

## APPENDIX C - DAYLIGHTING

The role of daylighting in the total energy balance and performance of a building is a significant one. The admission of useful daylight means that electrical lighting fixtures can be turned off, saving electricity. The daylighting effects of glazing also have direct and indirect influence on the building thermal loads. The glazed area that lets in light will either admit heat from insolation or lose it to the exterior through conduction, or both at the same time. Reduction in the use of electrical lighting will lower internal heat loads. Different types of buildings and building occupancies have different mechanical loads, sometimes heating, sometimes cooling.

No one concern will totally determine the final fenestration design. Therefore, it is best to evaluate each proposed building design according to its own significant features.

In any energy analysis, the final thermal balance of a proposed design will be compared to an alternate "standard" design in order to determine cost effectiveness. A cost analysis of an energy-conscious design includes operating costs as well as initial costs. The issues which must be considered in such an analysis are listed below:

1. Portion of occupied hours illumination is provided by daylight:
  - a. Required illumination level
  - b. Hours of occupancy
  - c. Availability of daylight
2. Electrical load of supplementary electrical lighting compared to electrical load of "standard" design lighting installation.
3. Heat loss through building envelope with daylight openings compared to heat loss of "standard" design envelope.
4. Heat gain through building envelope with daylighting openings compared to heat gain of "standard" design envelope.
5. Reductions in electrical lighting load due to lighting control systems.
6. Reductions in heat loss and heat gain due to insulating window treatments
7. Difference in lighting requirements during different times of day.

The building type and use will determine the required illumination and hours of occupancy. The climate will determine available daylight and quantities of heat loss and gain through the building envelope. Local electrical rates will determine the significance of electrical lighting fixture load. Design and operation of shading devices and lighting control systems will determine the probable reductions in operating load due to use of daylighting. Although general guidelines can be drawn up for typical skin-dominated and internal-load dominated buildings, the number of variables and the multitude of design decisions that affect them require individual analysis.

### INFLUENCE OF CLIMATE

Daylight is a dynamic function of site, changing with the latitude, dominant weather patterns, the seasons, local atmosphere, the diurnal cycle, and specific site conditions. The relationship between daylight and useful interior illumination is affected by all these factors, the most important being weather.

The weather is changing constantly. According to weather experts, no two days are alike. The sky is, likewise, changing constantly. It is not possible to predict accurately exactly how many hours of sunshine we will have in a particular year or month. As the conformation of the sky varies, so does its daylight contribution. When the sky is clear, the sun's apparent movement causes the brightness distribution of the sky to change constantly. The "partly cloudy sky" covers myriads of combinations, ranging from 3/10 to 7/10 of the sky being covered with

clouds. In addition, these clouds can be opposite to the sun, reflecting light, or obscuring the sun and casting shadows. The fully overcast sky is likewise variable, with differing degrees of thickness of cloud cover and darkness. It is difficult to define design conditions among all these variables. There is no standard that exactly duplicates reality. Some assumptions must be made in order to test and compare design alternatives. In this case, a standard is extremely useful allowing the comparison among alternatives on a base which represents known conditions.

## CLIMATE DATA FOR ENERGY CALCULATIONS

Information on the average number of clear and cloudy days is necessary for total energy use calculations in order to compare average daylight availability to average yearly radiation data. The amount of illumination from the sky will vary according to season of the year and time of day, so information on the average number of clear and cloudy days per month and associated average illumination levels are both necessary for a detailed analysis.

## INFLUENCE OF BUILDING TYPE

Lighting does not play a significant role in residential energy consumption patterns, but it is a prime contributor to energy consumption in office buildings, schools, commercial low-rise buildings, health-care facilities, and warehouses. As interest in energy-conscious building design grows, lighting and daylighting become important considerations in the overall energy balance of these buildings. The lighting load can account for as much as half of the total energy loads in an office building, for example, depending on building design and location. In addition, each watt of electric lighting requires approximately 1/2 watt of mechanical cooling to counteract its heat generation. Mechanical equipment and distribution systems are still considered a necessity in most of these building types. If energy conserving design efforts in large buildings are not limited to mechanical "fixes" only, then site and climate-responsive considerations such as passive solar heating and daylighting become critical design issues. Daylighting is an integral part of the balance equation, both for its ability to eliminate large parts of the electric lighting load, and also for its intimate association with heat delivery and heat loss through glazing.

The first consideration in designing for daylight is occupancy of a building: who and when? It is important to determine if people inhabiting the building have special visual requirements that dictate certain lighting qualities or illumination levels (low or high), or if they will be restrained in their movement (in a hospital bed, at a desk all day, etc.) so that exposure to direct sunlight or harsh would cause discomfort.

Direct sunlight admitted to a space can have a very positive effect, but it should be restricted to ancillary areas, and places where people are free to move about; or sun controls should be provided. Several techniques are available for designing and evaluating sun control devices. The amount of illumination available from the clear sky alone even without direct sunlight is greater than that from an overcast sky in the same season. For this reason, calculating daylight illumination under overcast sky conditions alone is considered sufficient in most cases to provide an adequate quantity of daylight. In hot climates, however, care must also be taken that too high a level of illumination doesn't cause a sensation of a hot, rather than a cool, interior.

"When" the building is occupied determines the usefulness of daylight contribution, with major daytime occupancy providing the greatest opportunity for daylight utilization. Schools and offices are prime examples since their operating hours coincide with daylight hours. Some health care facilities, on the other hand, are operating day and night. In this case, daylight can reduce a major electrical load but cannot totally substitute for it. One of the large-scale results of effective utilization of daylight occurs in the summer when daylight is plentiful everywhere, and that is reduction of peak power demand on utilities.

In the schematic design phase, consideration of occupancy patterns and lighting requirements will help determine the general configuration of the building and the location of various functions. An overall building configuration which is divided into wings rather than lumped together provides more daylight accessibility and, if properly oriented, optimum heat gain or heat loss. As another example, attention to the lighting requirements of various staff members could lead to locating personnel with visually demanding jobs near daylight sources. Individuals whose major office tasks are dictating, talking on the telephone, and holding conferences might be located in offices somewhat distant from the windows, while secretaries and clerks with predominately visual tasks might have stations near the windows. The architect's imagination might then be stretched to find another status symbol to compensate for the executive's loss of view.

Another example of energy-conserving building layout is grouping together functions that are on the same time schedule, so that the lighting and ventilation systems for that entire section can be shut down when it is not operating. This capability assumes an appropriate control system.

## DESIGN GUIDELINES

In considering daylighting along with passive cooling approaches, it is important not to focus on "devices", but rather to keep one's mind set on merging the building form with local environmental forces in order to minimize consumption of nonrenewable energy sources to satisfy comfort requirements of the inhabitants. Two issues must be considered: 1) solar control (providing the right amount of heat gain); and 2) thermal balance.

The issue of solar control requires an evaluation of the role of the glazing as a heat and light transmitter. Heat gain control most often involves exterior shading devices for maximum effectiveness. The shading technique that allows daylight to be utilized without adverse heat gain is a combination of clear glazing with an exterior shading device, such as an open-work horizontal overhang. This technique proves more effective than using tinted or heat-absorbing glass which blocks much of the daylight (approximately 50% reduction factor). If properly designed, south facing glazing can often provide maximum benefit in many shell dominated buildings where passive heating can also be helpful. Deciduous trees are excellent shading devices, providing shade in the summer and access to the sun in winter. Their period of leafing should be matched to seasonal requirements for shade or insolation.

Areas adjacent to the building affect the entry of light and heat into rooms through windows as well as creating microclimate effects at the building perimeter. These effects can be used advantageously; for instance, reflecting sunlight off exterior light paving while using plants on walls to prevent glare from visible bright surfaces.

When considering daytime balance between heat transfer and daylight admission, north glazing may provide helpful thermal transfer as well as high quality diffuse light for buildings where the dominant mechanical load is cooling, such as office buildings. The location of north glazing with regard to proximity to people is critical, however, since radiant heat loss from the body would be increased in underheated periods.

## HOW TO HANDLE DAYLIGHT

Daylight can ultimately be used.

### Capture It

- . Analyze site as to sources of light: sky, external reflectors (vertical, horizontal)
- . Analyze shading patterns

- from existing obstructions
- from existing vegetation
- . Orient building so that available light can be received
  - Consider different qualities of light from different directions
    - N. - no direct, uniform
    - S. - high direct, summer - mid-day
    - E. - morning, direct - low angle
    - W. - afternoon, direct - low angle
  - Consider elongating building along E-W axis
- . Use site and surrounds to direct lighting toward building
  - light-colored soffits
  - light-colored ground
  - light colored exterior walls
  - adjacent water
  - adjacent reflective buildings
- . Open building to receive light
  - open sides (side windows effect of shape, size and locations of windows, greenhouse)
  - open roof (roof monitors, clerestories)
- . Shape building to maximize penetration
  - narrow wings
  - stepped back form
  - sawtooth roof
  - courtyards or atriums

### Modify It

- . Block direct sunlight
  - plantings
  - horizontal overhang on south facade
- . Selectively absorb it
  - exterior plantings
  - interior surfaces to delineate different areas
- . Reflect it
  - ground and other horizontal surfaces
  - reflecting devices
  - clerestory reflecting devices
  - side window devices: bounce lighting deeper in room  
(beam sunlighting)
  - baffles within roof monitor lightwells
- . Direct, concentrate it
  - light shafts



- . If direct sun is admitted, it should be confined to areas where it will not disturb (overheat or cause glare for) inhabitants of the buildings. Direct sunlight can be modified to act as a sparking focus.
- . Use electric lighting fixtures to balance daylight as well as provide the nighttime lighting required.
- . Make sure that thermal insulating materials intended for daytime use do not block admission of daylight.
- . As a rough estimate, figure 1/2 watt of cooling load for each watt of electric lighting load.
- . In general, use efficient electric light sources (fluorescent & HID). However, the match light source to its use. A low-wattage incandescent lamp may be more appropriate for lighting a task from close-up than the same wattage fluorescent lamp which, emitting more light might cause glare conditions or too high a contrast with surroundings.
- . Consider lighting and ventilation requirements separately at first. Openings to admit light need not be the same ones used for ventilation.
- . Shading devices placed outside the glazing block heat more efficiently than ones placed inside glazing.
- . Vertical glazings ("windows") are much preferable to horizontal glazings ("skylights") due to adverse heat gain and glare during overheated periods. Skylights should only be considered if sloped for passive heating and if coupled with shading options in the warmer months.
- . Plan for reasonable levels of illumination. Provide higher levels for specific uses only where needed. If possible, group functions with similar illumination requirements together.
- . Place functions which require high levels of illumination near daylight openings.
- . Place some daylight openings (or all, if no view is required) high to let bright light wash to ceiling and reflect into the room without the inhabitants viewing the bright light source.
- . Screen views of the sky or other possible sources of glare such as light-colored walls.
- . Provide balanced daylighting and reduce contrast by admitting daylight from more than one side of a space.
- . Minimize contrasts in light levels whenever possible.

### DAYLIGHTING CALCULATIONS

Many methods have been developed to calculate the amount of daylight to be expected in a room due to a given fenestration design. The major determinants are the sky condition; the location, shape and size of the openings; the location, shape and size of exterior obstructions blocking direct skylight; and the interior surface reflectance. Different methods of calculation account for these factors in different ways.

### DAYLIGHT FACTOR CONCEPT

The constant variation of sky conditions cannot be acknowledged in calculation procedures, which require standardized conditions. The two sky conditions that have been standardized are the completely overcast sky

and the totally clear sky. Calculations involving the overcast sky are accomplished easily since variations are minimal. The C.I.E. Standard Overcast Sky is a close approximation to reality. Its luminance distribution as represented by a formula has been compared to several sets of luminance measurements of actual overcast skies and found to be in close agreement. Since the sky distribution pattern does the same light distribution pattern as the same window facing west, or any other direction, all other factors being equal.

Since the clear sky luminance distribution depends on sun position, which changes constantly, it is a much more complicated matter to represent resulting interior light distribution under clear sky conditions.

The daylight factor calculation approach treats the illumination from daylight that occurs at a reference point inside a room as a percentage of the simultaneous illumination on a horizontal plane from an unobstructed sky outdoors. This value is called the daylight factor, and is composed of three different contributions of daylight to the room:

1. The sky component, or light received at the reference point directly from the sky;
2. The externally reflected component, or light reflected from surfaces external to the room to the reference point; and
3. The internally reflected component, which is light reflected from interior room surface to the referenced point.

#### PHYSICAL SCALE MODELING OF DAYLIGHTING SYSTEMS

The physical properties of light are such that daylight penetrates into and inter-reflects within a scale model almost identically to how it would in a full-scale building. Therefore, the use of scale models allows the design team to evaluate both the quantitative and the qualitative performance of the daylighting system during the design phases of a building project. Because of the accuracy and relative ease with which models can be constructed, they are often used to support mathematical calculations in predicting the performance of daylighting systems and the interaction of daylighting with the energy performance of a building.

A physical model provides visual and photographic records that cannot be duplicated by mathematical analysis alone. These records, especially photographs, offer the client a tangible image of how the daylighting system will provide light in the building.

In designing and analyzing the performance characteristics of daylighting systems, the design team should use both mathematical and physical modeling to establish the lighting performance characteristics of the building design. Mathematical analysis can be used to establish general performance characteristics, lighting patterns, and visual comfort, while scale models can be used to refine a design concept and to establish the relationship of daylight to other design issues such as interior architecture, space layout, interior partitioning, and visual comfort. The results of scale model analysis can then be used, along with mathematical performance data, to establish the criteria for energy and economic analysis.

#### MATHEMATICAL MODELING OF DAYLIGHTING SYSTEMS

Mathematical modeling offers several advantages over scale modeling:

- . Mathematical modeling allows the design team to make quick analyses of various aperture configurations in order to gauge the sensitivity of a design concept to changes in room shape, aperture size, aperture location, or some other variable.

- . Most mathematical modeling techniques are available in computerized form, allowing fast and inexpensive analyses of a wide range of concepts that would be too time-consuming and costly to build and test properly with physical scale models.
- . Most mathematical modeling techniques can be used to determine lighting system performance (daylighting plus electrical lighting) over an extended period of time -such as a month or year. This cannot be accomplished with a physical scale model.

Along with these advantages of using mathematical modeling are some disadvantages, including:

- . The simplifying assumptions that allow the mathematical models to be used as simple manual design tools often limit their usefulness and reduce their accuracy in comparison to actual building performance or to performance by a physical scale model.
- . The more advanced and extensive mathematical modeling techniques such as the flux transfer method, are too complex to be used manually to analyze a design concept and can only be used readily in some form of computer analysis.
- . All mathematical modeling techniques are limited by the number of cases that have been studied to develop the mathematical model. By comparison, a daylighting concept can be designed in an infinite number of ways, many of which cannot be mathematically analyzed by any existing mathematic model. These can only be analyzed with a physical model.

It should be kept in mind that limitations also exist in the use of physical scale models and that mathematical modeling is often the quickest and simplest way to determine the performance characteristics of a daylighting concept. Further, mathematical modeling is the only way to analyze lighting performance over an extended period of time or to perform building energy analysis. Therefore, the members of the design team need to learn the various methods of mathematical analysis in order to determine which techniques are the most logical ones to use in analyzing a particular design concept that is being developed. In practice, the design team must learn to use a combination of mathematical and scale model analyses.

Source: Energy In Design Process, Tennessee Valley Authority.

Refer to Appendix L Acceptable Energy Analysis Software for listing of lighting and/or daylighting computer programs.