energy Saver - A Case Study, National Bureau of Standard, Dept. of Commerce, BSS 112 (1978).

[16]Selkowitz, p. 275.

[17]King, p. 11.

[18]C. Dunkerley, N. C. Rodgers, and J. A. Ballinger, "An Analysis of Innovative Methods in Natural Lighting," Architectural Science Review (June, 1979), p. 44.

[19]D. Bennett and D. A. Eijadi, "Solar Optics: Projecting Light into Buildings," AIA Journal (September, 1979), p. 86.

[20]S. Matthews and P. Calthorpe, "Daylight as a Central Determinant of Design," AIA Journal (September, 1979), p. 86.

[21]"TVA Office Complex - a Teamwork Approach to Energy Efficiency," Lighting Design and Application (November, 1980), p. 31.

[22]M. Villecco, S. Selkowitz, and J. W. Griffith, "Strategies of Daylight Design," AIA Journal (September, 1979), p. 68.

CHAPTER VI

DAYLIGHT ANALYSIS

Determining Available Daylight

Once a basic building design scheme has been determined and the characteristics for the daylight scheme have been established then, a daylight level analysis must be made. This analysis is essential for verifying the actual effective perimeter zone area. The primary objective is to determine the rate at which the daylight levels diminish as the distance increases away from the windows. Knowing this daylight level information for both clear and cloudy conditions will facilitate the actual integration with the artificial light scheme. This section specifically deals with the discussion of how daylight levels can be determined, the method and variables used for this study, the time segments used, and appropriate daylight distribution contours.

Determining the daylight intensities in the perimeter zone can be found in two similar ways. The objective for either approach is to establish a lighting level contour rating system for the illumination on a horizontal work plane. One method commonly used is the daylight factor approach, or the determination of the ratio of the interior daylight illumination to the daylight received externally from the sky. This procedure is flexible and easy to apply because the factors are calculated only once and from there interior levels are determined by multiplying the factors by the particular sky luminance for a given time.

Systems similar calculations are made for other methods but the result is the actual interior daylight footcandle levels for a particular time, season, and latitude. This approach is somewhat slower and more cumbersome because calculations must be repeated for each time segment. The final results, however, from either method are similar since the daylight factor can be determined for the calculated interior level and the outdoor luminance value used in the calculation.

A variety of analysis methods for calculating interior daylight levels are in use today, each with differing capabilities, and varying strengths and weaknesses.[1] A computational method is available from the IES Handbook or from the Libbey-Owens-Ford calculation kit.[2,3] A graphical analysis method is provided by a Waldram Diagram technique.[4] A protractor method by the Building Research Station (BRS) is available and there is an accompanying nomograph based on this method.[5] Computer programs such as UWLIGHT and QUICKLITE I are available to perform repetitive calculations for detailed analysis.[6,7] Physical modeling techniques using scale models also work well for determining interior illumination using actual outdoor conditions or artificial sky conditions.[8]

Lumen Method (LOF)

The method of analysis utilized in this study will be the Libbey-Owens-Ford (LOF) version of the lumen method developed by the Illuminating Engineering Society.[9] The lumen (LOF) method is a computational one based on several building design variables and calculates footcandle levels on the work plane for three points in a perimeter room. The calculations are made for only one solar altitude, one sky condition and one orientation at one point in time. This means that a repetition of the calculation process will be needed to accurately represent the building's annual cycle and varying orientations. The aid of a computer could help reduce this task.

Table V shows the variables utilized in the lumen (LOF) method. These variables represent different building and site characteristics which affect the amount of daylight at three points on the work plane. The major components in the analysis process and the variables upon which they are dependent are listed in Table VI.

Illumination on the window (E_{kuw}) is a function of both the diffuse sky component and the direct sun component. If it is assumed that no direct sun enters the space, then the direct sun component may not be considered. The sky component, on the other hand, is the major continuous contributor to interior levels and provides the major opportunity for daylight utilization. Figure 11 shows the available illumination versus solar altitude as a function of the horizontal angle between the window surface and the sun for three seasonal clear sky conditions. The chart shows clearly, that if clear conditions are predominant, then as much glazing as possible should face toward the sun as much of the day as possible. This, however, does not mean a predominant amount of the glazing should be oriented toward the south, because all orientation receive adequate daylight, even when they are facing away from the sun. If cloudy conditions occur most of the year, then the glazing should definitely be oriented to all directions because all receive the same amount of illumination. Figure 12 shows the available illumination for a given solar altitude for cloudy conditions.

Illumination on the ground (E_{kug}) is a function of both the diffused sky component and the direct sun component. In this case, direct

TABLE V

LUMEN METHOD (LOF) LIGHTING CONDITION VARIABLES

E_{kw}	Illumination from sky on window.
E_{kg}	Illumination from sky on ground.
E_{uw}	Illumination from sun on window.
E_{ug}	Illumination from sun on ground.
E_{kuw}	Illumination from sun and sky on window ($E_{kw} + E_{uw}$).
E_{kug}	Illumination from sun and sky on ground ($E_{kg} + E_{ug}$).
E_{gw}	Illumination from ground on window.
E_{kwp}	Illumination from sky (and sun) on work plane--Max, Mid, Min.
E_{gwp}	Illumination from ground on work plane--Max, Mid, Min.
R_g	Reflectance of ground surface.
A_g	Window area of transmittance.
T_g	Transmittance of glass for average daylight.
C_{os} and K_{os}	Coefficients of Utilization--overcast sky.
C_{cs} and K_{cs}	Coefficients of Utilization--clear sky.
C_{us} and K_{us}	Coefficients of Utilization--uniform sky.
C_{sv} and K_{sv}	Coefficients of Utilization--sky, with venetian blind.
C_{ug} and K_{ug}	Coefficients of Utilization--uniform ground.
C_{gv} and K_{gv}	Coefficients of Utilization--ground with venetian blind.
V_s	Venetian blind angle factor, sky.
V_g	Venetian blind angle factor, ground.

Source: How to Predict Interior Daylight Illumination (Toledo, Ohio, 1976), p. 35.

sun can be utilized as a reflected component since it enters the space from the ground instead of arriving directly as a sky component. Figure 13 shows available illumination from direct sun on a horizontal ground surface versus the solar altitude. This figure is also used for direct sun striking a window surface and the sun's impact is dependent on the incident angle between the window surface and the sun. The reflected sky components are used for ground illumination found on the lines labeled "horizontal" in Figures 11 and 13 for clear conditions and Figure 12 for cloudy conditions. Opportunities for improving daylight penetration into perimeter spaces exist in the ground reflectance variable.

TABLE VI

LUMEN METHOD (LOF) MAJOR LIGHTING COMPONENT VARIABLES

$E_{kw} + E_{uw} = E_{kuw}$ (Illumination on window)

$E_{kg} + E_{ug} = E_{kug}$ (Illumination on ground)

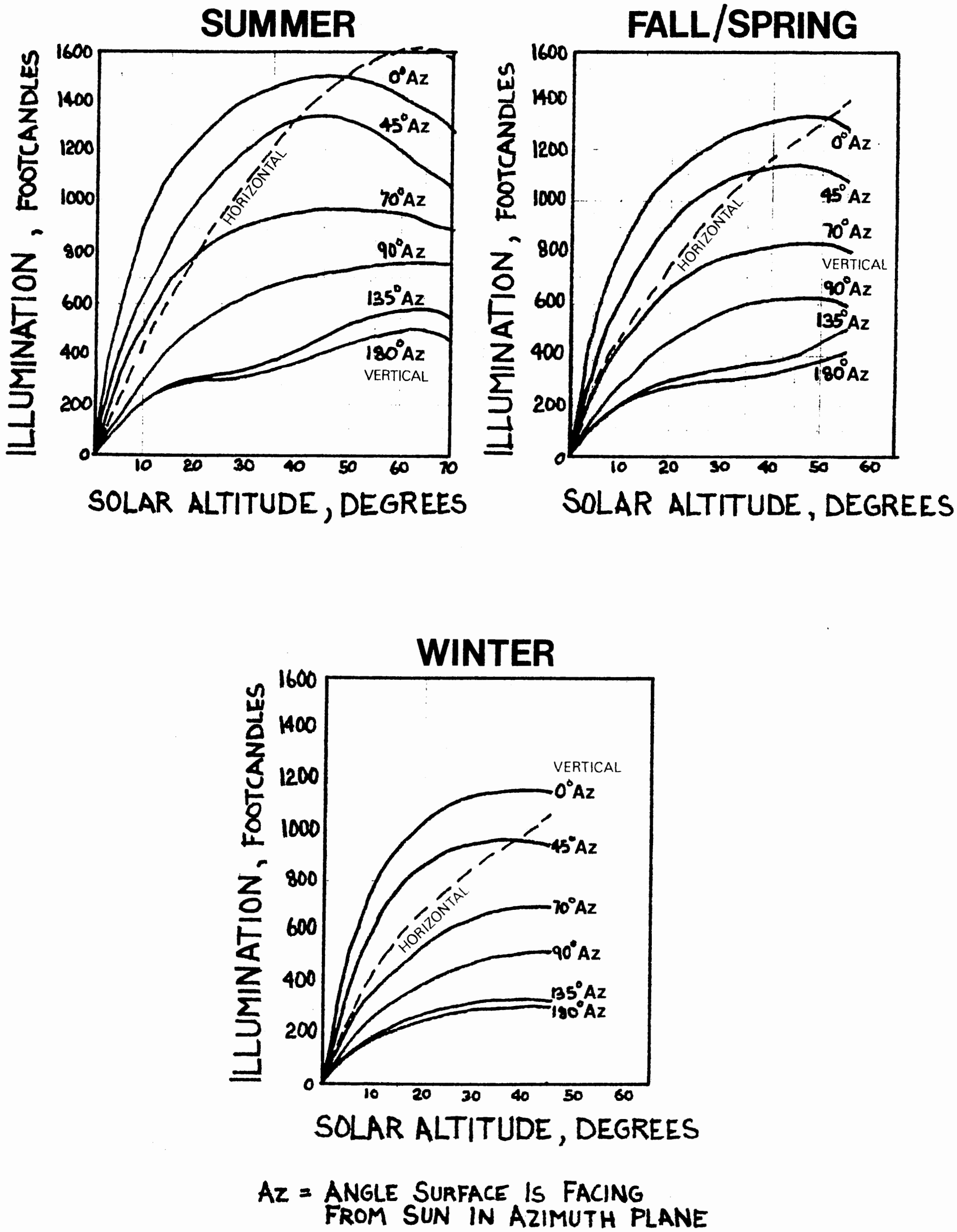
$E_{kug} \times R_g \times 0.5 = E_{gw}$ (Illumination from ground on window)

$E_{kuw} \times A_g \times T_g \times C \times K = E_{kwp}$ (Illumination from sky on work plane)

$E_{gw} \times A_g \times T_g \times C \times K = E_{gwp}$ (Illumination from ground on work plane)

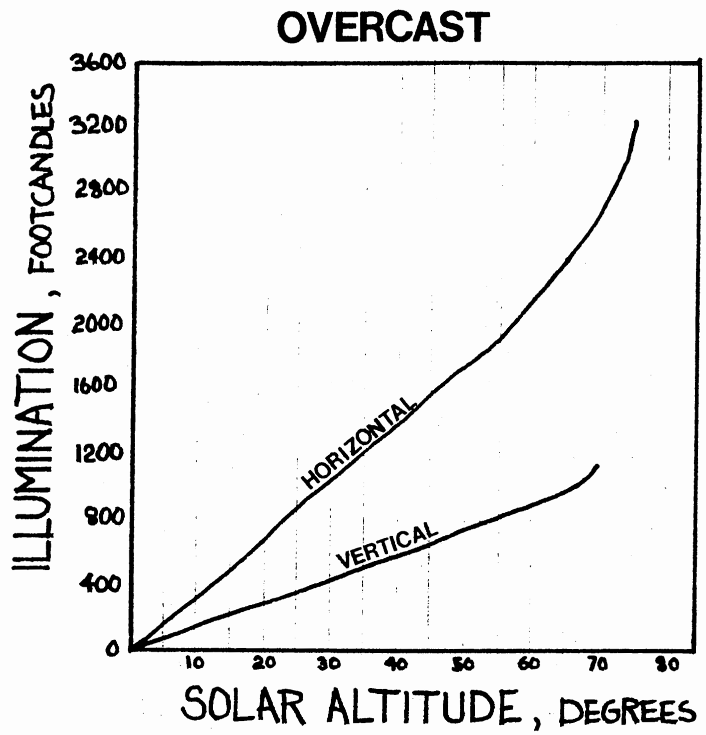
$E_{kwp} + E_{gwp}$ = Total illumination on work plane

Source: How to Predict Interior Daylight Illumination (Toledo, Ohio, 1976), p. 17.



Source: How to Predict Interior Daylight Illumination (Toledo, Ohio, 1976), p. 36.

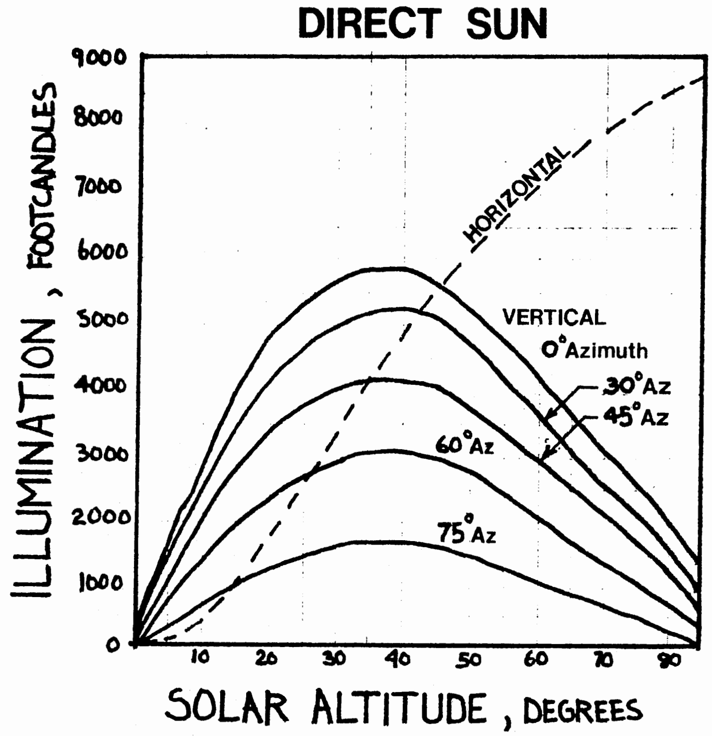
Figure 11. Available Daylight Graphs for Clear Sky Seasonal Conditions



Source: How to Predict Interior Daylight Illumination (Toledo, Ohio, 1976), p. 36.

Figure 12. Available Daylight Graph for Overcast Sky

Illumination from the ground on the window (E_{gw}) is a function of the previous illumination of the ground (E_{kug}) modified by the reflectance value of the given ground surface. These surface reflectances have been given in Table IV. An additional modification factor of 0.5 is used to represent the lower half of the visible field seen from the window. Increasing daylight penetration can only occur with the type of ground surface present outside the window. Surfaces with greater reflectance should be considered to improve the illumination levels, while being careful to control increased potentials for glare.



Source: How to Predict Interior Daylight Illumination (Toledo, Ohio, 1978), p. 37.

Figure 13. Available Daylight Graph for Direct Solar Illumination

Illumination from the sky on the work plane (E_{kwp}) is a function of the previous illumination on the window (E_{kuw}) modified by two window variables and two room characteristic variables. The window variables are area of light transmitting surface and the actual transmittance of the glass type selected for the project. Table VII shows transmittance values for typical glass types under average daylight conditions. The two room variables that affect the amount of light on the work plane are room length and room ceiling height; both are a function of room width versus the wall reflectances. Two wall reflectance values are provided, 30 or 70 percent and the ceiling and floor reflectances are always assumed to be 80 and 30 percent, respectively. Table VIII shows the

TABLE VII

TRANSMITTANCE VALUES FOR SELECTED GLAZING TYPES

Material	Approximate Transmittance (%)
Polished plate/float glass	80-90
Sheet glass	85-91
Heat-absorbing plate glass	70-80
Heat-absorbing sheet glass	70-85
Tinted polished plate	40-50
Reflective glass	23-30
Figure glass	70-90
Corrugated glass	80-85
Glass block	60-80
Clear plastic sheet	80-92
Tinted plastic sheet	42-90
Colorless patterned plastic	80-90
White translucent plastic	10-80
Glass fiber reinforced plastic	5-80
Double glazed, two lights clear glass	77
Tinted plus clear	37-45
Reflective glass	5-25

Source: R. N. Helms, Illumination Engineering for Energy Efficient Luminous Environments (Englewood Cliffs, New Jersey, 1980), p. 296.

TABLE VIII

COEFFICIENTS OF UTILIZATION FOR ILLUMINATION FROM THE SKY WITHOUT WINDOW CONTROLS

Overcast Sky

		C_{os}					
Room Length		20'		30'		40'	
Wall Reflectance		70%	30%	70%	30%	70%	30%
Room Width							
	20'	.0276	.0251	.0191	.0173	.0143	.0137
Max	30'	.0272	.0248	.0188	.0172	.0137	.0131
	40'	.0269	.0246	.0182	.0171	.0133	.0130
	20'	.0159	.0117	.0101	.0087	.0081	.0071
Mid	30'	.0058	.0050	.0054	.0040	.0034	.0033
	40'	.0039	.0027	.0030	.0023	.0022	.0019
	20'	.0087	.0053	.0063	.0043	.0050	.0037
Min	30'	.0032	.0019	.0029	.0017	.0020	.0014
	40'	.0019	.0009	.0016	.0009	.0012	.0008

		K_{os}							
Ceiling Ht.		8'		10'		12'		14'	
Wall Reflectance		70%	30%	70%	30%	70%	30%	70%	30%
Room Width									
	20'	.125	.129	.121	.123	.111	.111	.0991	.0973
Max	30'	.122	.131	.122	.121	.111	.111	.0945	.0973
	40'	.145	.133	.131	.126	.111	.111	.0973	.0982
	20'	.0908	.0982	.107	.115	.111	.111	.105	.122
Mid	30'	.156	.102	.0939	.113	.111	.111	.121	.134
	40'	.106	.0948	.123	.107	.111	.111	.135	.127
	20'	.0908	.102	.0951	.114	.111	.111	.118	.134
Min	30'	.0924	.119	.101	.114	.111	.111	.125	.126
	40'	.111	.0926	.125	.109	.111	.111	.133	.130

Clear Sky

		C_{cs}					
Room Length		20'		30'		40'	
Wall Reflectance		70%	30%	70%	30%	70%	30%
Room Width							
	20'	.0206	.0173	.0143	.0123	.0110	.0098
Max	30'	.0203	.0173	.0137	.0120	.0098	.0092
	40'	.0200	.0168	.0131	.0119	.0096	.0091
	20'	.0153	.0104	.0100	.0079	.0083	.0067
Mid	30'	.0082	.0054	.0062	.0043	.0046	.0037
	40'	.0052	.0032	.0040	.0028	.0029	.0023
	20'	.0106	.0060	.0079	.0049	.0067	.0043
Min	30'	.0054	.0028	.0047	.0023	.0032	.0021
	40'	.0031	.0014	.0027	.0013	.0021	.0012

		K_{cs}							
Ceiling Ht.		8'		10'		12'		14'	
Wall Reflectance		70%	30%	70%	30%	70%	30%	70%	30%
Room Width									
	20'	.145	.155	.129	.132	.111	.111	.101	.0982
Max	30'	.141	.149	.125	.130	.111	.111	.0954	.101
	40'	.157	.157	.135	.134	.111	.111	.0964	.0991
	20'	.110	.128	.116	.126	.111	.111	.103	.108
Mid	30'	.106	.125	.110	.129	.111	.111	.112	.120
	40'	.117	.118	.122	.118	.111	.111	.123	.122
	20'	.105	.129	.112	.130	.111	.111	.111	.116
Min	30'	.0994	.144	.107	.126	.111	.111	.107	.124
	40'	.119	.116	.130	.118	.111	.111	.120	.118

Source: How to Predict Interior Daylight Illumination (Toledo, Ohio, 1976), p. 38.

modifiers, known as coefficients of utilization, for both room length and ceiling height when no window controls are used, and for either clear or overcast conditions. If window controls are used, these modifiers should be obtained from Table IX in a similar fashion. One set of tables is for windows with diffusing window shades and assumes a uniform sky. The transmittance factor of the shade should be incorporated in the equation also. The other set of tables is for windows with venetian blinds and assumes direct sun is striking on the window. Once the room modifiers are found, assuming the use of venetian blinds, then an additional modifier is applied based on the angle at which the blinds are set to exclude direct sun. All of these room modifiers are given for the three room analysis point locations; MAX, MID and MIN and the modifiers can be found in Table V. The three prediction points occur on three desk tops, 30 inches high, centered in the length of the room, max is five feet from the window, min is five feet from the far wall, and mid is halfway between.

Illumination from the ground on the work plane (E_{gwp}) is very similar to the previous illumination from the sky on the work plane (E_{kwp}) except it is based on illumination from the ground on the window (E_{gw}). It is modified with the same window and room characteristic variables except the room modifiers come from a different set of tables. Table X is for windows without sun controls and Table XI is for windows with sun controls. All modifiers are given for the same three prediction point locations.

Maximizing daylight for both (E_{kwp}) and (E_{gwp}) can occur in either the window variable modifiers or the room variable modifiers. Designing for the most possible glazing and using glass with the highest

TABLE IX

COEFFICIENTS OF UTILIZATION FOR ILLUMINATION FROM THE SKY WITH WINDOW CONTROLS

With Diffuse Shade

C_{us}

Room Length		20'		30'		40'	
Wall Reflectance		70%	30%	70%	30%	70%	30%
Room Width							
Max	20'	.0247	.0217	.0174	.0152	.0128	.0120
	30'	.0241	.0214	.0166	.0151	.0120	.0116
	40'	.0237	.0212	.0161	.0150	.0118	.0113
Mid	20'	.0169	.0122	.0110	.0092	.0089	.0077
	30'	.0078	.0060	.0067	.0048	.0044	.0041
	40'	.0053	.0033	.0039	.0028	.0029	.0024
Min	20'	.0108	.0066	.0080	.0052	.0063	.0047
	30'	.0047	.0026	.0042	.0023	.0029	.0020
	40'	.0027	.0013	.0022	.0012	.0018	.0011

K_{us}

Ceiling Ht.		8'		10'		12'		14'	
Wall Reflectance		70%	30%	70%	30%	70%	30%	70%	30%
Room Width									
Max	20'	.145	.154	.123	.128	.111	.111	.0991	.0964
	30'	.141	.151	.126	.128	.111	.111	.0945	.0964
	40'	.159	.157	.137	.127	.111	.111	.0973	.0964
Mid	20'	.101	.116	.115	.125	.111	.111	.101	.110
	30'	.0952	.113	.105	.122	.111	.111	.110	.122
	40'	.111	.105	.124	.107	.111	.111	.130	.124
Min	20'	.0974	.111	.107	.121	.111	.111	.112	.119
	30'	.0956	.125	.103	.117	.111	.111	.115	.125
	40'	.111	.105	.125	.111	.111	.111	.133	.124

With Venetian Blind

C_{sv}

Room Length		20'		30'		40'	
Wall Reflectance		70%	30%	70%	30%	70%	30%
Room Width							
Max	20'	.0556	.0556	.0392	.0397	.0298	.0317
	30'	.0522	.0533	.0367	.0389	.0278	.0311
	40'	.0506	.0528	.0359	.0381	.0270	.0306
Mid	20'	.0556	.0556	.0418	.0411	.0320	.0364
	30'	.0372	.0339	.0278	.0286	.0220	.0256
	40'	.0217	.0211	.0192	.0186	.0139	.0164
Min	20'	.0556	.0556	.0422	.0456	.0320	.0409
	30'	.0294	.0233	.0222	.0203	.0189	.0194
	40'	.0139	.0110	.0133	.0108	.0120	.0100

K_{sv}

Ceiling Ht.		8'		10'		12'		14'	
Wall Reflectance		70%	30%	70%	30%	70%	30%	70%	30%
Room Width									
Max		.154	.170	.129	.131	.107	.112	.091	.091
Mid	20'	.100	.106	.101	.106	.099	.102	.091	.091
	30'	.074	.080	.086	.090	.091	.093	.091	.091
	40'	.070	.079	.079	.084	.088	.091	.091	.091
Min	20'	.080	.091	.091	.091	.093	.093	.091	.091
	30'	.068	.079	.079	.079	.087	.087	.091	.091
	40'	.064	.076	.076	.076	.084	.084	.091	.091

Source: How to Predict Interior Daylight Illumination (Toledo, Ohio, 1976), p. 38.

TABLE X

COEFFICIENTS OF UTILIZATION FOR ILLUMINATION FROM THE GROUND WITHOUT WINDOW CONTROLS

Uniform Ground

C_{ug}

Room Length		20'		30'		40'	
Wall Reflectance		70%	30%	70%	30%	70%	30%
Room Width							
	20'	.0147	.0112	.0102	.0088	.0081	.0071
Max	30'	.0141	.0112	.0098	.0088	.0077	.0070
	40'	.0137	.0112	.0093	.0086	.0072	.0069
	20'	.0128	.0090	.0094	.0071	.0073	.0060
Mid	30'	.0083	.0057	.0062	.0048	.0050	.0041
	40'	.0055	.0037	.0044	.0033	.0042	.0026
	20'	.0106	.0071	.0082	.0054	.0067	.0044
Min	30'	.0051	.0026	.0041	.0023	.0033	.0021
	40'	.0029	.0018	.0026	.0012	.0022	.0011

K_{ug}

Ceiling Ht.		8'		10'		12'		14'	
Wall Reflectance		70%	30%	70%	30%	70%	30%	70%	30%
Room Width									
	20'	.124	.206	.140	.135	.111	.111	.0909	.0859
Max	30'	.182	.188	.140	.143	.111	.111	.0918	.0878
	40'	.124	.182	.140	.142	.111	.111	.0936	.0879
	20'	.123	.145	.122	.129	.111	.111	.100	.0945
Mid	30'	.0966	.104	.107	.112	.111	.111	.110	.105
	40'	.0790	.0786	.0999	.106	.111	.111	.118	.118
	20'	.0994	.108	.110	.114	.111	.111	.107	.104
Min	30'	.0816	.0822	.0984	.105	.111	.111	.121	.116
	40'	.0700	.0656	.0946	.0986	.111	.111	.125	.132

Source: <u>How to Predict Interior Daylight Illumination</u> (Toledo, Ohio, 1976), p. 39.

TABLE XI

COEFFICIENTS OF UTILIZATION FOR ILLUMINATION FROM THE GROUND WITH WINDOW CONTROLS

Uniform Ground

C_{ug}

Room Length		20'		30'		40'	
Wall Reflectance		70%	30%	70%	30%	70%	30%
Room Width							
Max	20'	.0147	.0112	.0102	.0088	.0081	.0071
	30'	.0141	.0112	.0098	.0088	.0077	.0070
	40'	.0137	.0112	.0093	.0086	.0072	.0069
Mid	20'	.0128	.0090	.0094	.0071	.0073	.0060
	30'	.0083	.0057	.0062	.0048	.0050	.0041
	40'	.0055	.0037	.0044	.0033	.0042	.0026
Min	20'	.0106	.0071	.0082	.0054	.0067	.0044
	30'	.0051	.0026	.0041	.0023	.0033	.0021
	40'	.0029	.0018	.0026	.0012	.0022	.0011

K_{ug}

Ceiling Ht.		8'		10'		12'		14'	
Wall Reflectance		70%	30%	70%	30%	70%	30%	70%	30%
Room Width									
Max	20'	.124	.206	.140	.135	.111	.111	.0909	.0859
	30'	.182	.188	.140	.143	.111	.111	.0918	.0878
	40'	.124	.182	.140	.142	.111	.111	.0936	.0879
Mid	20'	.123	.145	.122	.129	.111	.111	.100	.0945
	30'	.0966	.104	.107	.112	.111	.111	.110	.105
	40'	.0790	.0786	.0999	.106	.111	.111	.118	.118
Min	20'	.0994	.108	.110	.114	.111	.111	.107	.104
	30'	.0816	.0822	.0984	.105	.111	.111	.121	.116
	40'	.0700	.0656	.0946	.0986	.111	.111	.125	.132

With Venetian Blind

C_{gv}

Room Length		20'		30'		40'	
Wall Reflectance		70%	30%	70%	30%	70%	30%
Room Width							
Max	20'	.0556	.0556	.0392	.0426	.0303	.0348
	30'	.0528	.0539	.0370	.0433	.0289	.0337
	40'	.0506	.0544	.0359	.0426	.0278	.0344
Mid	20'	.0556	.0556	.0414	.0459	.0320	.0381
	30'	.0367	.0356	.0274	.0308	.0217	.0270
	40'	.0239	.0233	.0192	.0222	.0153	.0181
Min	20'	.0556	.0556	.0430	.0486	.0328	.0398
	30'	.0261	.0228	.0214	.0211	.0170	.0192
	40'	.0128	.0108	.0119	.0107	.0098	.0097

K_{gv}

Ceiling Ht.		8'		10'		12'		14'	
Wall Reflectance		70%	30%	70%	30%	70%	30%	70%	30%
Room Width									
Max		.174	.200	.142	.157	.117	.123	.091	.091
Mid	20'	.104	.116	.110	.121	.106	.112	.091	.091
	30'	.074	.082	.092	.099	.099	.106	.091	.091
	40'	.058	.062	.079	.083	.092	.096	.091	.091
Min	20'	.078	.082	.093	.097	.099	.102	.091	.091
	30'	.058	.060	.074	.076	.090	.092	.091	.091
	40'	.052	.056	.070	.071	.086	.087	.091	.091

Source: How to Predict Interior Daylight Illumination (Toledo, Ohio, 1976), p. 41.

transmittance will obviously provide higher daylighting levels. However, this approach may not provide the best thermal resistance to the building envelope or the best glare and brightness control. Room variables also appear to affect daylighting, as higher wall reflectances, shorter room depths and narrower room widths will result in increased daylight levels. Spaces that are more compartmented seem to induce more secondary reflection and therefore maintain higher brightnesses. Lower ceiling heights provide higher daylight levels near the window, but higher ceilings increase penetration depths and provide more daylighted area. Window controls for modifying direct sun penetration reduce light levels, but facilitate glare and brightness control on designs that do not utilize exterior controls.

Once these variables are established, calculations can be performed to find (E_{kwp}) and (E_{gwp}). The addition of the sky and ground components yield the total illumination on the work plane. This is done for the three prediction points in the room; max, mid, and min. A summary of the procedure is given on page 17 of the LOF daylight illumination booklet.[10]

Time Segments

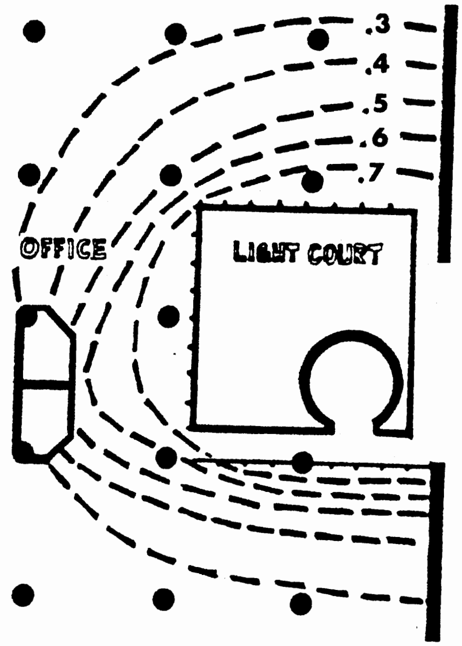
The ultimate goal of this study, which is determining annual savings, involves as much seasonal input as possible in order to simulate actual climatic variations that occur in an annual time span. Solar angles change on a daily and seasonal basis, so time segments have to be established in order to produce reasonable accuracy, but keep the number of calculations to a minimum. Usually, the smaller the time segments the more accurate the analysis will be, but there can be a tradeoff in the amount of time spent on a project. If this were a computer-aided process, detailed analysis could be used, but the lumen (LOF) method and the manual nature of this study dictate a computation method which averages seasonal differences and takes less time to accomplish.

The lumen (LOF) charts for available daylight in clear sky conditions are separated into three segments. They include summer, winter and the two mid-seasons, autumn/spring. Using the lumen (LOF) method, the annual breakdown of time segments are established for the three seasons and all monthly climatic data needed for the analysis can be averaged. The solar altitudes are available for any latitude and time of day with the use of a sun angle calculator.[11] This allows for a daily breakdown of time segments into each individual hour of the workday. Only half of the hours will have to be calculated, since the morning hours are a mirror image of the afternoon hours with regard to available illumination about the noon hour. The latitude at which the building is located and the orientations are established by the basic design. With this information, the daylight illumination can be determined for both clear and overcast conditions for each orientation at every hour of the working day and for an average day each month in each of the major seasons. This should provide a reasonably accurate picture of available daylight when the percent of overcast days for each month is determined from weather data in a weather atlas.[12]

Interior Daylight Contours

Once the daylight illumination levels have been calculated, then contours of either daylight factors or footcandles at the work plane can be drawn on the floor plan. This is an important step in determining the actual size of the effective perimeter zone and the rate at which illumination decreases going away from the window. This allows the designer to check and finalize an artificial lighting scheme. The location of interior zone lighting, which is not switched for daylight, starts at the point where the natural light is deemed inadequate. To be considered useful for an energy credit in office spaces, the daylight level should be at least one half of the task footcandle criteria level in order to accommodate practical switching controls.[13]

The final design of the luminaire system in the perimeter zone, and how, when and where they are switched must be considered. These considerations are resolved from the available daylight contours since they express the location of the daylight level changes. Different solutions may have to be examined for different orientations and for clear or overcast conditions. Seasonal differences may also influence the type and location of switching. A microprocessor programmed to respond only to seasons, orientations and times of day could be used, but may not be as efficient as a more sensitive dimming system. Day and night use must also be considered. All of the decisions can be finalized with a light level contour plan as shown in the example in Figure 14.



Source: L. L. Boyer, "Evaluation of Energy Savings Due to Daylighting," Proceedings of International Passive and Hybrid Cooling Conference, AS/ISES (Miami Beach, Florida, November, 1981), p. 346.

Figure 14. Typical Daylight Factor Contour Plan

FOOTNOTES

[1]S. Selkowitz, " Daylighting and Passive Solar Buildings," Proceedings of 3rd National Passive Solar Conference, AS/ISES (San Jose, California, January, 1979), p. 273.

[2]J. E. Kaufman, ed., IES Lighting Handbook - Application Volume (New York, 1981).

[3]How to Predict Interior Daylight Illumination (Toledo, Ohio, 1976).

[4]J. T. Walsh, The Science of Daylight (London, 1961).

[5]R. G. Hopkinson, Architectural Physics-Lighting (London, 1963).

[6]J. R. Bedrick, M. S. Millet, G. S. Spencer, D. R. Heerwagen, and G. B. Varey, "The Development and Use of the Computer Program UWLIGHT for the Simulation of Natural and Artificial Illumination in Buildings," Proceedings of the 2nd National Passive Solar Conference, AS/ISES (Philadelphia, Pennsylvania, March, 1978), p. 365.

[7]H. Bryan, R. Clear, J. Rosen, and S. Selkowitz, "Quicklite I, A Daylight Program for the TI-S59 Calculator," Lighting Design and Application (June, 1981), p. 28.

[8]H. Bryan, A. Lohr, R. C. Mathis, and J. Rosen, "The Use of Physical Models for Daylighting," Proceedings of the American Section of the International Solar Energy Society 1981 Annual Meeting, AS/ISES (Philadelphia, Pennsylvania, May, 1981), p. 653.

[9]Kaufman, p. 5-2.

[10]How to Predict Interior Daylight Illumination, p. 17.

[11]Sun Angle Calculator (Toledo, Ohio, 1976).

[12]Weather Atlas of the United States, U. S. Environmental Data Service (Detroit, Michigan, 1975).

[13]L. L. Boyer, "Evaluation of Energy Savings Due to Daylighting," Proceedings of International Passive and Hybrid Cooling Conference, AS/ISES (Miami Beach, Florida, November, 1981), p. 343.

CHAPTER VII

ARTIFICIAL LIGHTING INTEGRATION

Artificial Light Considerations

Optimizing the amount of electric energy that can be saved is the focus of this section on the artificial lighting scheme. Some savings will be achieved when a group of lamps or luminaires in the perimeter zone is dimmed or turned off. Of course, the total floor area will have to be served with lighting for night use, but some type of switching can be installed for clear sky conditions and overcast sky conditions. Nighttime use for building maintenance operations could also benefit from some type of switching mode because high light levels are not required for this task. For optimizing the luminaire layout, certain refinements will have to be made in the integration process after the daylight analysis has been conducted and the depth of useful penetration is known.

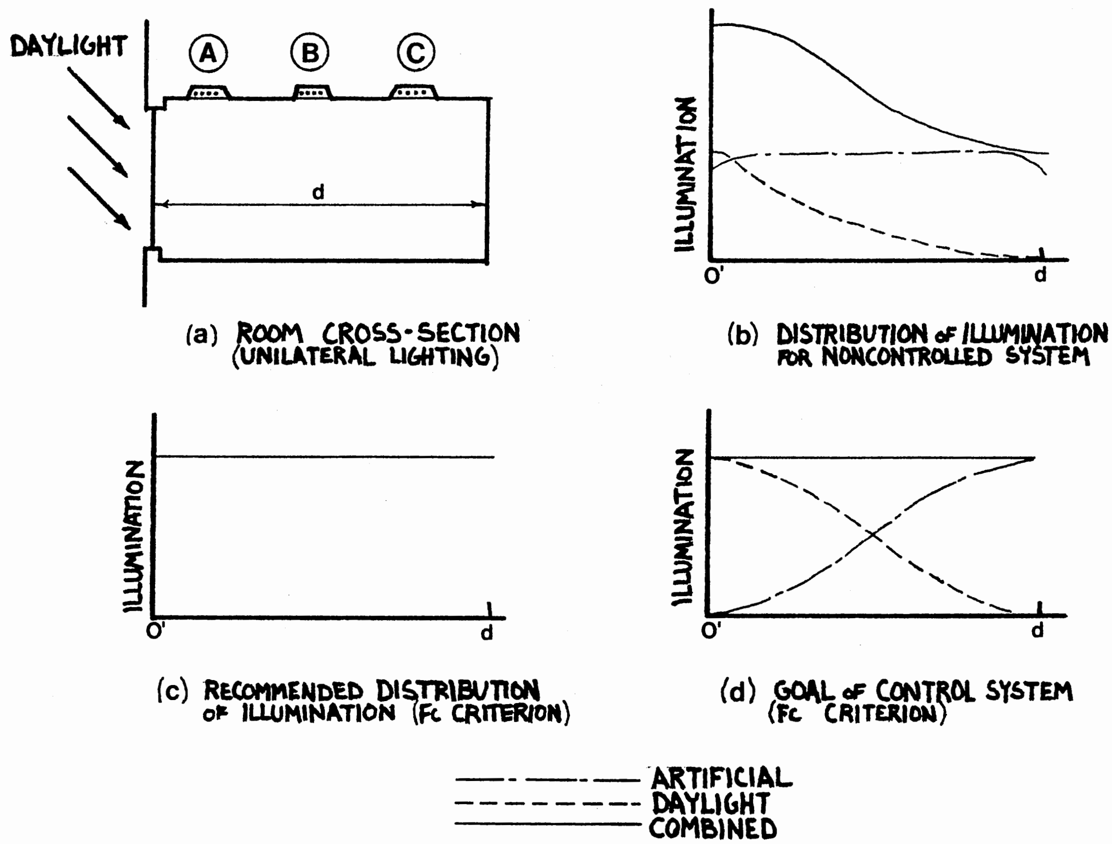
In this process, the design of artificial lighting in the core areas will not be discussed. This goes beyond the realm of this study, but efficient systems that prevent energy waste from overdesign are encouraged, especially the use of light heat reclaim systems. However, there is one facet that must be known and that is how much energy the system consumes on a square foot or luminaire basis. This is needed to establish an overall light usage which determines annual building savings. Discussion of the artificial system in the perimeter zone is the main focus of this section and once daylight levels are determined for clear and scheme can be checked.

Figure 15b shows how existing glass buildings do not take advantage of potential light savings through light switching. The designer must realize the potential of incoming daylight and switch luminaires near the window. The key to increasing energy savings is to find the most efficient mode of switching that is compatible with the occupants and their tasks. A given mode of switching and how the occupant responds to it is not fully understood due to the number of types of controls available. These include controls such as manual, automatic, a combination with occupant override, or even microprocessors. Other variables include the type of switching, on-off or a full range of dimming, and the type of photoelectric sensing devices used for automatic control.

Switching Controls

The simplest control device with the lowest initial cost is the on-off type. This system would probably be manually operated because the sharp changes in light levels would not be something the occupant would want done automatically. On the other hand, the occupant incentive to save energy may be reduced if the concept does not provide a stable environment, so all lights would be left on. It would probably be better to switch off too few lights on a circuit rather than too many and run the risk of not having the system used. Experimental results have been mixed on this issue, so careful consideration must be given to ensure its success.

> On-off can be handled on a circuit by circuit basis, fixture by fixture, on individual ballasts within a single fixture or with the use of multi-level ballasts. The latter options provide effective multi-level capability which may reduce the undesirable user response to on-off systems.[1]



Source: R. N. Helms, Illumination Engineering for Energy Efficient Luminous Environments (Englewood Cliffs, New Jersey, 1980), p. 292.

Figure 15. Combining Artificial and Daylight Source Contributions

Helms shows a simple on-off solution illustrated in Figure 15a.

One switch could be provided to control all the lamps in row A. A second switch could be used to turn off half the lamps in the second row B; a third switch would provide on-off control to row C and the other half of the lamps in row B. When a sufficient daylighting contribution exists in the space, switches A and B could be turned off to approximate the distribution in Figure 15d. If the daylighting contribution is inadequate (poor overcast, overcast, or nighttime) all three switches A, B, and C could be turned on.[2]

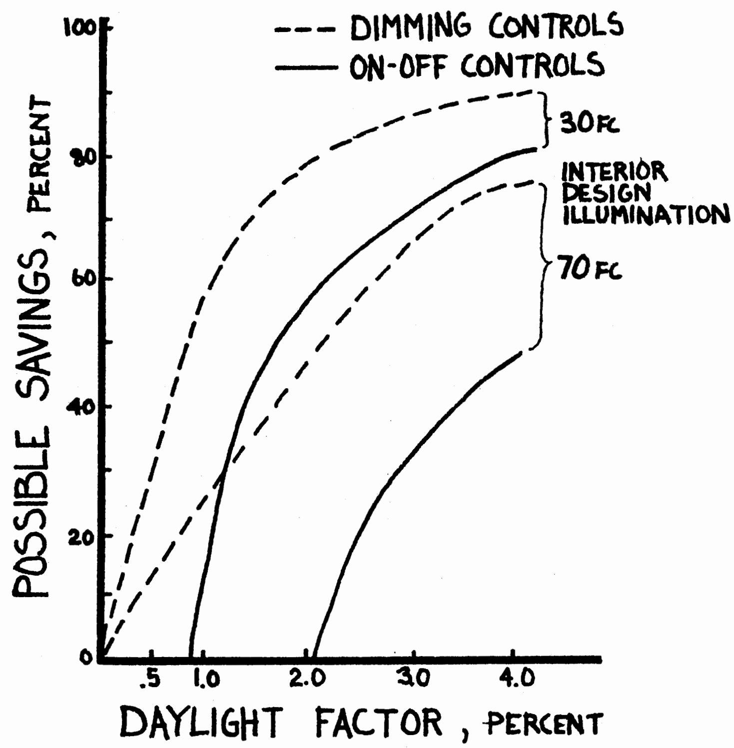
Helms is quick to point out that if the user of the space does not pay the utility bills, he will grow tired of making the appropriate adjustments and leave all artificial lights on. He suggests the key to daylight optimization lies in the use of automatic controls.

Dimmable systems are usually more complex and costly, but offer better interrelation with daylight. These systems offer small steps in light output and the user is not as distracted by the contrasts accompanying on-off systems. The key to optimizing dimming is knowing how much sophistication to purchase. A more sophisticated system will provide better integration and less occupant distraction, but savings may not justify first cost.

New solid state electronic ballasts for fluorescent lights are now being developed to handle the dimming controls.[3] With these ballasts, photosensing devices which actuate the light control becomes an important link. The number, location and interaction of photosensors with the lights is an important consideration. This responsibility may be left to the manufacturer when he develops a total packaged system, however, the same package may not be applicable to every design scheme. The sensitivity of the photosensors is also important so that they react to daylight conditions in a smooth and consistent manner. A comparison of three currently available systems of this type is shown by Pike.[4] He compared these systems to demonstrate occupant response, energy savings and cost effectiveness. All of these were demonstrated to be successful.

The selection of dimming systems versus on-off systems has an impact on the amount of energy that can be saved. Recent work outlines a procedure for determining the daylight savings with either dimming or on-off controls.[5,6] The results indicate that there are substantial additional savings realized from dimming control systems compared to on-off types.[7] This does not mean dimming systems are always better. Stability of the climate, office size and interior layout, and office tasks can influence the type of system to be selected. It becomes dangerous to always assume that maximizing savings is more important than occupant comfort requirements. So far, however, indications show that dimming systems are more favorable for energy savings and occupant comfort.

Another important aspect of selecting an on-off or dimming system is discussed by Selkowitz and illustrated in Figure 16.[8] The chart plots possible savings for both systems relative to two interior design illumination levels as a function of the daylight factor. It shows that at high daylight factors there is some difference in the two systems, but at low daylight factors the energy saved by dimmable systems is substantially higher. The chart also shows that as the interior design light level becomes higher the gap between savings becomes larger, and the lower the savings potential for either system. This emphasizes the importance of selecting an appropriate illumination level.[9]



Source: S. Selkowitz, "Daylighting and Passive Solar Buildings," Proceedings of the 3rd National Passive Solar Conference, AS/ISES (San Jose, California, January, 1979), p. 280.

Figure 16. Daylighting Savings Vs. Lighting Control Type

FOOTNOTES

[1]S. Selkowitz, "Daylighting and Passive Solar Buildings," _Proceedings of 3rd National Passive Solar Conference_, AS/ISES (San Jose, California, January, 1979), p. 275.

[2]R. N. Helms, _Illumination Engineering For Energy Efficient Luminous Environments_ (Englewood Cliffs, N. J., 1980), p. 291.

[3]R. Verderber, S. Selkowitz, and S. Berman, _Energy Efficiency and Performance of Solid State Ballasts_, Lawrence Berkeley Laboratory Report No. 7828 (Berkeley, California, 1978).

[4]T. F. Pike and J. Rizzuto, "Commercial Office Daylighting Demonstration," _Proceedings of the American Section of the International Solar Energy Society 1981 Annual Meeting_, AS/ISES (Philadelphia, Pennsylvania, May, 1981), p. 651.

[5]V. Crisp, "Energy Conservation in Buildings: A Preliminary Study of Automatic Daylight Control of Artificial Lighting," _Lighting Research and Technology_, Vol.9, No. 1 (1977), pp. 31-41.

[6]D. Hunt, "Simple Expression for Predicting Energy Savings from Photoelectric Control of Lighting," _Lighting Research and Technology_, Vol. 9, No. 2 (1977), pp. 93-102.

[7]Selkowitz, p. 276.

[8]Ibid.

[9]Ibid.

CHAPTER VIII

ANNUAL ENERGY SAVINGS

Annual Adjustments

Once a building's daylight design has been established and the electric lighting has been integrated, then the amount of energy saved can be calculated for the daylight scheme based on the usable daylight distribution. Switching lights off in daylight zones and then comparing the number off to the total number installed in the building can produce a percentage of lights not in use. This percentage can then be translated to instantaneous energy saved when the energy consumption is determined for the total lighting system. The total kilowatt-hours (kWh) of savings is found when an annual time segment is used to include the full range of solar angle variations and the typical cloud cover characteristics of the site.

The energy consumption of other systems directly related to the lighting system must also be considered for additional savings or subtractive spending potential. The energy use of dimmable ballasts in daylighted zones must be calculated as an annual percentage if the energy consumption rate is different from the conventional core ballasts used in the non-daylighted areas. Air-conditioning savings or heating non-savings must also be included as an annual percentage in order to reflect the total influence of the daylight design on the building's annual energy consumption.

The time segments used in the daylight level analysis are also used to determine displaced energy for each time segment of the annual time frame. First, the number of hours the lights are on in a typical working day is established starting at 7 a.m. and extending to 5 p.m. This includes the bulk of the daylight hours. The lunch hour can either be or not be included, depending on the operation of the building. Night-time hours are not included because daylighting is not effective at this time. In this process, an hourly evaluation, including the noon hour, yields eleven time points of solar variation during a typical working day. Examining the illumination levels produced by the daylight analysis can show if artificial lighting is needed at each point for each hour.

This summation process is repeated for each hour of the typical design day of each season. This is done because there are seasonal solar illumination differences for clear sky conditions. A typical seasonal day would be represented by a day with average available solar illumination for that season. The two mid-season days for fall and spring are September 21 and March 21. These two midpoint days do represent the average condition for their respective season and also happen to be the average condition for the whole year, so they fit the typical design day well. The midpoint days for the extreme seasons, summer and winter, do not represent typical seasonal conditions. June 21 and December 21 represent the most extreme conditions which only happen once a year. Realistically, a day halfway between the start and middle of the season should be used as a more typical value. June 1 or August 11 and December 1 or January 11 would more likely represent typical seasonal conditions. The problem with trying to use these values is the need for a sun-angle calculator or repetitious interpolation from solar angle tables of hourly sun angles for non-specific latitudes and times. In the interest of saving time in this process, the conditions for December 21 and June 21 are used because solar angle data are readily available and these two extreme conditions are assumed to average one another out for an annual analysis.

Cloud Cover Adjustments

Another major factor which affects the amount of daylight reaching a space is cloud cover. Overcast skies normally reduce the amount of illumination that can reach a space, but create equal light levels on all orientations because of diffused sky characteristics. In some cases this could be beneficial, especially if sufficient illumination levels are present and if the north orientation is receiving more light than it would under clear sky conditions. Also, the need for shading is reduced for all orientations. However, calculations for clear and overcast conditions for all time segments must be performed because of the unpredictability of climate. An example computer calculation tabulation of daylight footcandle levels for clear and overcast conditions is shown in Appendix B.

Applying cloud cover conditions to a project location is a somewhat arbitrary process. Weather data must be checked for the specific locale, and if not available, then data for a nearby town must be used, or must be determined from figures found in a weather atlas.[1] The type of data for cloud conditions comes in several forms, but the data is always based on a monthly average which can again be averaged for a seasonal average. A mean number of clear days or hours can be used for each month. There are also data for the mean number of overcast days, but the sum of both clear and overcast never equals the total amount of days for that time segment. The times which are not represented are presumably partly cloudy conditions which can be anything between clear and overcast.

A simple way to include cloud cover effects is to use the mean percentage of sunshine for each month. Then collapse the three months for seasonal averages and assume the remaining percentage is completely overcast. This gives weighting factors for each season which can be multiplied by design day averages for a typical representation of clear and overcast conditions. Reductions due to continual smog or haze should also be included. From here, the summation process for percent annual savings can begin.

Lighting Energy Savings

Figure 17 shows how the savings analysis is addressed for each prediction point. The time segment is one of the hourly conditions for one of the seasonally typical days. The three analysis points (Max, Mid, and Min) discussed in Chapter VI, establish perimeter bands parallel to the window wall. The illumination level derived from the lumen (LOF) method is used for each point to establish the illumination level for the whole zone even though it only represents the level at the cut-off point. Actually, all areas closer to the window than the cut-off line are assumed to have a higher level of illumination from daylight than the prediction point. A daylight level requirement can then be applied to each band. This requirement establishes the footcandle level at which the artificial lights can be switched off. The number of different conditions establishes the number of switching stages for each band. Finally, a percent annual savings can be determined using the cummulative area in each of the bands for each orientation divided by the total building area. The area approach can be utilized because office lighting fixtures are usually evenly spaced.

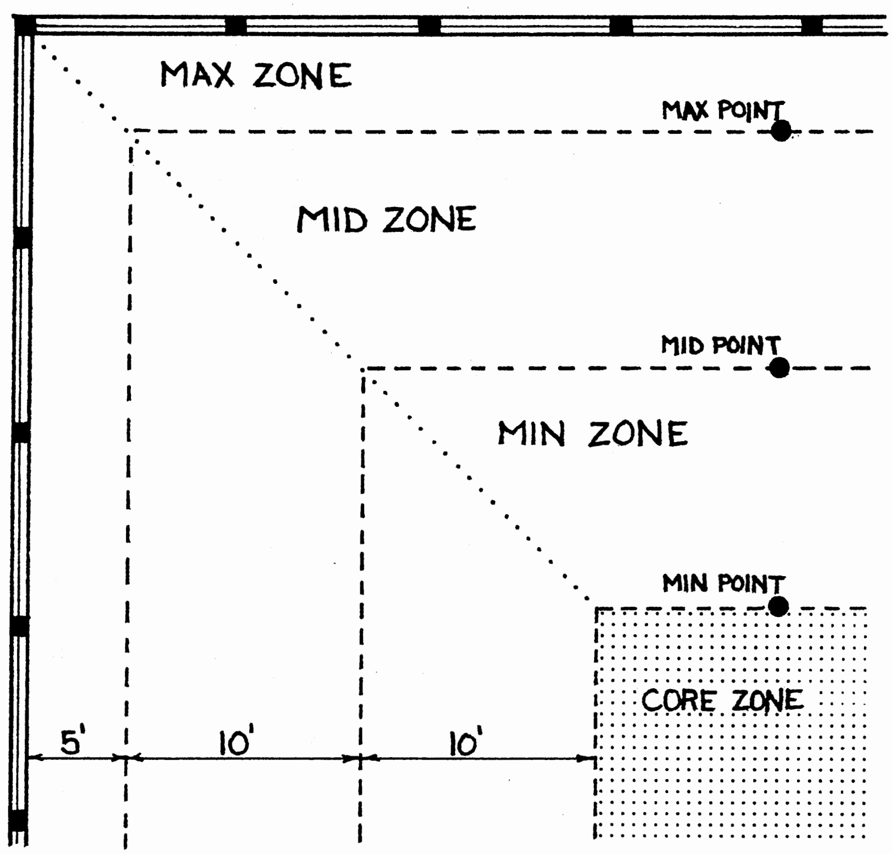


Figure 17. Perimeter Daylight Zoning Layout

The wattage of the entire building can be found once the lighting criteria, the room dimensions and the luminaire type are established. Dividing the total wattage of the lighting system by the total floor area gives a general watts per square foot energy use pattern for any given area of the building. Displaced electric energy can be tabulated by keeping track of the number of perimeter band areas which have the artificial lights switched totally or partially off. The size of these areas is calculated and if only half the lights are switched off in an area then only half the area considered saving energy. The summation of all areas with lights switched off can be divided by the total building area to give a percent area of daylighting. This percentage would be the same as the percent savings if it were assumed that the lighting layout is totally symmetrical, as in open plan office buildings.

The summation and averaging process would take place for all hours of the seasonal design day. The percent savings for both clear and overcast conditions should be independently summed over the eleven hourly analysis points and divided by eleven to give an average percent savings for the seasonal design day. Both of the values could then be multiplied by the corresponding cloud cover weighting factor for that season, and then the two could be added for a percent savings for each season. All four seasons could then be averaged to give an average percent annual energy savings for that project. The total energy saved could then be found by multiplying the percent value times the total installed building wattage for lighting and then times the total number of operating hours for that year. This process only represents the electric artificial lighting energy saved, assuming the same design were built without utilizing daylight. The total building electric load is not the basis, since outlet appliances and mechanical equipment are excluded.

Ventilation and Space Conditioning Savings

The savings achieved from the reduction of heat returning to the mechanical equipment from the lighting system can be predicted. This prediction, however, is somewhat complicated because of the interrelation of other building load variables. The savings could be described as in the equation in Chapter III; the total lighting energy load to the heating, ventilating and air-conditioning system (HVAC) with daylight divided by the total HVAC lighting energy load without daylight. The approach for this portion of the savings prediction is similar to the lighting energy savings prediction in that it is based only on the energy load produced by the lighting system. The percent savings, therefore, does not reflect the total building load, which includes climatic influences based on the envelope construction and other internal loads such as people, appliances, and equipment. It only predicts savings based on the same building being built without utilizing daylight.

With this approach the same analysis can be used as with the electric lighting savings. Since heat energy is proportional to the electric energy (watts per square foot), then the area analysis will also work for this percent savings calculation. In fact, the instantaneous percent savings value for the HVAC lighting load would be the same as the percent lighting savings except it may not necessarily represent a savings. The lights only give off heat, so in a typical summer location any reduction in a heat load, such as switching off lights, would indeed be a savings.

However, in the winter the heat generated by the lighting system may represent energy the heating system will have to make up if some of the lights are switched off in favor of daylighting. This would represent a negative savings. On the other hand, if a climate is not as cold in the winter or if the building has a large interior zone area and is producing more heat than it can use, then it would represent a savings. The mid-season performance could be just as mixed because of persistent temperature changes. The prediction of HVAC lighting energy savings is therefore very difficult.

An actual resolution of HVAC savings will not be addressed because of the complexity of the problem, and the number of variables involved. Perhaps in a future study weighting factors similar to the cloud cover factors could be developed for the variables that affect the savings potential. These might include the interior zone area compared to the total occupied floor area, the seasonal heating degree day requirements, and the thermal resistance of the envelope construction which uses extra glass area for daylight. These factors could be positive or negative and would multiply the percent area values to give more accurate percent savings or non-savings for daylighting.

Life-Cycle Economic Considerations

Annual energy savings of a design scheme using daylight, compared to the same scheme not using daylight, only provides a biased assurance that the daylighting is saving energy. The annual savings percentage represents only a part of the overall economic consideration given to a design scheme. The economic analysis for justification of a scheme is known as Life-Cycle-Cost Analysis (LCCA). This type of analysis for daylight design has been studied by Griffith.[2] It includes additional factors which have not been pointed out until now.

The approach to LCCA involves establishing all of the costs (inputs) and benefits (outputs) in terms of a common unit such as dollars. These inputs and outputs are then distributed annually over the life of the system at an established interest rate. This analysis can be performed for (1) the scheme using daylight, and for (2) the scheme not using daylight, and the one with the most desirable benefit-to-cost ratio is recommended. Specific costs and benefits for a scheme are shown in Table XII.

Primary cost items for a daylight scheme are in the first cost category. The addition of items beyond those required for a non daylighted building include the expense of added or improved glazing, exterior shading devices, any building appendages designed solely to increase daylight penetration, or the added electrical circuitry and switching needed to turn off a portion of the lights in the daylighted zones. The added maintenance cost to maintain any of this equipment must also be included as an annual cost. The primary benefits, which have been defined in this study, include the lighting energy savings and the HVAC lighting load savings. Each of these can be converted into dollar amounts on an annual basis. One other benefit, which should be established, is the worker productivity increase reportedly due to a daylighted building.[3] Estimating a dollar amount for this benefit might be difficult, but it should be shown to exist no matter how small or large it might be. These are the primary cost and benefit variables for daylighting. With the further development of knowledge about these variables, aside from lighting energy savings, a comprehensive analysis for daylighting could be developed.

TABLE XII

EXAMPLE LIFE-CYCLE-COST ANALYSIS FOR
A DAYLIGHTED PROJECT

Example	Daylight $
•First Costs	
- Glazing	50,000
- Shading	120,000
- Switching	100,000
- Circuitry	30,000
- Luminaires	100,000
•Annual Heating Costs	150,000
•Annual Maintenance Costs	5,000
•Annual Lighting Energy Savings	14,000
•Annual Cooling Savings	11,000
•Worker Productivity Savings	5,000

FOOTNOTES

[1]Weather Atlas of the United States, U.S. Environmental Data Service (Detroit, Michigan, 1975).

[2]J.W. Griffith, "Benefits of Daylighting - Cost and Energy Savings," ASHRAE Journal (January, 1978), p. 53.

[3]S. Selkowitz, "Daylighting and Passive Solar Buildings," Proceedings of 3rd National Passive Solar Conference, AS/ISES (San Jose, California, January, 1979), p. 279.

CHAPTER IX

SENSITIVITY ANALYSIS

Refinement Variables

The analysis performed in this chapter is done as an addition to Chapter VI on daylight analysis and points out refinement opportunities for the daylight design variables. The redesign loop in the energy analysis flow chart in Appendix A shows that, if daylight quantity levels are not as expected, then daylight variables can be modified. Graphs of these variables plotted against percent annual savings can show how the range of each single variable can affect the total design. The use of these graphs in the preliminary design phase can help the user make better decisions about the specific daylight variables.

The variables which are analyzed are the ones included in the lumen method, also known as the Libbey-Owens-Ford (LOF) daylight illumination procedure. These were discussed earlier and include: area of glass, glass transmittance, ground reflectance, wall reflectance, and ceiling height. The range of each of these variables was established by the choices available to the LOF method. In one case, the wall reflectance variable, the limited choices of 70 and 30 percent make the sensitivity graph suspect with respect to values not immediately adjacent to those points. Any value other than these two must be interpolated.

The other sensitivity variables have an adequate choice of values which represent most typical buildings. The first variable, ceiling height, has four choices: 8, 10, 12, or 14 feet. These provide a reasonably accurate picture of design choices available to office buildings and should effectively show annual savings over the whole range. The second variable, the area of glass, had a fixed room length dimension of 30 feet in the direction of the window and a typical 10-foot ceiling height. One foot increments were taken with respect to window height which gave areas of glass of: 30, 60, 90, 120, 150, 180, 210, 240, 270, and 300 square feet. The last two variables, glass transmittance and ground reflectance, were both graphed with a full range of 0 to 100 percent. This range should provide a more than adequate picture of percent annual savings with respect to these two variables.

Typical Reference Values

The validity of such an analysis on a particular parameter is based on all of the other variables being fixed to some constant value. These values are described as 'typical' in this analysis because they most nearly represent values associated with a daylight design. Each variable has its own typical or reference value and a typical savings run can be made using these values.

A site in St. Louis, Missouri, was chosen for its typical United States latitude of approximately 38 degrees and because of its typical sunshine and overcast conditions. The latitude determines the solar altitudes, and subsequent illumination availability can be determined for both clear and overcast conditions. Solar illumination is found for each hour in a typical working day for the summer, winter and intermediate seasons. The illumination for clear and overcast skys is weighted by a percent of possible sunshine for each season according to the weather atlas for this location.[1] The remaining percent not considered sunshine will be assumed to be overcast. For St. Louis these percentages have been determined by averaging the three months for each of the four seasons.

A hypothetical building has been established as a 100-foot square which has only one level and a 10-foot ceiling height. The orientations of this square building are north, south, east, and west, and the glazing is assumed continuous along each side. A sill height of three feet is assumed along the bottom of all outside walls and no overhang is present. The usable portion of the glass is established at 90 percent, because of mullions present on the fixed windows.

The reference room dimensions chosen are 30-by-30 feet, since they are the average values available to the Lumen (LOF) method. This yields the following analysis points for this hypothetical building; Max, 5 feet from the window, Mid, 15 feet from the window, Min, 25 feet from the window. The typical interior wall reflectance for this building is assumed to be 70 percent. The floor and ceiling reflectances are constant throughout the room and are established as 30 and 80 percent, respectively. The typical external ground reflectance value is set at 30 percent, and typical glass transmittance is selected as 70 percent.[2] The typical area of glass for this 30 foot long reference space is established as 210 square feet for each orientation, which is the entire wall visible from the interior except for the three-foot sill height. It must be noted that the reference room is used because the LOF method does not provide analysis for open plan spaces.

Analysis Program

The sensitivity analysis computer program shown in Appendix C is discussed according to the order of the program. The first section begins with solar illumination inputs shown in Table XIII for five symmetrical hours and one noon hour of the day. These are listed for three seasons, and for both clear and overcast sky conditions. If the analyst wishes to change the site, the illumination input can be changed by using appropriate illumination levels from Figures 11 and 12. The sensitivity program assumes no direct sun on the windows and no window controls. Next, the typical reference values are listed and then the coefficients of utilization are given. These coefficients of utilization combine the room dimension and wall reflectance effects into four variables. If the analyst wishes to change these for a different room, new values must be input from Tables VIII and X. The next area of the program performs calculations for the clear and overcast conditions for the Max, Mid, and Min points in terms of footcandle levels. This process is repeated for all orientations, hours of the day and seasons. At this point, a printout of the values can be obtained.

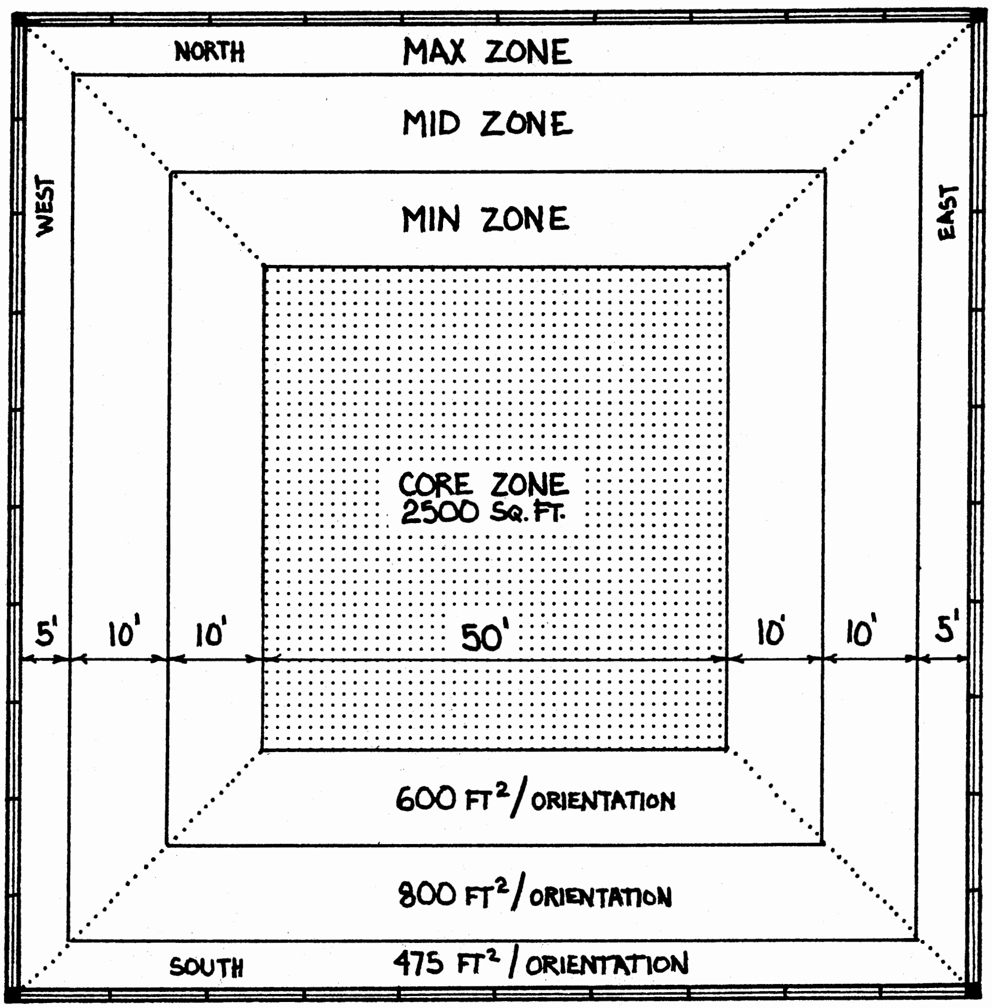
The next section of the program checks the values for the Max, Mid, and Min points by assuming the points to be lines at specified distances from the window wall and running parallel to the window the length of the building. This defines bands of perimeter area as shown in Figure 18. The illumination level at the Max, Mid, and Min lines is the lowest for that band area. Light switching and luminaire layout can then be determined for any of the daylighted areas by condition statements discussed in Chapter VIII. For this analysis the conditions have been established as follows. If any one of the zones' daylight level is

TABLE XIII

EXTERIOR SOLAR ILLUMINATION INPUTS FOR THE SENSITIVITY ANALYSIS

		Overcast		Clear					
	Morning	Vertical	Horizontal	North	South	East	West	Horizontal	Afternoon
June 21	7	350	900	750	550	1300	300	1050	5
	8	500	1300	700	700	1450	350	1300	4
	9	700	1700	650	850	1450	450	1500	3
	10	900	2150	650	900	1350	500	1600	2
	11	1100	2800	550	1050	1050	550	1600	1
	Noon	1200	3200	450	1250	750	750	1600	Noon
Sep/Mar 21	7	150	400	300	450	900	200	550	5
	8	300	800	450	700	1100	300	850	4
	9	450	1200	400	1050	1150	350	1050	3
	10	600	1500	400	1100	1100	400	1250	2
	11	700	1750	400	1200	900	550	1300	1
	Noon	750	1800	350	1300	600	600	1350	Noon
December 21	7	0	0	0	0	0	0	0	5
	8	100	250	150	400	600	150	350	4
	9	200	550	250	850	850	250	600	3
	10	300	800	250	950	700	350	750	2
	11	350	900	300	1050	60	400	800	1
	Noon	400	1000	300	1100	450	450	850	Noon

Note: Derived from Figures 11 and 12.



Total area = 10,000 ft^2. Continuous glazing at all orientations for 10' ceiling height.

Figure 18. Perimeter Zoning Layout for Sensitivity Analysis Example

than 50 footcandles (FC), then the area defined by that line has no artificial lighting in use. If any of the zone daylight levels is greater than 25 FC, but less than 50 FC, then half of the artificial lights are on in that area. If the zone level is less than 25 FC, then all artificial lights are on. A tabulation is kept on all daylighted and artificial-lighted areas and the interior zone area is added in with the artificial since it is never daylighted. The user can alter the conditional footcandle readings of 25 and 50 if the switching conditions are to be modified. The size and shape of the building can also be changed in a similar fashion by altering the area assignments of the same condition statements.

The final section of the program performs the summation process for the daylight and artificial areas for all hours of the working day. Next, the total artificial area for each typical seasonal day is divided by the total area of the building to produce the percent area of artificial light used for clear and overcast conditions. The clear and overcast weighting percentages for each season are then multiplied by the seasonal artificial area percentage and added together to yield a seasonal percentage of artificial lights used in the building. The four seasonal totals are then added and divided by four to produce the average annual percentage of artificial light used for the given conditions. Percent annual savings is then calculated and printed with respect to any other variable value. See Appendix C for a complete program listing.

Usable Area and Sensitivity

The results obtained from the sensitivity analyses for the hypothetical building are shown in Figures 19 through 28. The first important piece of information, however, is shown in Table XIV which illustrates the percentage of time each of the perimeter zones is using daylight. These percentages are derived from the example printout calculated using all reference values for the hypothetical building, in Appendix B. The percentages are listed for both clear and overcast conditions and also by the light switching condition requirements of greater than 50 FC, between 25 FC and 50 FC, and less than 25 FC. This table shows how each of the perimeter bands is functioning on a annual time frame. If the analyst sees that a band is not receiving usable daylighting then he can change the switching conditions or the location of the Max, Mid, and Min analysis points. This situation would probably only occur furthest from the window, or in the Min area, but as the table shows for this example the worst case is during overcast conditions and the half on-half off switching occurs 42 percent of the time. During clear conditions the northerly oriented Min area does not respond to daylight only 25 percent of the year and this is probably only the winter season. This type of table can be used as a design and for laying out luminaires and switching circuitry.

This next portion deals with the sensitivity analysis of the variables described earlier. The discussion considers the results of the graph for each variable range versus the percent annual energy savings. It also includes the results of the graphs for each variable range versus the change from the reference value in percent annual energy savings. The variables include area of glass, glass transmittance,

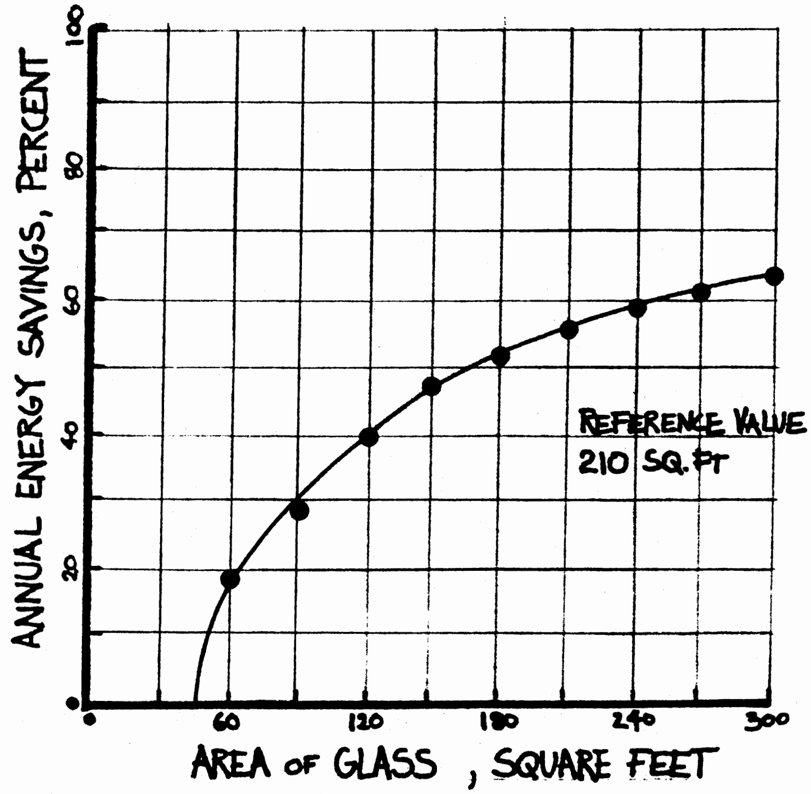


Figure 19. Annual Energy Savings Versus Area of Glass

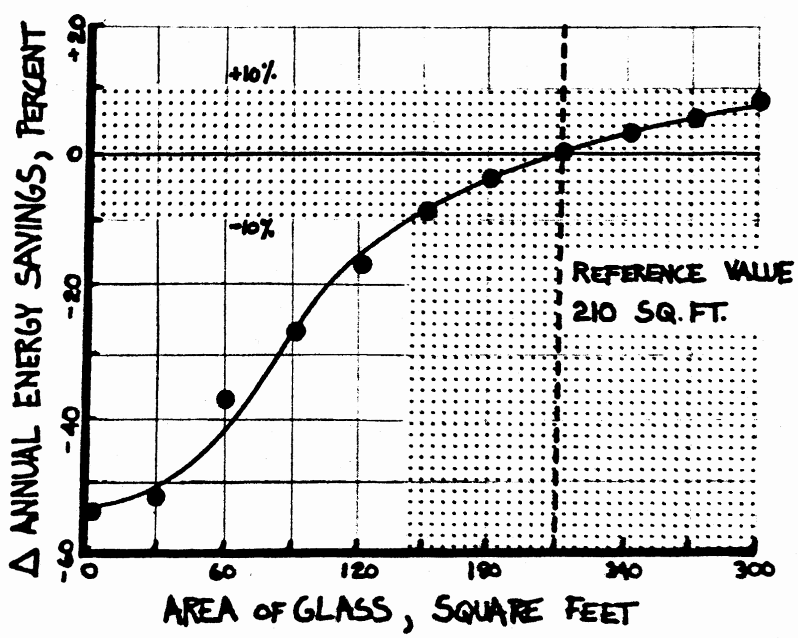


Figure 20. Area of Glass Sensitivity

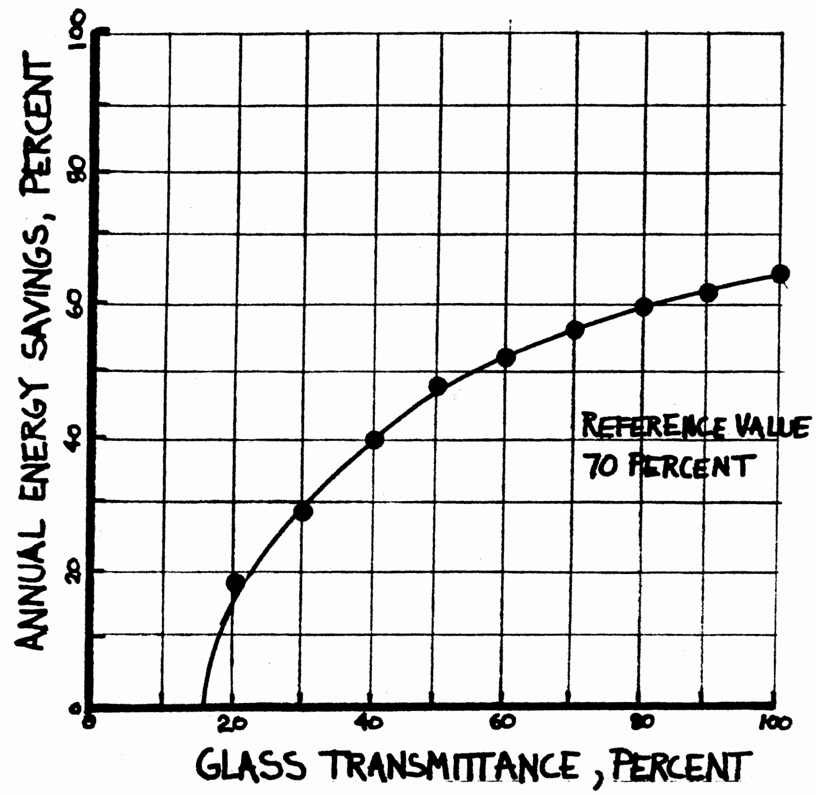


Figure 21. Annual Energy Savings Versus Glass Transmittance

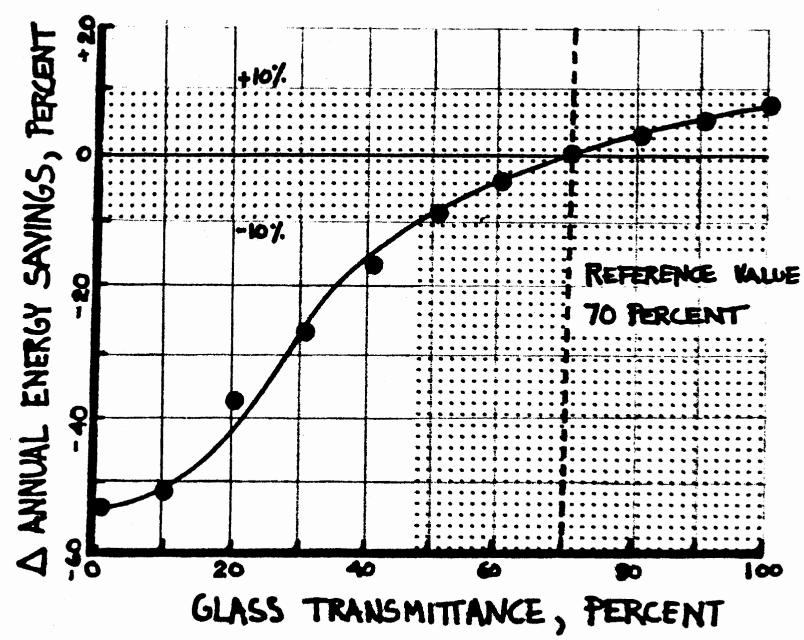


Figure 22. Glass Transmittance Sensitivity

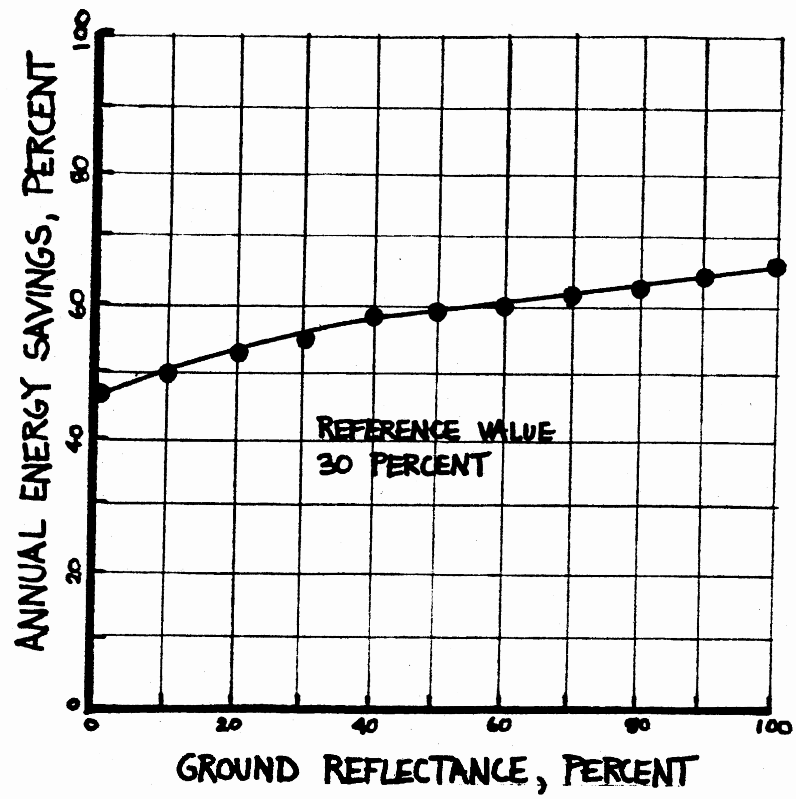


Figure 23. Annual Energy Savings Versus Ground Reflectance

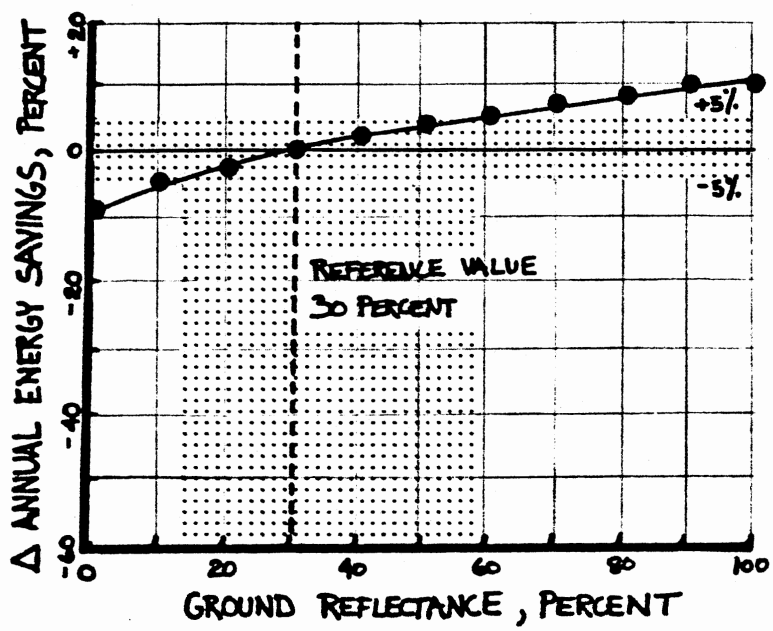


Figure 24. Ground Reflectance Sensitivity

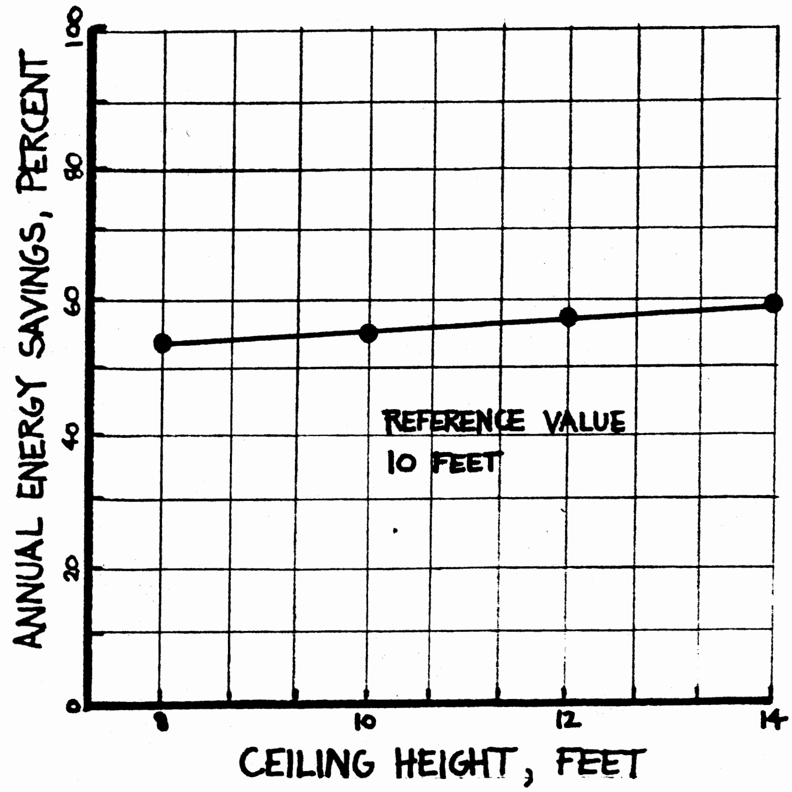


Figure 25. Annual Energy Savings Versus Ceiling Height

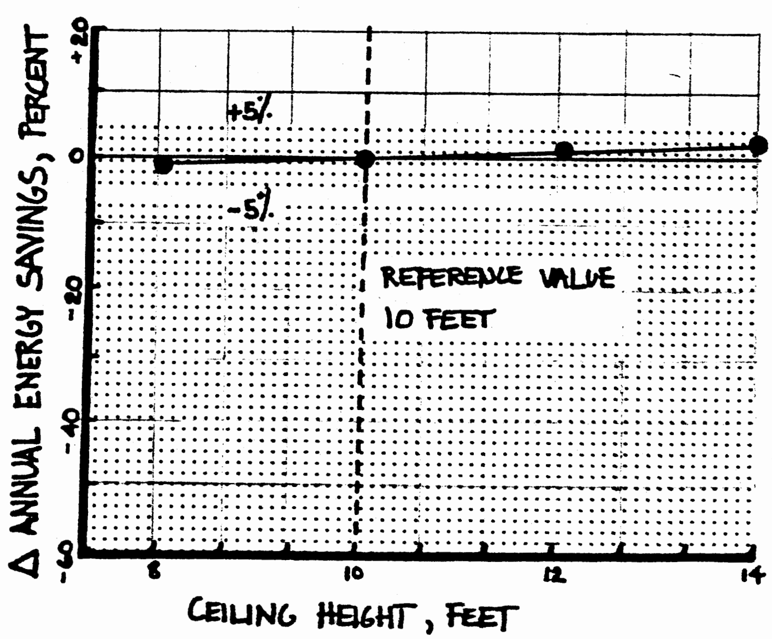


Figure 26. Ceiling Height Sensitivity

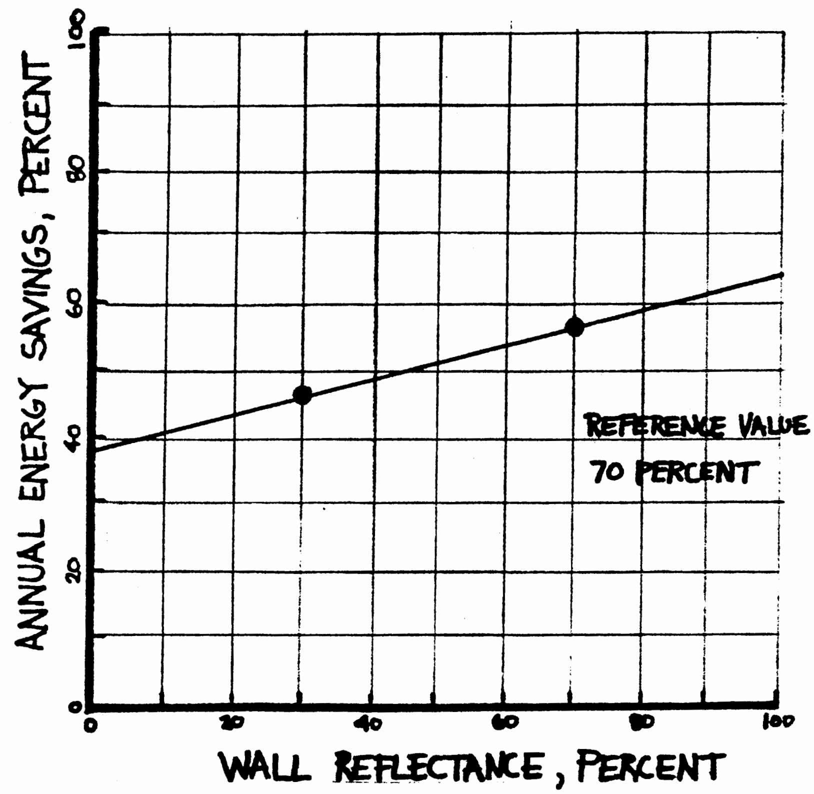


Figure 27. Annual Energy Savings Versus Wall Reflectance

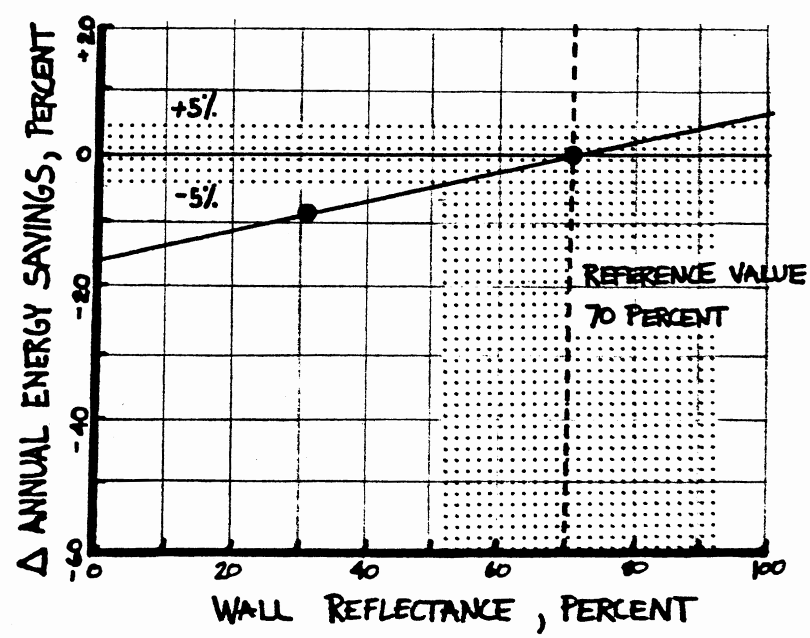


Figure 28. Wall Reflectance Sensitivity

TABLE XIV

PERCENT TIME EACH PERIMETER ZONE IS OPERATING UNDER A GIVEN CONDITION FOR TYPICAL VALUES OF THE SENSITIVITY ANALYSIS

Overcast	All Artificial Off >50FC	1/2 Artificial Off 50>25	No Artificial Off <25FC
MAX	92	04	04
MID	46	33	21
MIN	12	42	46

Clear		All Artificial Off >50FC	1/2 Artificial Off 50>25	No Artificial Off <25FC
MAX	North	92	04	04
MID	North	58	33	09
MIN	North	17	58	25
MAX	South	96	0	04
MID	South	83	13	04
MIN	South	75	21	04
MAX	East or West	94	2	4
MID	East or West	71	23	6
MIN	East or West	48	40	12

ground reflectance, ceiling height, and wall reflectance. The percent annual energy savings for lighting in this hypothetical building using all reference values is 55 percent.

The range of the area of glass variable is plotted against percent savings in Figure 19. The figure shows an exponential savings curve that begins between 30 and 60 square feet of glass area. This late begining is due to the switching requirement of 25 FC needed before savings can be achieved. After about half the wall area is used for glass the saving potential begins to reduce. The sensitivity curve in Figure 20b reinforces this fact as percent change becomes less than 10 for areas of glass greater than 150 square feet. The highest percent savings achieved for this building was 63 percent using an all glass exterior wall.

The glass transmittance variable is plotted against percent annual energy savings in Figure 21. It is exactly the same curve as plotted for area of glass so it presumably affects savings in a similar manner. Savings begin between a transmittance of 10 and 20 percent. After about 50 percent transmittance, the savings potential begins to reduce. Figure 22 shows a similar sensitivity curve as in Figure 20. Again the highest saving achieved was 63 percent and that assumes a perfect transmittance of 100 percent.

The ground reflectance variable is plotted against percent annual energy savings in Figure 23. The figure shows an almost linear relationship between the two. The savings potential is only reduced to 46 percent when the ground reflectance is making no contribution at 0 percent. This shows the secondary position the ground component takes with respect to the sky component. No significant changes occur in savings as shown on the sensitivity graph in Figure 24. The most savings achieved was 65 percent and it occured when a perfect ground reflectance of 100 percent was used.

The ceiling height variable was plotted against percent annual energy savings in Figure 25. Earlier statements about significant savings increases due to increased ceiling heights do not show in this analysis. This is due to the program not utilizing the increased daylight penetration depths associated with higher ceilings. The additional area of wall could have been used for glazing, but remained at the 210 square foot reference value. This situation produced only a 4 percent increase in savings by using a 14 foot ceiling rather than an 8 foot ceiling. The sensitivity curve in Figure 26 reiterates this fact since the changes from the reference value are very small.

The wall reflectance variable was plotted against percent annual energy savings in Figure 27a. Only two points were available but a line can be drawn to estimate other points. This line is similar to the ground reflectance line since the savings potential is reduced to approximately 37 percent when the wall reflectance is 0. Using 100 percent wall reflectance produces a 63 percent savings. The sensitivity curve in 28 shows minor changes for normal reflectances in percent savings from the reference value.

An overview of the variables in this sensitivity analysis shows that, according to the lumen (LOF) method, only two have a significant influence on the design. The area of glass and the glass transmittance must be kept as high as possible to maintain high savings percentages. Ground and wall reflectance are not nearly as important but should be kept as high as possible to maintain savings, but not so high so as to create undersirable glaze sources. Ceiling height, according to this analysis, is not a major contributor to annual savings, but the increased penetration depths due to higher ceilings and the additional areas for glazing are not realized in this analysis.

FOOTNOTES

[1]*Weather Atlas for the United States*, U.S. Environmental Data Service (Detroit, Michigan, 1975).

[2]L. L. Boyer, "Evaluation of Energy Savings Due to Daylight," *Proceedings of International Passive and Hybrid Cooling Conference*, AS/ISES (Miami Beach, Florida, November, 1981), p. 343.

CHAPTER X

EXAMPLE PROJECT

Project Description

Now that the description of the analysis process is complete, an actual example project is needed to substantiate the process' ability to evaluate the savings potential. A project that fits the assumptions of the LOF analysis method would be ideal because few changes would have to be made to the sensitivity program. This type of project would probably be a typical rectangular low rise project with no special external shading devices. However, a building which does not represent a typical project, but perhaps is more indicative of future energy conserving design trends, could be more beneficial in proving the process' ability to predict savings. One such building, which will be used for this example, is the California State Office Building, designed for the 1977 National Energy Design Competition. The building which won the competition was designed by Benham Blair and Affiliates of Oklahoma City, and it has been said to be energy conserving.[1] Actual energy savings due to daylighting have been conservatively estimated to be about 9 percent on an annual basis.[2] This was determined from a preliminary design building analysis, similar to this study. The assumptions made then will be carried over as much as possible in this analysis. This will enable comparisons to be made between the two studies.

The project is located in Sacramento, California, which is at approximately 38 degrees north latitude. The building is mostly open plan office space of 230,000 square feet gross area and is divided into two main sections. At the north end of the site is a six-story 'solar slab' that slopes southward at 45 degrees and contains 12,000 square feet of solar collector area. Behind the collectors are four levels of office space which open northward into an atrium space formed by the south wall of an adjacent building, shown in Figure 29. Daylight is bounced off the adjacent building and is filtered down into the six-story lightwell. The remainder of the office space is two levels of subterranean structure. Daylight is introduced with six separate light-courts and a longitudinal spine that splits the area in half as shown in Figure 30. Overhangs and desk-height opaque exterior walls control direct sun and operable blinds allow occupant control of window brightness. Daylight penetration is increased by using light colored reflective wall surfaces on the exterior as well as in the office interiors. Circular stair towers are placed in the lightcourts and central spine to help direct and diffuse daylight toward more than one direction. Luminaires located in a 15-foot-wide band around the window walls are controlled by photo-electric cells which can reduce the lighting levels in those bands when daylight provides adequate illumination.

Annual Savings Prediction

The computer program developed for the sensitivity analysis in Chapter IX is modified to accommodate this example project and is shown in Appendix E. The same criteria used in Boyer's initial analysis will be used here, but some of the assumptions and methodology required by this program will differ from the original study.[3] A discussion of the changes and the approach to the changes is made.

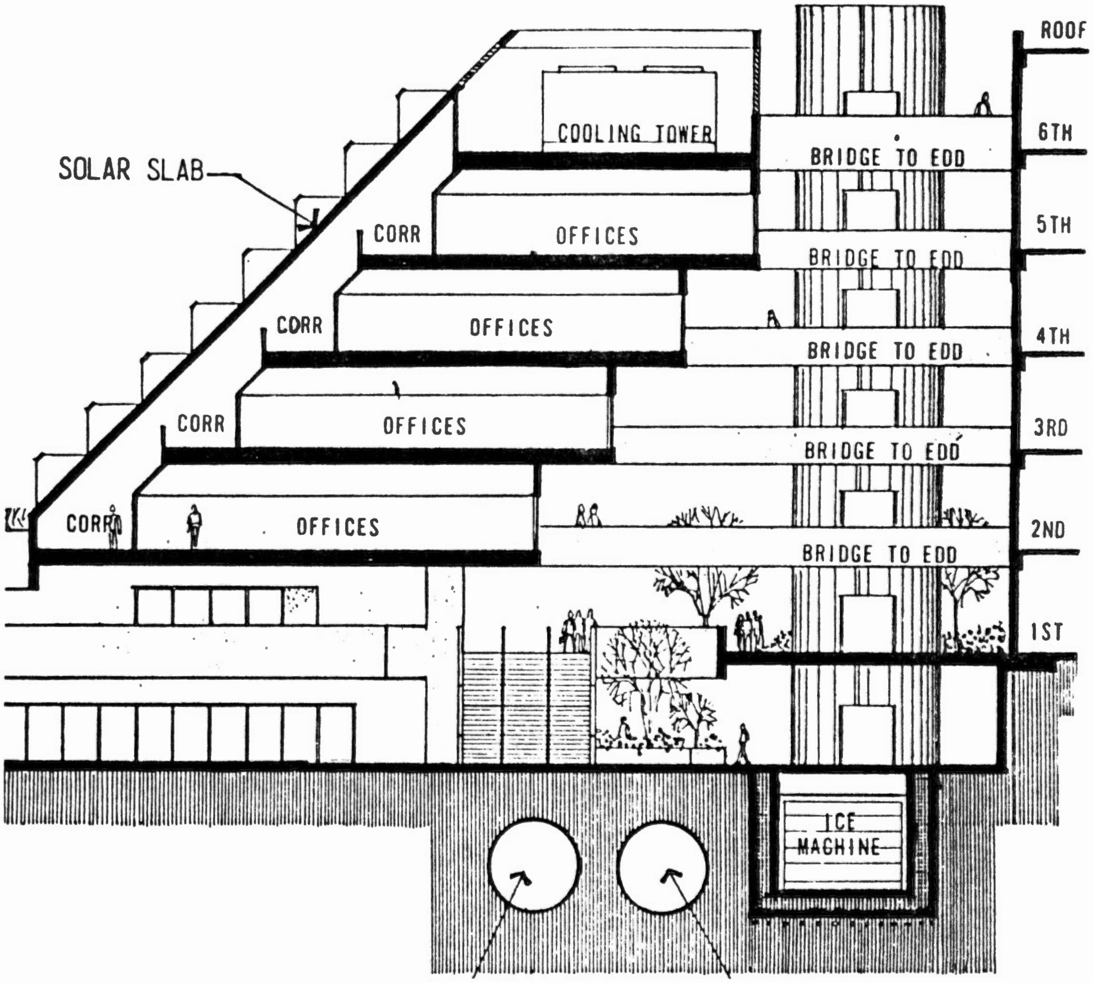


Figure 29. Section Through North Lightwell Offices

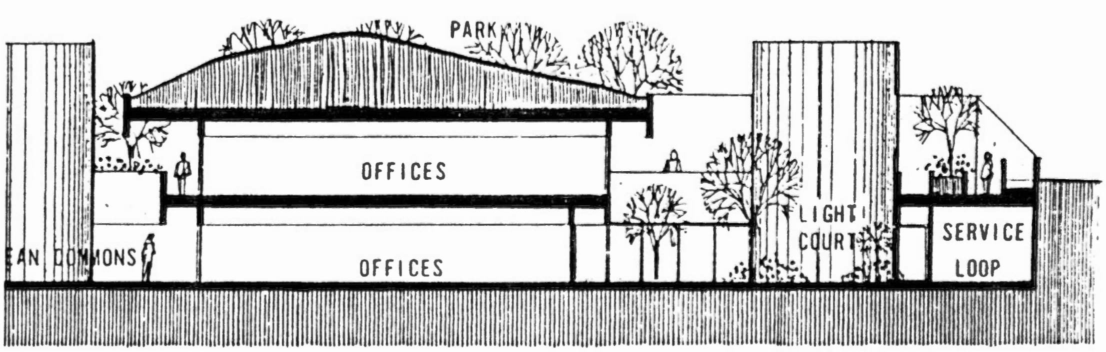


Figure 30. Section Through Subterranean Offices at the Lightcourt

The first changes involve the solar illumination data for each hour of the seasonal design day. Sacramento is located at roughly 38 degrees latitude so the same illumination values used in the sensitivity study will be used here. One assumption made by Boyer was that any solar altitude less than 30 degrees would yield illumination too weak for actual energy credit. Acknowledging this assumption means certain hours cannot be used for daylighting. Table I shows the 7 a.m./5 p.m. hours for the summer design day to have solar altitudes less than 30 degrees, both the 7 a.m./5 p.m. and the 8 a.m./4 p.m. hours for the mid-season design day to have solar altitudes less than 30 degrees, and all hours for the winter design day to have solar altitudes less than 30 degrees. The values for these time points will be assumed to be zero and no daylight credit can be given.

The next changes involve the reference values for the typical daylight variables. It turns out that these remain the same as in the sensitivity analysis except for one new addition. A building reflectance value is required to simulate the conditions in the lightcourts. The building's own structure and neighboring buildings obscure part of the incoming sky component. Therefore, a vertical wall reflectance modifier is needed and it will be treated like the ground reflectance, except it will be modifying illumination on a vertical surface. This variable is assumed to be 0.5 for light colored exterior wall surfaces.

The next change involves the actual calculations which determine the illumination levels at the Max, Mid and Min points. According to the LOF method, only sky and ground contribution components are given. In this case vertical walls are contributing reflected light and they are in the field of view for both the sky and ground. The wall reflectance is treated as a ground reflectance so the ground reflectance equation is modified according to the angles in Figure 31. The angle of view between vertical and the bottom of the opposing wall forms the weighting factor for the ground contribution. This factor is based on 0.5 which is used as a maximum for the total 90 degree angle of view in the standard anaylsis by the LOF method. The ground contribution factor for this project was found to be 0.45. The angle of view between the bottom and the top of the opposing wall forms the weighting factor for the wall component and it is also based on the 0.5 used for ground reflectance. For this project a 0.3 wall contribution factor is assumed and the vertical wall surface modified by the factor is always assumed to be north instead of the actual opposing orientation. This is a conservative assumption and it simplifies the program logic. The final weighting factor is from the top of the opposing wall back to vertical. In the LOF method this is typically a 90 degree angle and this component is based on a unit value. Therefore, the available sky illumination must be derated by a factor of one-third or multiplied by 0.66 according to Figure 31.

The next change comes with the addition of the north lightwell office areas. Since only reflected light reaches the offices in this space, then a single equation, based again on ground reflectance, can express the amount of light reaching the analysis points. Vertical illumination on a south facing wall is used and multiplied times the wall reflectance and an assumed usable angle of reflected light of 0.5. This is shown in Figure 32.

The next major change is the modification of the Max, Mid and Min points when the building incorporates an overhang such as this example

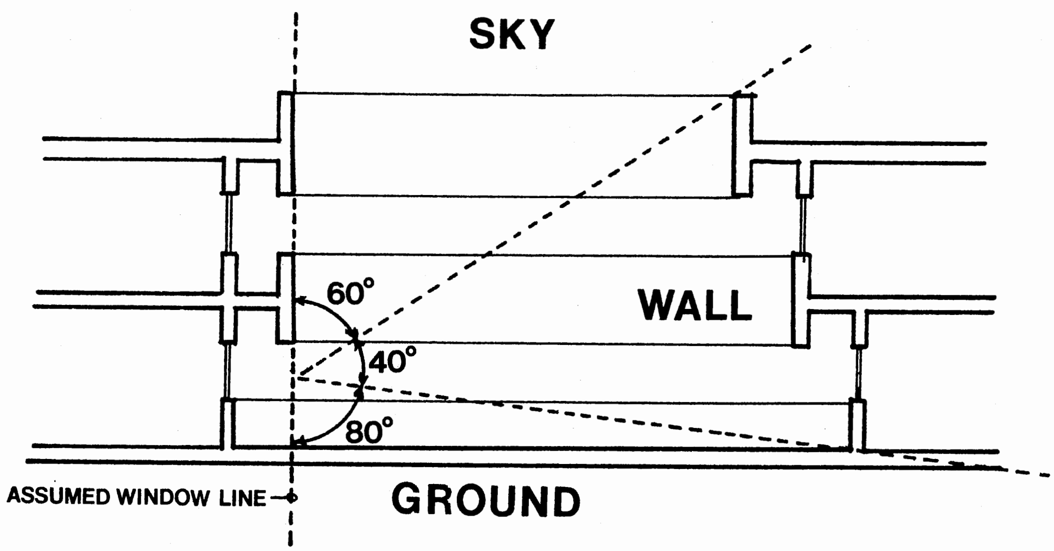


Figure 31. Angle of View Modifiers for Daylight Contribution Components of the Subterranean Offices

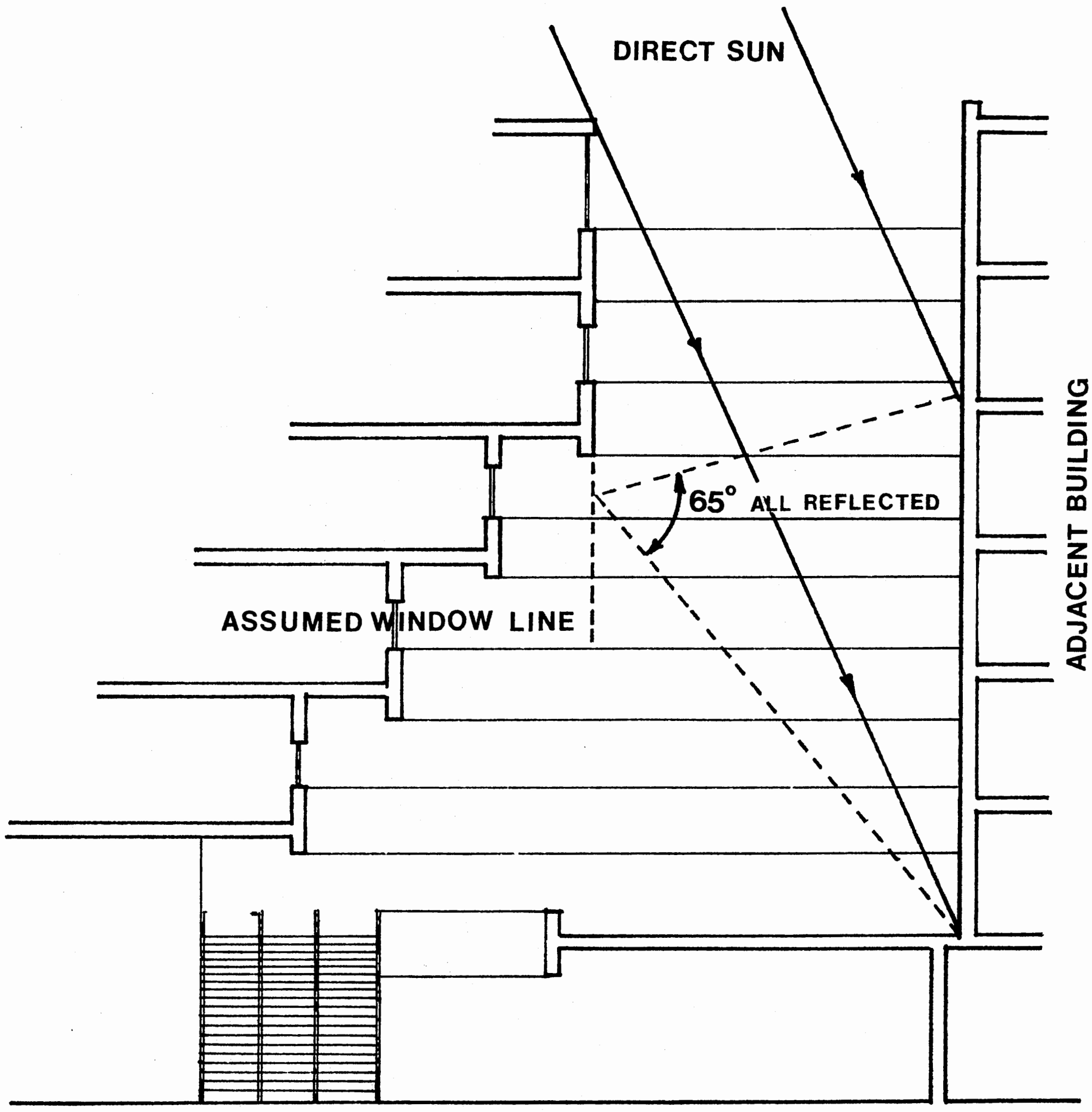


Figure 32. Daylight Contribution Components for the North Lightwell Offices

project. According to the LOF method the points would be repositioned as if the room were actually extended to the edge of the overhang. If a 5 foot overhang is assumed for all window walls, then the new Max point would occur right at the window. The new Mid point would occur 12.5 feet away from the window and the new Min point would remain 25 feet away because the Min point is always 5 feet from the back wall. This means only two bands of daylighted perimeter could be tested and their corresponding layout and area are shown in the office plan of Figures 33 and 34. A list of the daylight illumination levels for this example project is shown in Appendix D.

Results and Comparisons

Now that the annual savings prediction program has been modified, it can be executed to simulate the conditions for the example project to determine a percent annual savings of lighting energy due to daylighting. This percentage is then compared to Boyer's analysis on the same building and the reasons for differences can be explained.

The computer program yields percent annual savings for each portion of the example project separately. The two level subterranean portion of the building contains approximately 150,000 square feet of office space and the program calculated a 29 percent annual savings for this area. The four levels of solar offices in the north lightwell contain approximately 50,000 square feet of office space and the program calculated only a 3 percent annual savings for this area. By multiplying each of these percentages by a weighting factor, the percent of the total building area for, each portion, then the savings can be predicted for the entire building. This produces a 23 percent annual savings of lighting energy due to daylighting.

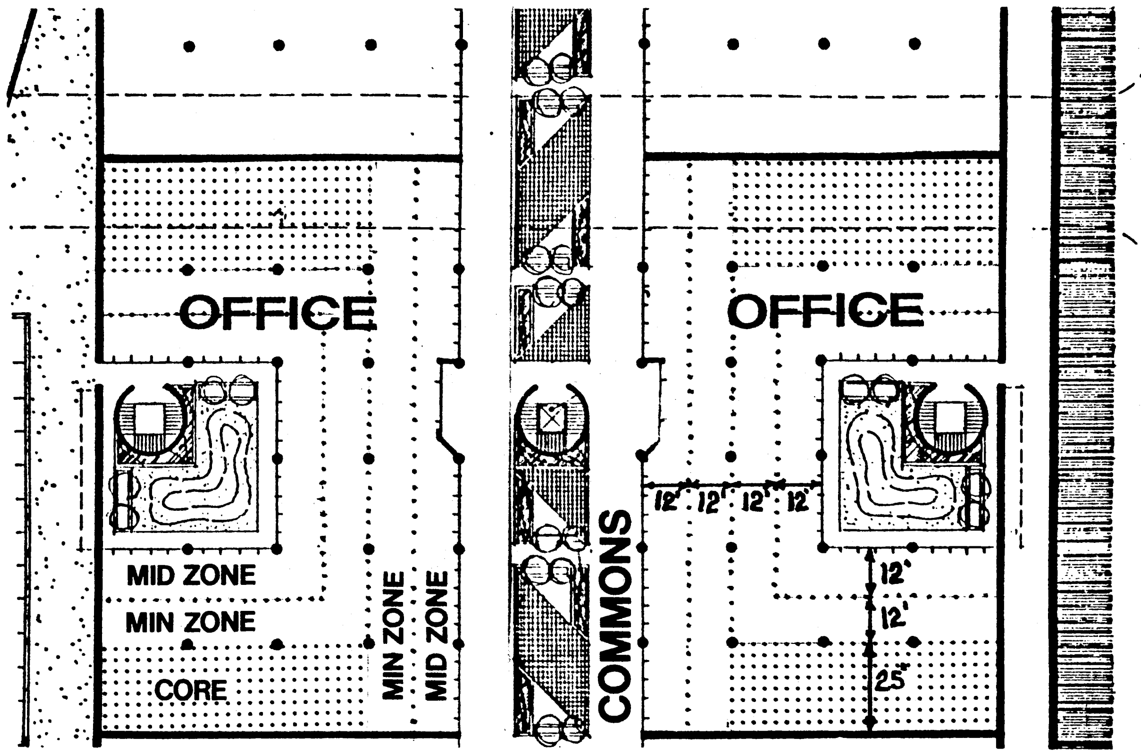


Figure 33. Usable Daylight Zones for Subterranean Offices

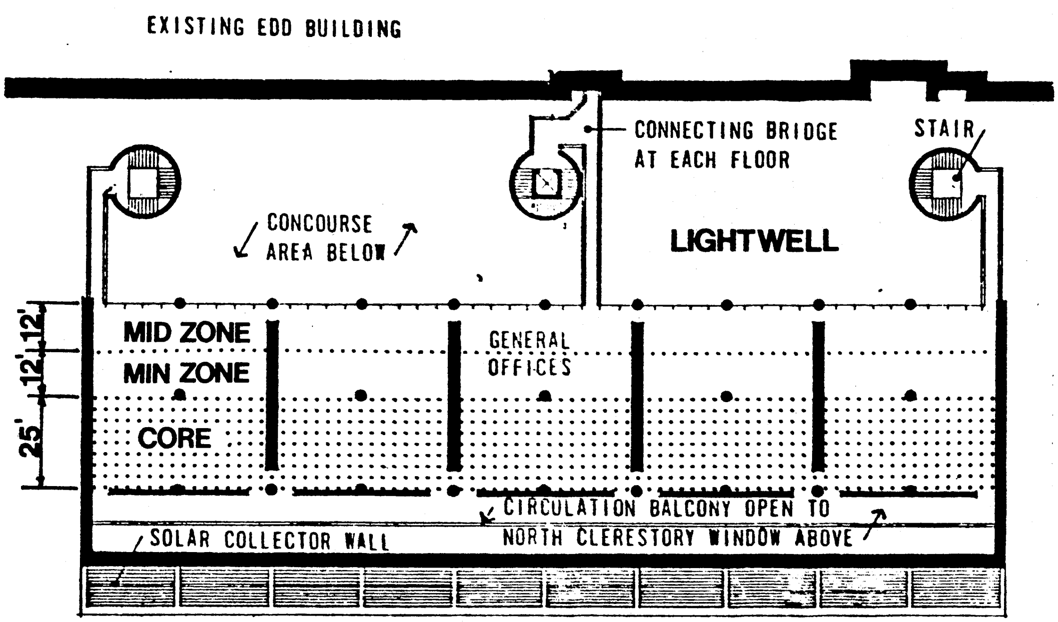


Figure 34. Usable Daylight Zones for the North Lightwell Offices

Boyer's conservative analysis of the energy savings due to daylighting on this projected yielded an annual savings of only 9 percent. His analysis was performed in a much smaller time frame. Only using hand calculating methods, so more conservatism was build into his prediction. Specifically, the area of daylighted perimeter and the one switching condition are largely reponsible for this lower value.

Boyer's analysis was based on only one perimeter area which was 15 feet wide. This analysis used a 25 foot wide perimeter depth and it was broken down into two separate areas so luminaire switching could compliment interior daylight levels. Secondly, Boyer's analysis only assumed one light switching condition for that entire zone and that was only half the lights could be switched off. This analysis assumed not only a half off stage, but also a stage that had all electric lights switch off in a perimeter zone. These two factors are probably the biggest reason for a percent savings figure roughly twice that of Boyer's prediction. Estimation of the external wall reflection components and other modifications of the LOF daylight calculation procedure could have had a smaller impact on the savings prediction. Nevertheless, this computer program seems to program seems to be modeling the example project adequately for a prediction of light energy savings due to daylight utilization.

FOOTNOTES

[1]B. V. Setty, "The Nation's Most Energy-Efficient Office Building," ASHRAE Journal (November, 1979) p. 31.

[2]L. L. Boyer, "Evaluation of Energy Savings Due to Daylight," Proceeding of International Passive and Hybrid Cooling Conference, AS/ISES (Miami Beach, Florida, November, 1981), p. 343.

[3]Ibid.

CHAPTER XI

SUMMARY AND CONCLUSIONS

Design determinants establish the general design approach on a daylighted office building. General design characteristics can then be established and assumptions made for any uncertain variables. Lighting criteria is set for the task requirements and light level quantities defined. Detailed daylight design variables for glazing, shading and reflection are considered and established for the project. After all variables are decided upon, the interior daylight illumination levels are calculated using the lumen (LOF) method. Hourly analysis points for the seasonal design days define available solar illumination. Coefficients of utilization specified by the building design modify exterior illumination to give three different points of interior illumination for overcast conditions and all orientations for clear conditions. These points define the perimeter daylight zones in which switching off the electric lighting can produce savings. The actual daylight levels at which switching occurs are established and the perimeter zones are checked for each hour of the design days. A percentage of area from the total building is found to daylighted for each analysis hour and for both clear and overcast conditions. Percentages for all hours of the working day can be average hand weight factors can be applied for cloud cover conditions to produce an average percentage of daylighted area for each season. Results for all four seasons can be averaged to yield an annual percentage of daylighted area which actually represents the percent annual savings of lighting energy.

The sensitivity analyses of the detailed daylight design variables indicated that the area of glass and the glass transmittance had the greatest impact on energy saving potential. Interior wall reflectance and exterior ground reflectance were shown to have a small impact on the overall savings potential, but ground reflectance had a slightly higher impact. Ceiling height was shown to have a small impact on annual savings, and the potential for increased depth of penetration due to higher ceilings was not realized in this analysis.

The example project used to apply the process seemed to be modeling light energy savings accurately. Although the value of 23 percent is more than twice the 9 percent determined by Boyer's analysis, the reasons for the difference can be shown in the assumptions made for each analysis. Boyer's approach was very conservative while this approach assumed more realized opportunities for savings potential. Neither analysis included cooling load savings, although each discussed the additional potential savings.

The inclusion of cooling load savings and heat load spendings could be in future studies. The incorporation of this component makes the savings prediction model more accurate, even though it is difficult to execute. The computer program used in this study could be upgraded to include this component possibly by again using an area analysis modified by design and weather factors. The program could eventually be made interactive and include life-cycle-cost analysis which would accurately demonstrate the long term potential savings of a preliminary design.

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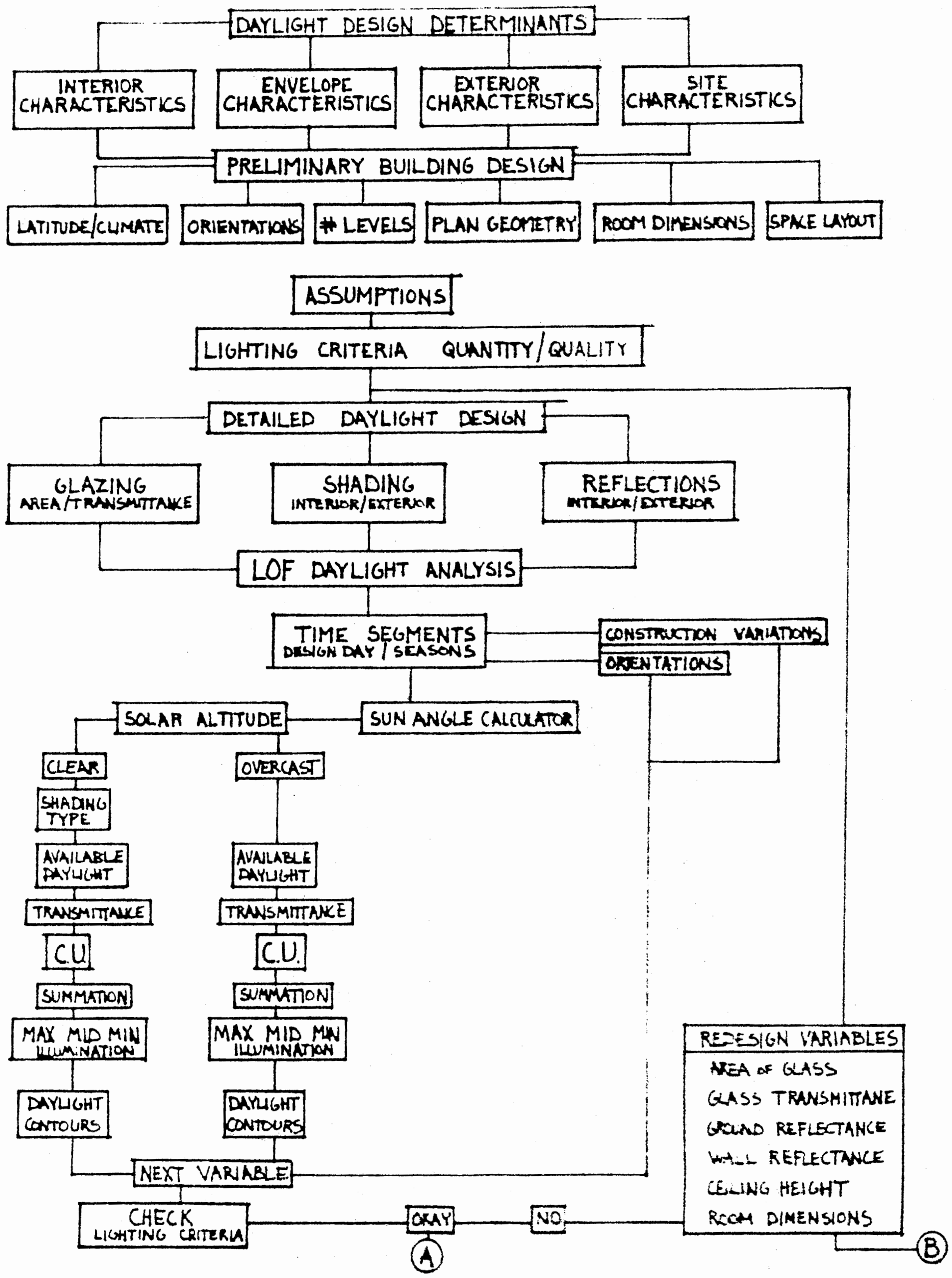
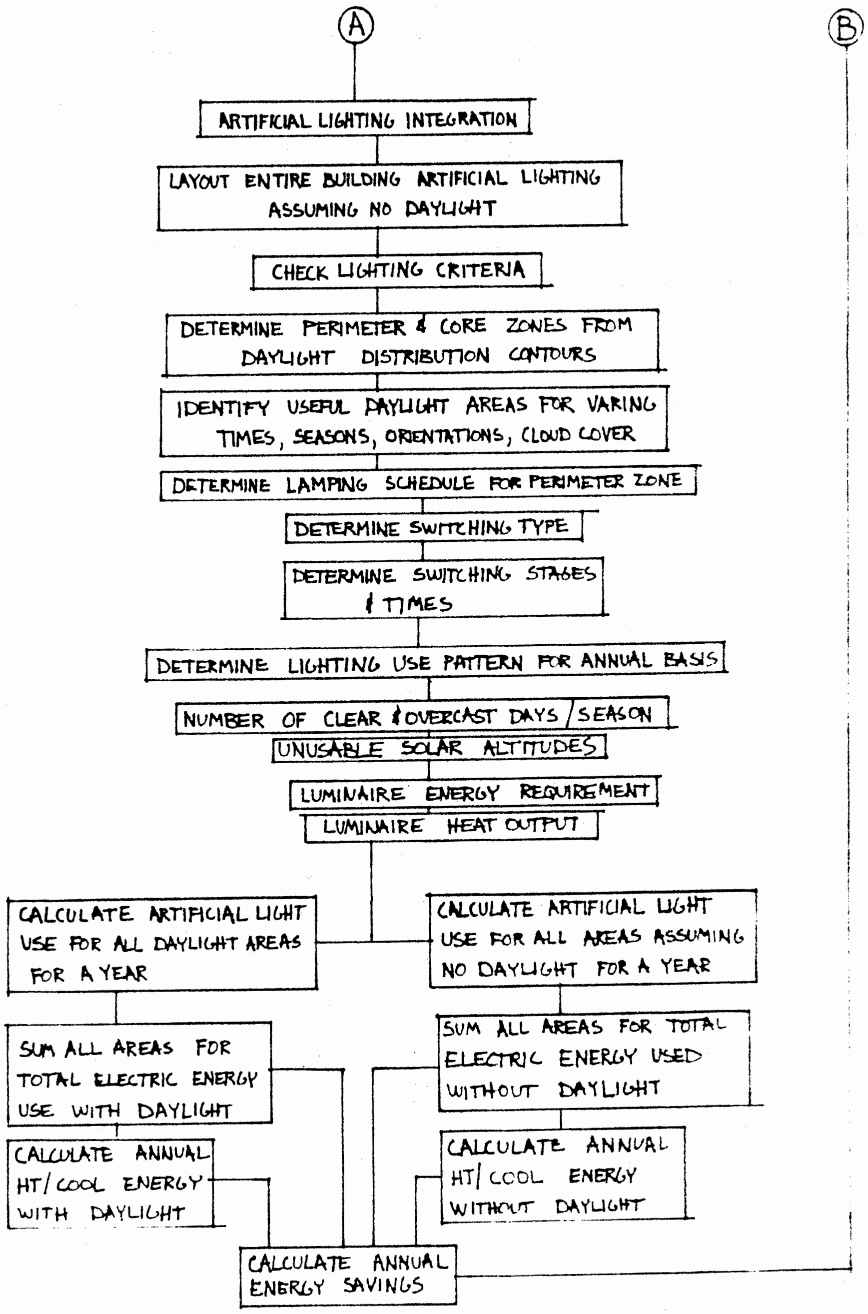
APPENDIX A

ENERGY ANALYSIS FLOW CHART FOR

DAYLIGHT UTLIZATION


DAYLIGHT DESIGN DETERMINANTS
INTERIOR CHARACTERISTICS
ENVELOPE CHARACTERISTICS
EXTERIOR CHARACTERISTICS
SITE CHARACTERISTICS
PRELIMINARY BUILDING DESIGN
LATITUDE/CLIMATE
ORIENTATIONS
LEVELS
PLAN GEOMETRY
ROOM DIMENSIONS
SPACE LAYOUT
ASSUMPTIONS
LIGHTING CRITERIA QUANTITY/QUALITY
DETAILED DAYLIGHT DESIGN
GLAZING AREA/TRANSMITTANCE
SHADING INTERIOR/EXTERIOR
REFLECTIONS INTERIOR/EXTERIOR
LOF DAYLIGHT ANALYSIS
TIME SEGMENTS DESIGN DAY / SEASONS
CONSTRUCTION VARIATIONS
ORIENTATIONS
SOLAR ALTITUDE
SUN ANGLE CALCULATOR
CLEAR
OVERCAST
SHADING TYPE
AVAILABLE DAYLIGHT
AVAILABLE DAYLIGHT
TRANSMITTANCE
TRANSMITTANCE
C.U.
C.U.
SUMMATION
SUMMATION
MAX MID MIN ILLUMINATION
MAX MID MIN ILLUMINATION
DAYLIGHT CONTOURS
DAYLIGHT CONTOURS
NEXT VARIABLE
CHECK LIGHTING CRITERIA
OKAY
A
NO
REDESIGN VARIABLES
AREA OF GLASS
GLASS TRANSMITTANCE
GROUND REFLECTANCE
WALL REFLECTANCE
CEILING HEIGHT
ROOM DIMENSIONS
B


A
B
ARTIFICIAL LIGHTING INTEGRATION
LAYOUT ENTIRE BUILDING ARTIFICIAL LIGHTING ASSUMING NO DAYLIGHT
CHECK LIGHTING CRITERIA
DETERMINE PERIMETER & CORE ZONES FROM DAYLIGHT DISTRIBUTION CONTOURS
IDENTIFY USEFUL DAYLIGHT AREAS FOR VARING TIMES, SEASONS, ORIENTATIONS, CLOUD COVER
DETERMINE LAMPING SCHEDULE FOR PERIMETER ZONE
DETERMINE SWITCHING TYPE
DETERMINE SWITCHING STAGES & TIMES
DETERMINE LIGHTING USE PATTERN FOR ANNUAL BASIS
NUMBER OF CLEAR & OVERCAST DAYS / SEASON
UNUSABLE SOLAR ALTITUDES
LUMINAIRE ENERGY REQUIREMENT
LUMINAIRE HEAT OUTPUT
CALCULATE ARTIFICIAL LIGHT USE FOR ALL DAYLIGHT AREAS FOR A YEAR
CALCULATE ARTIFICIAL LIGHT USE FOR ALL AREAS ASSUMING NO DAYLIGHT FOR A YEAR
SUM ALL AREAS FOR TOTAL ELECTRIC ENERGY USE WITH DAYLIGHT
SUM ALL AREAS FOR TOTAL ELECTRIC ENERGY USED WITHOUT DAYLIGHT
CALCULATE ANNUAL HT/COOL ENERGY WITH DAYLIGHT
CALCULATE ANNUAL HT/COOL ENERGY WITHOUT DAYLIGHT
CALCULATE ANNUAL ENERGY SAVINGS

APPENDIX B

EMAMPLE PRINTOUT OF MAX, MID AND MIN DAYLIGHT

ILLUMINATION LEVELS FOR THE SENSITIVITY

ANALYSIS USING ALL REFERENCE VALUES

SUMMER SKY - JUNE 21

\>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>7AM/5PM

5′	15′	25′DISTANCE FROM WINDOW
131	35	21 OVERCAST LEVELS
199	81	58 CLEAR LEVELS FOR NORTH
153	63	45 CLEAR LEVELS FOR SOUTH
323	131	95 CLEAR LEVELS FOR EAST
97	41	28 CLEAR LEVELS FOR WEST

\>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>8AM/4PM

5′	15′	25′DISTANCE FROM WINDOW
187	51	30 OVERCAST LEVELS
194	80	57 CLEAR LEVELS FOR NORTH
194	80	57 CLEAR LEVELS FOR SOUTH
364	148	107 CLEAR LEVELS FOR EAST
115	49	34 CLEAR LEVELS FOR WEST

\>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>9AM/3PM

5′	15′	25′DISTANCE FROM WINDOW
259	69	41 OVERCAST LEVELS
188	78	55 CLEAR LEVELS FOR NORTH
233	96	69 CLEAR LEVELS FOR SOUTH
369	151	108 CLEAR LEVELS FOR EAST
143	60	42 CLEAR LEVELS FOR WEST

\>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>10AM/2PM

5′	15′	25′DISTANCE FROM WINDOW
332	89	52 OVERCAST LEVELS
191	80	56 CLEAR LEVELS FOR NORTH
247	102	73 CLEAR LEVELS FOR SOUTH
349	143	103 CLEAR LEVELS FOR EAST
157	66	46 CLEAR LEVELS FOR WEST

\>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>10AM/1PM

5′	15′	25′DISTANCE FROM WINDOW
410	111	65 OVERCAST LEVELS
168	71	49 CLEAR LEVELS FOR NORTH
281	116	83 CLEAR LEVELS FOR SOUTH
281	116	83 CLEAR LEVELS FOR EAST
168	71	49 CLEAR LEVELS FOR WEST

\>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>12NOON

5′	15′	25′DISTANCE FROM WINDOW
451	123	72 OVERCAST LEVELS
146	62	43 CLEAR LEVELS FOR NORTH
327	134	96 CLEAR LEVELS FOR SOUTH
213	89	63 CLEAR LEVELS FOR EAST
213	89	63 CLEAR LEVELS FOR WEST

MID SKY - SEP/MAR 21

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>7AM/5PM

5′	15′	25′DISTANCE FROM WINDOW
56	15	9 OVERCAST LEVELS
83	34	24 CLEAR LEVELS FOR NORTH
117	48	34 CLEAR LEVELS FOR SOUTH
219	88	64 CLEAR LEVELS FOR EAST
60	25	18 CLEAR LEVELS FOR WEST

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>8AM/4PM

5′	15′	25′DISTANCE FROM WINDOW
113	31	18 OVERCAST LEVELS
125	52	37 CLEAR LEVELS FOR NORTH
182	74	53 CLEAR LEVELS FOR SOUTH
272	110	80 CLEAR LEVELS FOR EAST
91	38	27 CLEAR LEVELS FOR WEST

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>9AM/3PM

5′	15′	25′DISTANCE FROM WINDOW
169	46	27 OVERCAST LEVELS
119	50	35 CLEAR LEVELS FOR NORTH
266	109	78 CLEAR LEVELS FOR SOUTH
289	118	85 CLEAR LEVELS FOR EAST
108	45	32 CLEAR LEVELS FOR WEST

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>10AM/2PM

5′	15′	25′DISTANCE FROM WINDOW
223	60	35 OVERCAST LEVELS
125	53	37 CLEAR LEVELS FOR NORTH
283	116	83 CLEAR LEVELS FOR SOUTH
283	116	83 CLEAR LEVELS FOR EAST
125	53	37 CLEAR LEVELS FOR WEST

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>10AM/1PM

5′	15′	25′DISTANCE FROM WINDOW
260	70	41 OVERCAST LEVELS
126	53	37 CLEAR LEVELS FOR NORTH
307	125	90 CLEAR LEVELS FOR SOUTH
239	99	70 CLEAR LEVELS FOR EAST
160	67	47 CLEAR LEVELS FOR WEST

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>12NOON

5′	15′	25′DISTANCE FROM WINDOW
277	74	43 OVERCAST LEVELS
116	49	34 CLEAR LEVELS FOR NORTH
331	135	97 CLEAR LEVELS FOR SOUTH
173	72	51 CLEAR LEVELS FOR EAST
173	72	51 CLEAR LEVELS FOR WEST

WINTER SKY - DEC 21

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>7AM/5PM

5′	15′	25′DISTANCE FROM WINDOW
0	0	0 OVERCAST LEVELS
0	0	0 CLEAR LEVELS FOR NORTH
0	0	0 CLEAR LEVELS FOR SOUTH
0	0	0 CLEAR LEVELS FOR EAST
0	0	0 CLEAR LEVELS FOR WEST

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>8AM/4PM

5′	15′	25′DISTANCE FROM WINDOW
37	10	6 OVERCAST LEVELS
44	18	13 CLEAR LEVELS FOR NORTH
100	41	29 CLEAR LEVELS FOR SOUTH
145	59	43 CLEAR LEVELS FOR EAST
44	18	13 CLEAR LEVELS FOR WEST

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>9AM/3PM

5′	15′	25′DISTANCE FROM WINDOW
76	21	12 OVERCAST LEVELS
73	30	21 CLEAR LEVELS FOR NORTH
209	85	61 CLEAR LEVELS FOR SOUTH
209	85	61 CLEAR LEVELS FOR EAST
73	30	21 CLEAR LEVELS FOR WEST

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>10AM/2PM

5′	15′	25′DISTANCE FROM WINDOW
113	31	18 OVERCAST LEVELS
77	32	23 CLEAR LEVELS FOR NORTH
236	96	69 CLEAR LEVELS FOR SOUTH
179	73	53 CLEAR LEVELS FOR EAST
100	41	29 CLEAR LEVELS FOR WEST

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>10AM/1PM

5′	15′	25′DISTANCE FROM WINDOW
131	35	21 OVERCAST LEVELS
90	38	26 CLEAR LEVELS FOR NORTH
260	105	76 CLEAR LEVELS FOR SOUTH
158	65	46 CLEAR LEVELS FOR EAST
112	47	33 CLEAR LEVELS FOR WEST

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>12NOON

5′	15′	25′DISTANCE FROM WINDOW
149	40	24 OVERCAST LEVELS
91	38	27 CLEAR LEVELS FOR NORTH
272	110	80 CLEAR LEVELS FOR SOUTH
125	52	37 CLEAR LEVELS FOR EAST
125	52	37 CLEAR LEVELS FOR WEST

APPENDIX C

SENSITIVITY ANALYSIS PROGRAM LISTING

```
10    !  ********** DAN FITZGERALD   DECEMBER 1981
20    !  ********** SENSITIVITY ANALYSIS FOR MASTERS THESIS - CHAPTER 9
30    !
40    ! THIS PROGRAM COMPUTES THE PERCENT ANNUAL SAVINGS FOR A BUILDING
50    ! WITH A FIXED DESIGN BY USING THE LUMEN METHOD OR (LOF) DAYLIGHT
60    ! PREDICTION METHOD.  ANY OF THE ASSIGNED VALUES CAN BE CHANGED
70    ! TO SHOW HOW THEY AFFECT THE PERCENT ANNUAL SAVINGS.  THE BASIC
80    ! ASSUMPTIONS ARE GIVEN BELOW:
90    !
100   !   * SITE LOCATION - ST. LOUIS, MISSOURI    38 DEGREES N. LATITUDE
110   !   * SEASONAL CLEAR & OVERCAST % - SUMMER  >  CLEAR=.680   OVERCAST=.320
120   !        FROM THE: "WEATHER ATLAS   AUTUMN  >  CLEAR=.666   OVERCAST=.334
130   !        OF THE UNITED STATES"      WINTER  >  CLEAR=.468   OVERCAST=.514
140   !                                   SPRING  >  CLEAR=.546   OVERCAST=.454
150   !   * BUILDING DIMENSIONS - 100 FEET x 100 FEET x 10 FOOT CEILING HEIGHT
160   !                           ONE LEVEL   N-S-E-W ORIENTATIONS WITH
170   !                                       CONTINUOUS GLASS FOR EACH SIDE
180   !   * DESIGN DAY PER SEASON - SUMMER  >  JUNE 21
190   !                             AUTUMN  >  SEPTEMBER 21
200   !                             WINTER  >  DECEMBER 21
210   !                             SPRING  >  MARCH 21
220   !   * WORKING DAY HOURS - 7AM TO 5PM (ASSUMES SOLAR TIME)
230   !                         ILLUMINATION LEVELS SYMETRIC ABOUT NOON
240   !
250   !
260   !
270   OPTION BASE 1
280   SHORT I(3,6,7)
290   !
300   !
310   ! ILLUMINATION DATA IS ENTERED IN THIS ORDER:
320   !
330   !  VERTICAL OVERCAST/HORIZONTAL OVERCAST/VERTICAL CLEAR NORTH/VERTICAL CLE
AR SOUTH/VERTICAL CLEAR EAST/VERTICAL CLEAR WEST/HORIZONTAL CLEAR
340   !
350   DATA 350,900,750,550,1300,300,1050       ! 7AM/5PM
360   DATA 500,1300,700,700,1450,350,1300      ! 8AM/4PM
370   DATA 700,1700,650,850,1450,450,1500      ! 9AM/3PM
380   DATA 900,2150,650,900,1350,500,1600      ! 10AM/2PM
390   DATA 1100,2800,550,1050,1050,550,1600    ! 11AM/1PM
400   DATA 1200,3200,450,1250,750,750,1600     ! 12NOON ^ JUNE 21
410   !
420   DATA 150,400,300,450,900,200,550         ! 7AM/5PM
430   DATA 300,800,450,700,1100,300,850        ! 8AM/4PM
440   DATA 450,1200,400,1050,1150,350,1050     ! 9AM/3PM
450   DATA 600,1500,400,1100,1100,400,1250     ! 10AM/2PM
460   DATA 700,1750,400,1200,900,550,1300      ! 11AM/1PM
470   DATA 750,1800,350,1300,600,600,1350      ! 12NOON ^ SEPT/MAR 21
480   !
490   DATA 0,0,0,0,0,0,0                       ! 7AM/5PM
500   DATA 100,250,150,400,600,150,350         ! 8AM/4PM
510   DATA 200,550,250,850,850,250,600         ! 9AM/3PM
520   DATA 300,800,250,950,700,350,750         ! 10AM/2PM
530   DATA 350,900,300,1050,600,400,800        ! 11AM/1PM
540   DATA 400,1000,300,1100,450,450,850       ! 12NOON ^ DEC 21
550   !
560   READ I(*)
570   PRINTER IS 0
580  ! PRINT I(*)    >>>>>>>IF A LIST OF THE ILLUMINATION DATA IS NEEDED REMOVE !
590   PRINTER IS 16
600   DIM Hrs$(6)[20],Sea$(3)[20]
```

```
610   SHORT Ekwc(4),Maxo(3,6),Mido(3,6),Mino(3,6),Maxc(3,6,6),Midc(3,6,6),Minc(3
,6,6)
620   !
630 Given_averages:! >>>>>>>LOF DAYLIGHT DESIGN VARIABLES
640   !
650   Rg=.3       !GROUND REFLECTANCE .3
660   Agl=210     !AREA OF GLASS     (EXCLUDING SILL HEIGHT)
670   Pg=.9       !USABLE AREA OF GLASS
680   Tg=.7       !TRANSMITTANCE OF GLASS  .7
690   Wr=.7       !WALL REFLECTANCE
700   L=30        !LENGTH
710   W=30        !WIDTH
720   H=10        !CEILING HEIGHT
730   !
740 Time_data:  ! >>>>>>>>OUTPUT PRINT HEADINGS
750   !
760   Hrs$(1)="7AM/5PM"
770   Hrs$(2)="8AM/4PM"
780   Hrs$(3)="9AM/3PM"
790   Hrs$(4)="10AM/2PM"
800   Hrs$(5)="11AM/1PM"
810   Hrs$(6)="12NOON"
820   Sea$(1)="SUMMER SKY - JUNE 21"
830   Sea$(2)="MID SKY - SEP/MAR 21"
840   Sea$(3)="WINTER SKY - DEC 21"
850   !
860 Input_cu:  ! COEFFICIENTS OF UTILIZATION FOR 30x30x10 ROOM
870   !           REFLECTANCES - WALL 70%  FLOOR 30%  CEILING  90%
880   Cosx=.0188
890   Cosd=.0054
900   Cosn=.0029
910   Kosx=.122
920   Kosd=.0939
930   Kosn=.101
940   Ccsx=.0137
950   Ccsd=.0062
960   Ccsn=.0047
970   Kcsx=.125
980   Kcsd=.110
990   Kcsn=.107
1000  Cugx=.0098
1010  Cugd=.0062
1020  Cugn=.0041
1030  Kugx=.140
1040  Kugd=.107
1050  Kugn=.0984
1060  !
1070 Calcs_mmm: ! CLEAR AND OVERCAST CALCULATIONS FOR MAX,MID,MIN
1080  !            S=#SEASONS  H=#HOURS  O=#ORIENTATIONS
1090  FOR S=1 TO 3
1100  FOR H=1 TO 6
1110  !
1120  Egwo=I(S,H,2)*Rg*.5
1130  Egwc=I(S,H,7)*Rg*.5
1140  Ag=Agl*Pg
1150  Ekwpxo=I(S,H,1)*Ag*Tg*Cosx*Kosx     !OVERCAST
1160  Egwpxo=Egwo*Ag*Tg*Cugx*Kugx
1170  Maxo(S,H)=Ekwpxo+Egwpxo
1180  Ekwpdo=I(S,H,1)*Ag*Tg*Cosd*Kosd
1190  Egwpdo=Egwo*Ag*Tg*Cugd*Kugd
1200  Mido(S,H)=Ekwpdo+Egwpdo
```

```
1210  Ekwpno=I(S,H,1)*Ag*Tg*Cosn*Kosn
1220  Egwpno=Egwo*Ag*Tg*Cugn*Kugn
1230  Mino(S,H)=Ekwpno+Egwpno
1240  FOR O=3 TO 6
1250  Ekwpxc=I(S,H,O)*Ag*Tg*Ccsx*Kcsx        !CLEAR
1260  Egwpxc=Egwc*Ag*Tg*Cugx*Kugx
1270  Maxc(S,H,O)=Ekwpxc+Egwpxc
1280  Ekwpdc=I(S,H,O)*Ag*Tg*Ccsd*Kcsd
1290  Egwpdc=Egwc*Ag*Tg*Cugd*Kugd
1300  Midc(S,H,O)=Ekwpdc+Egwpdc
1310  Ekwpnc=I(S,H,O)*Ag*Tg*Ccsn*Kcsn
1320  Egwpnc=Egwc*Ag*Tg*Cugn*Kugn
1330  Minc(S,H,O)=Ekwpnc+Egwpnc
1340  NEXT O
1350  NEXT H
1360  NEXT S
1370   GOTO 1650   ! >>>>>>>IF MAX,MID,MIN PRINTOUTS WANTED REMOVE GOTO
1380  PRINTER IS 0
1390  PRINT "38 DEGREES LATITUDE - ST. LOUIS, MO."
1400  PRINT "N-S-E-W ORIENTATIONS FOR `TYPICAL´ DESIGN CONDITIONS"
1410  PRINT
1420  PRINT
1430  PRINT
1440  FOR S=1 TO 3
1450  PRINT "*********************************************************************"
1460  PRINT Sea$(S)
1470  PRINT "*********************************************************************"
1480  PRINT
1490  FOR H=1 TO 6
1500  PRINT "FOOTCANDLE ILLUMINATION LEVELS FOR      ";Hrs$(H)
1510  PRINT
1520  PRINT "..................................................................."
1530  PRINT " 5´"," 15´"," 25´";"DISTANCE FROM WINDOW"
1540  PRINT "..................................................................."
1550  PRINT Maxo(S,H),Mido(S,H),Mino(S,H);"OVERCAST LEVELS"
1560  PRINT
1570  PRINT Maxc(S,H,3),Midc(S.H,3),Minc(S,H,3);"CLEAR LEVELS FOR NORTH"
1580  PRINT Maxc(S,H,4),Midc(S,H,4),Minc(S,H,4);"CLEAR LEVELS FOR SOUTH"
1590  PRINT Maxc(S,H,5),Midc(S,H,5),Minc(S.H,5);"CLEAR LEVELS FOR EAST"
1600  PRINT Maxc(S,H,6),Midc(S,H,6),Minc(S,H,6);"CLEAR LE ELS FOR WEST"
1610  PRINT
1620  PRINT
1630  NEXT H
1640  NEXT S
1650  !
1660 Conditions_ov: ! CHECKS MAX,MID.MIN AND SUMS AREAS BY FOOTCANDLE LEVELS
1670  !
1680  SHORT Axo(3,6),Acx(3,6),Ado(3,6),Acd(3,6),Ano(3,6),Acn(3,6),Axc(3,6,6),Adc
(3,6,6),Anc(3,6,6),Aax(3,6,6),Aad(3,6,6),Aan(3,6,6)
1690  INTEGER Arto(3,6),Dayo(3,6),Artor(6),Dayor(6),Artc(3,6),Dayc(3.6),Artcc(3,
6)
1700  !
1710  Acore=2500   !BUILDING CORE AREA WHICH NEVER HAS DAYLIGHTING
1720  !
1730  FOR S=1 TO 3
1740  FOR H=1 TO 6
1750  !
1760  !
1770  IF Maxo(S,H)>50 THEN Axo(S,H)=1900       !OVERCAST CONDITIONS
1780  IF Maxo(S,H)>50 THEN GOTO 1830          ! MAX ZONE AREA FOR TOTAL
1790  IF Maxo(S,H)<25 THEN GOTO 1810          ! BUILDING = 1900 SQ.FT.
```

```
1800  Axo(S,H)=Acx(S,H)=950
1810  IF Maxo(S,H)<25 THEN Acx(S,H)=1900
1820  !
1830  IF Mido(S,H)>50 THEN Ado(S,H)=3200       ! MID ZONE FOR TOTAL
1840  IF Mido(S,H)>50 THEN 1890               ! BUILDING = 3200 SQ.FT.
1850  IF Mido(S,H)<25 THEN 1870
1860  Ado(S,H)=Acd(S,H)=1600
1870  IF Mido(S,H)<25 THEN Acd(S,H)=3200
1880  !
1890  IF Mino(S,H)>50 THEN Ano(S,H)=2400
1900  IF Mino(S,H)>50 THEN GOTO 1950          ! MIN ZONE FOR TOTAL
1910  IF Mino(S,H)<25 THEN GOTO 1930          ! BUILDING = 2400 SQ.FT.
1920  Ano(S,H)=Acn(S,H)=1200
1930  IF Mino(S,H)<25 THEN Acn(S,H)=2400
1940  !
1950  Arto(S,H)=Acx(S,H)+Acd(S,H)+Acn(S,H)+Acore      !SUM ARTIFICAL AREAS
1960  Dayo(S,H)=Axo(S,H)+Ado(S,H)+Ano(S,H)            !SUM DAYLIGHT AREAS
1970  !
1980  ! PRINT Arto(S,H),Dayo(S,H) !>>>>>>IF PRINTOUT NEEDED REMOVE !
1990  !
2000 Conditions_cl:  ! CHECKS MAX,MID,MIN FOR EACH ORIENTATION AND SUMS AREAS
2010  !
2020  SHORT Maxc_all(6),Maxc_half(6),Maxc_nun(6),Midc_all(6),Midc_half(6),Midc_n
un(6),Minc_all(6),Minc_half(6),Minc_nun(6)
2030  FOR O=3 TO 6
2040  !
2050  !
2060  IF Maxc(S,H,O)>50 THEN Axc(S,H,O)=475             !CLEAR CONDITIONS
2070  IF Maxc(S,H,O)>50 THEN GOTO 2120                  ! MAX ZONE AREA FOR EACH
2080  IF Maxc(S,H,O)<25 THEN GOTO 2100                  ! ORIENTATION = 475 SQ.FT.
2090  Axc(S,H,O)=Aax(S,H,O)=237.5
2100  IF Maxc(S,H,O)<25 THEN Aax(S,H,O)=475
2110  !
2120  IF Midc(S,H,O)>50 THEN Adc(S,H,O)=800             ! MID ZONE FOR EACH
2130  IF Midc(S,H,O)>50 THEN GOTO 2180                  ! ORIENTATION = 800 SQ.FT.
2140  IF Midc(S,H,O)<25 THEN GOTO 2160
2150  Adc(S,H,O)=Aad(S,H,O)=400
2160  IF Midc(S,H,O)<25 THEN Aad(S,H,O)=800
2170  !
2180  IF Minc(S,H,O)>50 THEN Anc(S,H,O)=600             ! MIN ZONE AREA FOR EACH
2190  IF Minc(S,H,O)>50 THEN GOTO 2240                  !ORIENTATION = 600 SQ.FT.
2200  IF Minc(S,H,O)<25 THEN GOTO 2220
2210  Anc(S,H,O)=Aan(S,H,O)=300
2220  IF Minc(S,H,O)<25 THEN Aan(S,H,O)=600
2230  !
2240  Artor(O)=Aax(S,H,O)+Aad(S,H,O)+Aan(S,H,O)        !SUM ARTIF. ORIENTATIONS
2250  Dayor(O)=Axc(S,H,O)+Adc(S,H,O)+Anc(S,H,O)        !SUM DAYLT. ORIENTATIONS
2260  Artc(S,H)=Artc(S,H)+Artor(O)
2270  Dayc(S,H)=Dayc(S,H)+Dayor(O)
2280  NEXT O
2290  Artcc(S,H)=Artc(S,H)+Acore
2300  ! PRINT Artcc(S,H),Dayc(S,H)   !>>>>>>IF PRINTOUT NEEIED REMOVE !
2310  ! PRINT
2320  NEXT H
2330  NEXT S
2340  !
2350  SHORT Ao(3),Do(3),Ac(3),Dc(3),Aoo(3),Acc(3),Po(3),Pc(3)
2360  FIXED 2
2370  FOR S=1 TO 3
2380  FOR H=1 TO 5
2390  Ao(S)=Ao(S)+Arto(S,H)          !SUM ARTIFICIAL OVERCAST HOURS
```

```
2400  Do(S)=Do(S)+Dayo(S,H)         !SUM DAYLIGHT OVERCAST HOURS
2410  Ac(S)=Ac(S)+Artcc(S,H)        !SUM ARTIFICAL CLEAR HOURS
2420  Dc(S)=Dc(S)+Dayc(S,H)         !SUM DAYLIGHT CLEAR HOURS
2430  NEXT H
2440  Aoo(S)=Ao(S)*2                !HOURS x 2 FOR FULL DAY PATTERN
2450  Acc(S)=Ac(S)*2
2460  Aoo(S)=Aoo(S)+Arto(S,6)       !ADD ONLY ONE NOON CONDITION
2470  Acc(S)=Acc(S)+Artcc(S,6)
2480  Po(S)=Aoo(S)/110000           !11 HOUR AREA / 11 HOUR TOTAL AREA FOR % HR
2490  Pc(S)=Acc(S)/110000
2500 ! PRINT Po(S),Pc(S)
2510  IF S=1 THEN Yos=Po(S)*.320         !BASED ON MEAN PERCENTAGE
2520  IF S=1 THEN Ycs=Pc(S)*.680         !OF POSSIBLE SUNSHINE
2530  IF S=2 THEN Yop=Po(S)*.454         !FOR EACH SEASON
2540  IF S=2 THEN Ycp=Pc(S)*.546
2550  IF S=2 THEN Yof=Po(S)*.334
2560  IF S=2 THEN Ycf=Pc(S)*.666
2570  IF S=3 THEN Yow=Po(S)*.514
2580  IF S=3 THEN Ycw=Pc(S)*.468         !CLOUD COVER WEIGHTINGS
2590  NEXT S
2600  Ys=Yos+Ycs                         !SUM SEASONAL % AFTER CLEAR/OVERCAST
2610  Yp=Yop+Ycp                         !WEIGHTINGS
2620  Yf=Yof+Ycf
2630  Yw=Yow+Ycw
2640  Y=(Ys+Yp+Yf+Yw)/4                  !ANNUAL %
2650  Savings=(1-Y)*100
2660  IF Savings<O THEN Savings=0
2670  !
2680  !
2681  PRINTER IS 0
2690  PRINT "ANNUAL SAVINGS=";Savings;"%";"   GRD. REF.=";Rg  !>>>>>>INSERT DESI
RED VARIABLE HERE
2700  PRINTER IS 16
2710  !
2720  FIXED 0
2730  END
```

APPENDIX D

EXAMPLE PRINTOUT OF MAX, MID AND MIN DAYLIGHT

ILLUMINATION LEVELS FOR THE EXAMPLE

PROJECT ANALYSIS

SUMMER SKY - JUNE 21

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>7AM/5PM

12.5´	25´DISTANCE FROM WINDOW
0	0 OVERCAST - COURTS/COMMONS
0	0 OVERCAST - NORTH LIGHTWELL
0	0 CLEAR NORTH - COURTS/COMMONS
0	0 CLEAR SOUTH - COURTS/COMMONS
0	0 CLEAR EAST - COURTS/COMMONS
0	0 CLEAR WEST - COURTS/COMMONS
0	0 CLEAR NORTH LIGHTWELL

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>8AM/4PM

12.5´	25´DISTANCE FROM WINDOW
47	28 OVERCAST - COURTS/COMMONS
12	7 OVERCAST - NORTH LIGHTWELL
71	49 CLEAR NORTH - COURTS/COMMONS
71	49 CLEAR SOUTH - COURTS/COMMONS
119	84 CLEAR EAST - COURTS/COMMONS
49	33 CLEAR WEST - COURTS/COMMONS
16	10 CLEAR NORTH LIGHTWELL

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>9AM/3PM

12.5´	25´DISTANCE FROM WINDOW
65	38 OVERCAST - COURTS/COMMONS
16	10 OVERCAST - NORTH LIGHTWELL
70	48 CLEAR NORTH - COURTS/COMMONS
82	57 CLEAR SOUTH - COURTS/COMMONS
121	85 CLEAR EAST - COURTS/COMMONS
57	38 CLEAR WEST - COURTS/COMMONS
20	12 CLEAR NORTH LIGHTWELL

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>10AM/2PM

12.5´	25´DISTANCE FROM WINDOW
83	49 OVERCAST - COURTS/COMMONS
21	13 OVERCAST - NORTH LIGHTWELL
71	49 CLEAR NORTH - COURTS/COMMONS
87	60 CLEAR SOUTH - COURTS/COMMONS
116	81 CLEAR EAST - COURTS/COMMONS
61	41 CLEAR WEST - COURTS/COMMONS
21	13 CLEAR NORTH LIGHTWELL

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>11AM/1PM

12.5´	25´DISTANCE FROM WINDOW
103	61 OVERCAST - COURTS/COMMONS
26	16 OVERCAST - NORTH LIGHTWELL
63	43 CLEAR NORTH - COURTS/COMMONS
95	66 CLEAR SOUTH - COURTS/COMMONS
95	66 CLEAR EAST - COURTS/COMMONS
63	43 CLEAR WEST - COURTS/COMMONS
25	15 CLEAR NORTH LIGHTWELL

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>12NOON

12.5´	25´DISTANCE FROM WINDOW
114	68 OVERCAST - COURTS/COMMONS
28	17 OVERCAST - NORTH LIGHTWELL
55	37 CLEAR NORTH - COURTS/COMMONS
106	75 CLEAR SOUTH - COURTS/COMMONS
75	51 CLEAR EAST - COURTS/COMMONS
75	51 CLEAR WEST - COURTS/COMMONS
29	18 CLEAR NORTH LIGHTWELL

MID SKY - SEP/MAR 21

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>7AM/5PM

12.5'	25'DISTANCE FROM WINDOW	
0	0	OVERCAST - COURTS/COMMONS
0	0	OVERCAST - NORTH LIGHTWELL
0	0	CLEAR NORTH - COURTS/COMMONS
0	0	CLEAR SOUTH - COURTS/COMMONS
0	0	CLEAR EAST - COURTS/COMMONS
0	0	CLEAR WEST - COURTS/COMMONS
0	0	CLEAR NORTH LIGHTWELL

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>8AM/4PM

12.5'	25'DISTANCE FROM WINDOW	
0	0	OVERCAST - COURTS/COMMONS
0	0	OVERCAST - NORTH LIGHTWELL
0	0	CLEAR NORTH - COURTS/COMMONS
0	0	CLEAR SOUTH - COURTS/COMMONS
0	0	CLEAR EAST - COURTS/COMMONS
0	0	CLEAR WEST - COURTS/COMMONS
0	0	CLEAR NORTH LIGHTWELL

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>9AM/3PM

12.5'	25'DISTANCE FROM WINDOW	
43	25	OVERCAST - COURTS/COMMONS
11	6	OVERCAST - NORTH LIGHTWELL
44	30	CLEAR NORTH - COURTS/COMMONS
86	61	CLEAR SOUTH - COURTS/COMMONS
92	66	CLEAR EAST - COURTS/COMMONS
41	28	CLEAR WEST - COURTS/COMMONS
25	15	CLEAR NORTH LIGHTWELL

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>10AM/2PM

12.5'	25'DISTANCE FROM WINDOW	
56	33	OVERCAST - COURTS/COMMONS
14	9	OVERCAST - NORTH LIGHTWELL
47	32	CLEAR NORTH - COURTS/COMMONS
92	65	CLEAR SOUTH - COURTS/COMMONS
92	65	CLEAR EAST - COURTS/COMMONS
47	32	CLEAR WEST - COURTS/COMMONS
26	16	CLEAR NORTH LIGHTWELL

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>11AM/1PM

12.5'	25'DISTANCE FROM WINDOW	
65	39	OVERCAST - COURTS/COMMONS
16	10	OVERCAST - NORTH LIGHTWELL
48	32	CLEAR NORTH - COURTS/COMMONS
99	70	CLEAR SOUTH - COURTS/COMMONS
80	56	CLEAR EAST - COURTS/COMMONS
57	39	CLEAR WEST - COURTS/COMMONS
28	17	CLEAR NORTH LIGHTWELL

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>12NOON

12.5'	25'DISTANCE FROM WINDOW	
69	41	OVERCAST - COURTS/COMMONS
18	11	OVERCAST - NORTH LIGHTWELL
44	30	CLEAR NORTH - COURTS/COMMONS
105	75	CLEAR SOUTH - COURTS/COMMONS
60	42	CLEAR EAST - COURTS/COMMONS
60	42	CLEAR WEST - COURTS/COMMONS
31	19	CLEAR NORTH LIGHTWELL

WINTER SKY - DEC 21

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>7AM/5PM

12.5'	25'DISTANCE FROM WINDOW
0	0 OVERCAST - COURTS/COMMONS
0	0 OVERCAST - NORTH LIGHTWELL
0	0 CLEAR NORTH - COURTS/COMMONS
0	0 CLEAR SOUTH - COURTS/COMMONS
0	0 CLEAR EAST - COURTS/COMMONS
0	0 CLEAR WEST - COURTS/COMMONS
0	0 CLEAR NORTH LIGHTWELL

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>8AM/4PM

12.5'	25'DISTANCE FROM WINDOW
0	0 OVERCAST - COURTS/COMMONS
0	0 OVERCAST - NORTH LIGHTWELL
0	0 CLEAR NORTH - COURTS/COMMONS
0	0 CLEAR SOUTH - COURTS/COMMONS
0	0 CLEAR EAST - COURTS/COMMONS
0	0 CLEAR WEST - COURTS/COMMONS
0	0 CLEAR NORTH LIGHTWELL

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>9AM/3PM

12.5'	25'DISTANCE FROM WINDOW
0	0 OVERCAST - COURTS/COMMONS
0	0 OVERCAST - NORTH LIGHTWELL
0	0 CLEAR NORTH - COURTS/COMMONS
0	0 CLEAR SOUTH - COURTS/COMMONS
0	0 CLEAR EAST - COURTS/COMMONS
0	0 CLEAR WEST - COURTS/COMMONS
0	0 CLEAR NORTH LIGHTWELL

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>10AM/2PM

12.5'	25'DISTANCE FROM WINDOW
0	0 OVERCAST - COURTS/COMMONS
0	0 OVERCAST - NORTH LIGHTWELL
0	0 CLEAR NORTH - COURTS/COMMONS
0	0 CLEAR SOUTH - COURTS/COMMONS
0	0 CLEAR EAST - COURTS/COMMONS
0	0 CLEAR WEST - COURTS/COMMONS
0	0 CLEAR NORTH LIGHTWELL

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>11AM/1PM

12.5'	25'DISTANCE FROM WINDOW
0	0 OVERCAST - COURTS/COMMONS
0	0 OVERCAST - NORTH LIGHTWELL
0	0 CLEAR NORTH - COURTS/COMMONS
0	0 CLEAR SOUTH - COURTS/COMMONS
0	0 CLEAR EAST - COURTS/COMMONS
0	0 CLEAR WEST - COURTS/COMMONS
0	0 CLEAR NORTH LIGHTWELL

>>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>>>12NOON

12.5'	25'DISTANCE FROM WINDOW
0	0 OVERCAST - COURTS/COMMONS
0	0 OVERCAST - NORTH LIGHTWELL
0	0 CLEAR NORTH - COURTS/COMMONS
0	0 CLEAR SOUTH - COURTS/COMMONS
0	0 CLEAR EAST - COURTS/COMMONS
0	0 CLEAR WEST - COURTS/COMMONS
0	0 CLEAR NORTH LIGHTWELL

APPENDIX E

EXAMPLE PROJECT ANALYSIS PROGRAM LISTING

```
10    !  *********** DAN FITZGERALD   DECEMBER 1981
20    !  *********** EXAMPLE - CALIFORNIA STATE OFFICE BUILDING - CHAPTER 10
30    !
40    ! THIS PROGRAM COMPUTES THE PERCENT ANNUAL SAVINGS FOR THE EXAMPLE
50    ! PROJECT BY USING THE LIBBEY-OWENS-FORD DAYLIGHT PREDICTION METHOD.
60    ! SOME OF THE BASIC DESIGN VALUES HAVE BEEN ESTABLISHED BY L.L.BOYER'S
70    ! INITIAL ANALYSIS OF THE PRELIMINARY DESIGN SCHEME.  THE BASIC
80    ! ASSUMPTIONS ARE GIVEN BELOW:
90    !
100   !   * SITE LOCATION - SACRAMENTO,CALIFORNIA - 38 DEGREES N. LATITUDE
110   !   * SEASONAL CLEAR & OVERCAST % - SUMMER  >  CLEAR=.893   OVERCAST=.107
120   !        FROM THE: "WEATHER ATLAS   AUTUMN  >  CLEAR=.896   OVERCAST=.104
130   !        OF THE UNITED STATES"      WINTER  >  CLEAR=.510   OVERCAST=.490
140   !                                   SPRING  >  CLEAR=.666   OVERCAST=.334
150   !   * BUILDING DIMENSIONS - 100 FEET x 150 FEET x 10 FOOT CEILING HEIGHT
160   !                         - WITH 50x50 COURT CENTERED AND AGAINST THE 150
170   !                         - WALL. OPPOSITE 150 WALL IS OPEN TO COMMONS.
180   !                         - TWO LEVEL   N-S-E-W ORIENTATIONS WITH
190   !                         - CONTINUOUS GLASS FOR ALL EXPOSURES
200   !   * DESIGN DAY PER SEASON - SUMMER  >  JUNE 21
210   !                             AUTUMN  >  SEPTEMBER 21
220   !                             WINTER  >  DECEMBER 21
230   !                             SPRING  >  MARCH 21
240   !   * WORKING DAY HOURS - 7AM TO 5PM
250   !
260   !
270   !
280   !
290   OPTION BASE 1
300   SHORT I(3,6,7)
310   !
320   !
330   ! ILLUMINATION DATA IS TYPED IN BY THIS ORDER:
340   !
350   !  VERTICAL OVERCAST/HORIZONTAL OVERCAST/VERTICAL CLEAR NORTH/VERTICAL CLE
AR SOUTH/VERTICAL CLEAR EAST/VERTICAL CLEAR WEST/HORIZONTAL CLEAR
360   !
370   DATA 0,0,0,0,0,0,0
380   DATA 500,1300,700,700,1450,350,1300      ! 8AM/4PM
390   DATA 700,1700,650,850,1450,450,1500      ! 9AM/3PM
400   DATA 900,2150,650,900,1350,500,1600      ! 10AM/2PM
410   DATA 1100,2800,550,1050,1050,550,1600    ! 11AM/1PM
420   DATA 1200,3200,450,1250,750,750,1600     ! 12NOON ^ JUNE 21
430   !
440   DATA 0,0,0,0,0,0,0
450   DATA 0,0,0,0,0,0,0
460   DATA 450,1200,400,1050,1150,350,1050     ! 9AM/3PM
470   DATA 600,1500,400,1100,1100,400,1250     ! 10AM/2PM
480   DATA 700,1750,400,1200,900,550,1300      ! 11AM/1PM
490   DATA 750,1800,350,1300,600,600,1350      ! 12NOON ^ SEPT/MAR 21
500   !
510   DATA 0,0,0,0,0,0,0                       ! 7AM/5PM
520   DATA 0,0,0,0,0,0,0
530   DATA 0,0,0,0,0,0,0                       ! 9AM/3PM
540   DATA 0,0,0,0,0,0,0                       ! 10AM/2PM
550   DATA 0,0,0,0,0,0,0                       ! 11AM/1PM
560   DATA 0,0,0,0,0,0,0                       ! 12NOON ^ DEC 21
570   !
580   READ I(*)
590   PRINTER IS 0
600  ! PRINT I(*)    >>>>>>>IF A LIST OF THE ILLUMINATION DATA IS NEEDED REMOVE !
```

```
610   PRINTER IS 16
620   DIM Hrs$(6)[20],Sea$(3)[20]
630   !
640 Given_averages:! >>>>>>>LOF DAYLIGHT DESIGN VARIABLES
650   !
660   Rg=.3       !GROUND REFLECTANCE
670   Rb=.5       !BUILDING REFLECTANCE
680   Agl=210     !AREA OF GLASS(ALWAYS MAXIMUM EXCLUDING SILL HEIGHT)
690   Pg=.9       !USABLE AREA OF GLASS
700   Tg=.75      !TRANSMITTANCE OF GLASS
710   Wr=.7       !INTERIOR WALL REFLECTANCE
720   L=30        !LENGTH
730   W=30        !WIDTH
740   H=10        !CEILING HEIGHT
750   !
760 Time_data:  ! >>>>>>>>OUTPUT PRINT HEADINGS
770   !
780   Hrs$(1)="7AM/5PM"
790   Hrs$(2)="8AM/4PM"
800   Hrs$(3)="9AM/3PM"
810   Hrs$(4)="10AM/2PM"
820   Hrs$(5)="11AM/1PM"
830   Hrs$(6)="12NOON"
840   Sea$(1)="SUMMER SKY - JUNE 21"
850   Sea$(2)="MID SKY - SEP/MAR 21"
860   Sea$(3)="WINTER SKY - DEC 21"
870   !
880 Input_cu:  ! COEFFICIENTS OF UTILIZATION FOR 30x30x10 ROOM
890   !          REFLECTANCES - WALL 70%  FLOOR 30%  CEILING  80%
900   Cosx=.0188
910   Cosd=.0054
920   Cosn=.0029
930   Kosx=.122
940   Kosd=.0939
950   Kosn=.101
960   Ccsx=.0137
970   Ccsd=.0062
980   Ccsn=.0047
990   Kcsx=.125
1000  Kcsd=.110
1010  Kcsn=.107
1020  Cugx=.0098
1030  Cugd=.0062
1040  Cugn=.0041
1050  Kugx=.140
1060  Kugd=.107
1070  Kugn=.0984
1080  !
1090 Calcs_mmm: ! CLEAR AND OVERCAST CALCULATIONS FOR MAX,MID,MIN
1100  !           S=#SEASONS  H=#HOURS  O=#ORIENTATIONS
1110  FOR S=1 TO 3
1120  FOR H=1 TO 6
1130  !
1140  !                                  >>>>>COMPONENTS FOR SUBTERRANEAN SECTION
1150  Egwo=I(S,H,2)*Rg*.45+I(S,H,1)*Rb*.3     !GROUND REFLECTANCE COMPONENTS
1160  Egwc=I(S,H,7)*Rg*.45+I(S,H,3)*Rb*.3
1170  Ag=Agl*Pg
1180  Ekwpxo=I(S,H,1)*Ag*Tg*Cosx*Kosx*.66     !OVERCAST SKY COMPONENTS
1190  Egwpxo=Egwo*Ag*Tg*Cugx*Kugx
1200  Maxo(S,H)=Ekwpxo+Egwpxo
1210  Ekwpdo=I(S,H,1)*Ag*Tg*Cosd*Kosd*.66
```

```
1220  Egwpdo=Egwo*Ag*Tg*Cugd*Kugd
1230  Mido(S,H)=Ekwpdo+Egwpdo
1240  Ekwpno=I(S,H,1)*Ag*Tg*Cosn*Kosn*.66
1250  Egwpno=Egwo*Ag*Tg*Cugn*Kugn
1260  Mino(S,H)=Ekwpno+Egwpno
1270  FOR O=3 TO 6
1280  Ekwpxc=I(S,H,O)*Ag*Tg*Ccsx*Kcsx*.66     !CLEAR SKY COMPONENTS
1290  Egwpxc=Egwc*Ag*Tg*Cugx*Kugx
1300  Maxc(S,H,O)=Ekwpxc+Egwpxc
1310  Ekwpdc=I(S,H,O)*Ag*Tg*Ccsd*Kcsd*.66
1320  Egwpdc=Egwc*Ag*Tg*Cugd*Kugd
1330  Midc(S,H,O)=Ekwpdc+Egwpdc
1340  Ekwpnc=I(S,H,O)*Ag*Tg*Ccsn*Kcsn*.66
1350  Egwpnc=Egwc*Ag*Tg*Cugn*Kugn
1360  Minc(S,H,O)=Ekwpnc+Egwpnc
1370  NEXT O
1380  DIM Ndo(3,6),Nno(3,6),Ndc(3,6),Nnc(3,6)
1390  !                                   >>>>>>COMPONENTS FOR NORTH LIGHTWELL
1400  Ndo(S,H)=I(S,H,1)*Rb*.5*Ag*Tg*Cugd*Kugd  !WALL REFLECTANCE COMPONENTS
1410  Nno(S,H)=I(S,H,1)*Rb*.5*Ag*Tg*Cugn*Kugn
1420  Ndc(S,H)=I(S,H,4)*Rb*.5*Ag*Tg*Cugd*Kugd
1430  Nnc(S,H)=I(S,H,4)*Rb*.5*Ag*Tg*Cugn*Kugn
1440  NEXT H
1450  NEXT S
1460    GOTO 1780   ! >>>>>>>>IF MAX,MID,MIN PRINTOUTS WANTED REMOVE GOTO
1470  PRINTER IS 0
1480  FIXED 0
1490  PRINT "38 N DEGREES LATITUDE - SACRAMENTO,CA."
1500  PRINT "N-S-E-W ORIENTATIONS FOR 'AVERAGE' DESIGN CONDITIONS"
1510  PRINT
1520  PRINT
1530  PRINT
1540  FOR S=1 TO 3
1550  PRINT "______________________________________________________________________"
1560  PRINT Sea$(S)
1570  PRINT "______________________________________________________________________"
1580  PRINT
1590  FOR H=1 TO 6
1600  PRINT ">>>>>FOOTCANDLE ILLUMINATION LEVELS FOR>>>> ";Hrs$(H)
1610  PRINT "..................................................................."
1620  PRINT "12.5'"," 25'";"DISTANCE FROM WINDOW"
1630  PRINT "..................................................................."
1640  PRINT Mido(S,H),Mino(S,H);"OVERCAST - COURTS/COMMONS"
1650  PRINT Ndo(S,H),Nno(S,H);"OVERCAST - NORTH LIGHTWELL"
1660  PRINT Midc(S,H,3),Minc(S,H,3);"CLEAR NORTH - COURTS/COMMONS"
1670  PRINT Midc(S,H,4),Minc(S,H,4);"CLEAR SOUTH - COURTS/COMMONS"
1680  PRINT Midc(S,H,5),Minc(S,H,5);"CLEAR EAST - COURTS/COMMONS"
1690  PRINT Midc(S,H,6),Minc(S,H,6);"CLEAR WEST - COURTS/COMMONS"
1700  PRINT Ndc(S,H),Nnc(S,H);"CLEAR NORTH LIGHTWELL"
1710  PRINT
1720  NEXT H
1730  PRINT
1740  PRINT
1750  PRINT
1760  PRINT
1770  NEXT S
1780  !
1790 Conditions_ov: ! CHECKS MAX,MID,MIN AND SUMS AREAS BY FOOTCANDLE LEVELS
1800  !
1810  DIM Maxo(3,6),Mido(3,6),Mino(3,6),Maxc(3,6,6),Midc(3,6,6),Minc(3,6,6)
1820  DIM Axo(3,6),Acx(3,6),Ado(3,6),Acd(3,6),Ano(3,6),Acn(3,6),Axc(3,6,6),Adc(3
,6,6),Anc(3,6,6),Aax(3,6,6),Aad(3,6,6),Aan(3,6,6)
```

```
1830  INTEGER Arto(3,6),Dayo(3,6),Artor(6),Dayor(6),Artc(3,6),Dayc(3,6),Artcc(3,
6)
1840  !
1850  Acore=7500   ! SUBTERRANEAN BUILDING CORE AREA
1860  Nacore=6250  ! NORTH LIGHTWELL OFFICE CORE AREA
1870  !
1880  FOR S=1 TO 3
1890  FOR H=1 TO 6
1900  !
1910  IF Mido(S,H)>50 THEN Ado(S,H)=8125      ! SUBTERRANEAN MID ZONE CONDITIONS
1920  IF Mido(S,H)>50 THEN 1960
1930  IF Mido(S,H)<25 THEN 1950
1940  Ado(S,H)=Acd(S,H)=8125/2
1950  IF Mido(S,H)<25 THEN Acd(S,H)=8125
1960  !
1970  !
1980  IF Mino(S,H)>50 THEN Ano(S,H)=9375
1990  IF Mino(S,H)>50 THEN GOTO 2030         ! SUBTERRANEAN MIN ZONE CONDITIONS
2000  IF Mino(S,H)<25 THEN GOTO 2020
2010  Ano(S,H)=Acn(S,H)=9375/2
2020  IF Mino(S,H)<25 THEN Acn(S,H)=9375
2030  !
2040 DIM Dod(3,6),Doe(3,6),Nod(3,6),Noe(3,6),Narto(3,6),Ndayo(3,6)
2050  !
2060  IF Ndo(S,H)>50 THEN Dod(S,H)=3125    ! NORTH LIGHTWELL MID ZONE CONDITIONS
2070  IF Ndo(S,H)>50 THEN GOTO 2110
2080  IF Ndo(S,H)<25 THEN GOTO 2100
2090  Dod(S,H)=Doe(S,H)=3125/2
2100  IF Ndo(S,H)<25 THEN Doe(S,H)=3125
2110  !
2120  !
2130  IF Nno(S,H)>50 THEN Nod(S,H)=3125    ! NORTH LIGHTWELL MIN ZONE CONDITIONS
2140  IF Nno(S,H)>50 THEN GOTO 2220
2150  IF Nno(S,H)<25 THEN GOTO 2170
2160  Nod(S,H)=Noe(S,H)=3125/2
2170  IF Nno(S,H)<25 THEN Noe(S,H)=3125
2180  !
2190  !
2200  Narto(S,H)=Doe(S,H)+Noe(S,H)+Nacore  ! SUMMATION OF NORTH LIGHTWELL AREAS
2210  Ndayo(S,H)=Dod(S,H)+Nod(S,H)
2220  !
2230  !
2240  Arto(S,H)=Acd(S,H)+Acn(S,H)+Acore    ! SUMMATION OF SUBTERRANEAN AREAS
2250  Dayo(S,H)=Ado(S,H)+Ano(S,H)
2260  !
2270  GOTO 2320  ! DELEATE STATEMENT IF AREA PRINTOUT IS NEEDED
2280  PRINT Narto(S,H),Ndayo(S,H);"  NORTH - ELEC/DAY"
2290  PRINT Arto(S,H),Dayo(S,H);"  SUB - ELEC/DAY"
2300  PRINT "^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^>OVERCAST"
2310  !
2320 Conditions_cl:  ! CHECKS MAX,MID,MIN FOR EACH ORIENTATION AND SUMS AREAS
2330  !
2340  FOR O=3 TO 6
2350  !
2360  IF O=3 THEN Ad=1458.33333  ! NORTH ZONE AREAS
2370  IF O=3 THEN An=1875
2380  IF O=4 THEN Ad=1458.33333  ! SOUTH ZONE AREAS
2390  IF O=4 THEN An=1875
2400  IF O=5 THEN Ad=2604.16666  ! EAST ZONE AREAS
2410  IF O=5 THEN An=2812.5
2420  IF O=6 THEN Ad=2604.16666  ! WEST ZONE AREAS
```

```
2430  IF O=6 THEN An=2812.5
2440  !
2450  IF Midc(S,H,O)>50 THEN Adc(S,H,O)=Ad    ! SUBTERRANEAN MID ZONE CONDITIONS
2460  IF Midc(S,H,O)>50 THEN GOTO 2520
2470  IF Midc(S,H,O)<25 THEN GOTO 2490
2480  Adc(S,H,O)=Aad(S,H,O)=Ad/2
2490  IF Midc(S,H,O)<25 THEN Aad(S,H,O)=Ad
2500  !
2510  !
2520  IF Minc(S,H,O)>50 THEN Anc(S,H,O)=An    ! SUBTERRANEAN MIN ZONE CONDITIONS
2530  IF Minc(S,H,O)>50 THEN GOTO 2590
2540  IF Minc(S,H,O)<25 THEN GOTO 2560
2550  Anc(S,H,O)=Aan(S,H,O)=An/2
2560  IF Minc(S,H,O)<25 THEN Aan(S,H,O)=An
2570  !
2580  !
2590  Artor(O)=Aad(S,H,O)+Aan(S,H,O)           !SUM SUBTERRANEAN ORIENTATIONS
2600  Dayor(O)=Adc(S,H,O)+Anc(S,H,O)
2610  Artc(S,H)=Artc(S,H)+Artor(O)             ! SUM SUBTERRANEAN ZONES
2620  Dayc(S,H)=Dayc(S,H)+Dayor(O)
2630  NEXT O
2640  Artcc(S,H)=Artc(S,H)+Acore
2650  !
2660  !
2670  DIM Dcd(3,6),Dce(3,6),Ncd(3,6),Nce(3,6),Nartc(3,6),Ndayc(3,6)
2680  !
2690  !
2700  IF Ndc(S,H)>50 THEN Dcd(S,H)=3125     ! NORTH LIGHTWELL MID ZONE CONDITIONS
2710  IF Ndc(S,H)>50 THEN GOTO 2760
2720  IF Ndc(S,H)<25 THEN GOTO 2740
2730  Dcd(S,H)=Dce(S,H)=3125/2
2740  IF Ndc(S,H)<25 THEN Dce(S,H)=3125
2750  !
2760  !
2770  IF Nnc(S,H)>50 THEN Ncd(S,H)=3125     ! NORTH LIGHTWELL MIN ZONE CONDITIONS
2780  IF Nnc(S,H)>50 THEN GOTO 2830
2790  IF Nnc(S,H)<25 THEN GOTO 2810
2800  Ncd(S,H)=Nce(S,H)=3125/2
2810  IF Nnc(S,H)<25 THEN Nce(S,H)=3125
2820  !
2830  !
2840  Nartc(S,H)=Dce(S,H)+Nce(S,H)+Nacore  ! SUM NORTH LIGHTWELL ZONES
2850  Ndayc(S,H)=Dcd(S,H)+Ncd(S,H)
2860  !
2870  GOTO 2910  ! DELEATE IF PRINOUT OF AREAS IS NEEDEI
2880  PRINT Nartc(S,H),Ndayc(S,H);"  NORTH ELEC/DAY"
2890  PRINT Artcc(S,H),Dayc(S,H);"  SUB ELEC/DAY"
2900  PRINT "^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^CLEAR"
2910  NEXT H
2920  NEXT S
2930  !
2940  SHORT Ao(3),Do(3),Ac(3),Dc(3),Aoo(3),Acc(3),Po(3),Pc(3)
2950  SHORT Nao(3),Nndo(3),Nac(3),Nndc(3),Naoo(3),Nacc(3,Npo(3),Npc(3)
2960  FIXED 0
2970  FOR S=1 TO 3
2980  FOR H=1 TO 5
2990  !                          >>>>>>>>SUBTERRANEAN SECTIONS
3000  Ao(S)=Ao(S)+Arto(S,H)          !SUM ARTIFICIAL OVERCAST HOURS
3010  Do(S)=Do(S)+Dayo(S,H)          !SUM DAYLIGHT OVERCAST HOURS
3020  Ac(S)=Ac(S)+Artcc(S,H)         !SUM ARTIFICAL CLEAR HOURS
3030  Dc(S)=Dc(S)+Dayc(S,H)          !SUM DAYLIGHT CLEAR HOURS
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3040  !                        >>>>>>>>NORTH LIGHTWELL SECTIONS
3050  Nao(S)=Nao(S)+Narto(S,H)        !REPEAT
3060  Nndo(S)=Nndo(S)+Ndayo(S,H)
3070  Nac(S)=Nac(S)+Nartc(S,H)
3080  Nndc(S)=Nndc(S)+Ndayc(S,H)
3090  !
3100  NEXT H
3110  !
3120  Aoo(S)=Ao(S)*2                  !HOURS x 2 FOR FULL DAY PATTERN
3130  Acc(S)=Ac(S)*2
3140  !
3150  Naoo(S)=Nao(S)*2
3160  Nacc(S)=Nac(S)*2
3170  !
3180  Aoo(S)=Aoo(S)+Arto(S,6)         !ADD ONLY ONE NOON CONDITION
3190  Acc(S)=Acc(S)+Artcc(S,6)
3200  !
3210  Naoo(S)=Naoo(S)+Narto(S,6)
3220  Nacc(S)=Nacc(S)+Nartc(S,6)
3230  !
3240  Po(S)=Aoo(S)/275000              !11 HOUR AREA / 11 HOUR TOTAL AREA FOR % HR
3250  Pc(S)=Acc(S)/275000
3260  !
3270  Npo(S)=Naoo(S)/137500
3280  Npc(S)=Nacc(S)/137500
3290  !
3300  FIXED 2
3310  ! PRINT Po(S);Pc(S);Npo(S);Npc(S);"   SUB - O/C   NOR - O/C"
3320    FIXED 0
3330  !       >>>>>>WEIGHTING FACTORS BASSED ON MEAN PERCENT OF POSSIBLE SUNSHINE
3340  !                          SUMMER
3350  IF S=1 THEN Yos=Po(S)*.107          !OVERCAST
3360  IF S=1 THEN Nos=Npo(S)*.107
3370  IF S=1 THEN Ycs=Pc(S)*.893          !CLEAR
3380  IF S=1 THEN Ncs=Npc(S)*.893
3390  !                          SPRING
3400  IF S=2 THEN Yop=Po(S)*.334          !OVERCAST
3410  IF S=2 THEN Nop=Npo(S)*.334
3420  IF S=2 THEN Ycp=Pc(S)*.666          !CLEAR
3430  IF S=2 THEN Ncp=Npc(S)*.666
3440  !                          FALL
3450  IF S=2 THEN Yof=Po(S)*.104          !OVERCAST
3460  IF S=2 THEN Nof=Npo(S)*.104
3470  IF S=2 THEN Ycf=Pc(S)*.896          !CLEAR
3480  IF S=2 THEN Ncf=Npc(S)*.896
3490  !                          WINTER
3500  IF S=3 THEN Yow=Po(S)*.490          !OVERCAST
3510  IF S=3 THEN Now=Npo(S)*.490
3520  IF S=3 THEN Ycw=Pc(S)*.510          !CLEAR
3530  IF S=3 THEN Ncw=Npc(S)*.510
3540  NEXT S
3550  Ys=Yos+Ycs                          !SUM SEASONAL % AFTER CLEAR/OVERCAST
3560  Yp=Yop+Ycp                          !WEIGHTINGS
3570  Yf=Yof+Ycf
3580  Yw=Yow+Ycw
3590  Ns=Nos+Ncs
3600  Np=Nop+Ncp
3610  Nf=Nof+Ncf
3620  Nw=Now+Ncw
3630  !
3640 ! PRINT Ys;Yp;Yf;Yw,Ns;Np;Nf;Nw
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```
3650  Y=(Ys+Yp+Yf+Yw)/4                        !ANNUAL % SUBTERRANEAN
3660  N=(Ns+Np+Nf+Nw)/4                        !ANNUAL % NORTH LIGHTWELL
3670  Savings=(1-Y)*100              !% ANNUAL LIGHTING ENERGY SAVINGS SUBTERRANEAN
3680  Nsavings=(1-N)*100       !% ANNUAL LIGHTING ENERGY SAVINGS NORTH LIGHTWELL
3690  IF Savings<0 THEN Savings=0
3700  IF Nsavings<0 THEN Nsavings=0
3710  !
3720  !
3730  PRINTER IS 0
3740  PRINT "SUBTERRANEAN                SOLAR SLAB"
3750  PRINT "ANNUAL SAVINGS=";Savings;"%","        ANNUAL SAVINGS=";Nsavings;"%"
3760  PRINTER IS 16
3770  !
3780  !
3790  FIXED 0
3800  END
```

VITA

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Master of Architectural Engineering

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