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# DESIGN TOOLS FOR DAYLIGHTING ILLUMINATION AND ENERGY ANALYSIS

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ABSTRACT

This paper reviews the problems and potentials for using daylighting to provide illumination in building interiors. It describes some of the design tools now or soon to be available for incorporating daylighting into the building design process. It also describes state-of-the-art methods for analyzing the impacts daylighting can have on selection of lighting controls, lighting energy consumption, heating and cooling loads, and peak power demand.

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## INTRODUCTION

A review of award-winning designs for new commercial buildings suggests that daylighting is a consistent energy and design theme. In any discussion of energy use in commercial buildings, lighting emerges as a major consumer of energy and daylighting almost always follows as an effective means of conservation. But how can one know if the buildings described in articles or papers are, in fact, effectively daylighted? One can examine the design sketches and follow the ubiquitous yellow arrows of light originating in the sky or sun, bouncing one or more times off shading devices, light shelves, ceilings, and walls, and finally arriving conveniently at the task location. The photographs of the finished buildings show glazed walls, courtyards, luxurious green vegetation, all convincingly bathed in daylight, even though careful inspection may reveal that the electric lights are always on. The intent in these drawings and photographs is quite clear. Designers of the current generation of energy-efficient commercial buildings are convinced that daylighting is a major energy-saving strategy and are desirous of incorporating these strategies in their designs.

Unfortunately, bouncing light rays don't always follow the architect's pen as surely as hot or cold water flows through the pipes that the engineer lays out. Furthermore, photographs can be deceiving because even if a snapshot tells the truth for one instant in time, it may not adequately express the quality of the indoor environment as experienced by a building occupant. In fact, while daylighting is potentially a very important energy-efficient design strategy, as of 1982 it is still extremely difficult to find examples of occupied buildings in which daylighting demonstrably saves energy. While many new buildings are "conceptually" daylighted in the initial planning stages, some effectiveness is lost as the concept progresses through the design process to the working drawing stage. The harsh realities of economics and client priorities narrows the field further. The bidding process and the construction that follows claim still more casualties. And even after a shakedown period, the uncertainties of occupant response plays further havoc with the designer's original concepts. The implied analogy to evolution may not be far wrong: of the multitude of intriguing daylighting concepts that spring from the minds of designers, only a small number survive through design, construction, and occupancy to the point where the building's measured energy consumption reflects the success of the daylighting strategy. The potential clearly exists; the difficulty is in separating potential from reality.

If daylighting strategies are to have a positive impact on the new generation of energy-efficient buildings, we need to answer three simple but critical questions: 1) what works? 2) how well does it work? 3) why does it work? The last question is important because some successful designs may work for the "wrong" reasons. Unlike many HVAC systems, daylighting strategies are not hidden within the fabric of the building but are exposed for all to see. Failures, such as terrible glare conditions, are often obvious and the subject of bitter occupant complaints. Success, as measured by occupant response to esthetics, view, and the overall quality of the indoor environment, may be equally obvious and pleasing. The energy impacts, however, are less obvious and generally require some effort to quantify. Understanding the energy issues may be complicated by the fact that lighting design is a mystery to many architects and engineers, as well as to some lighting designers.

The potential benefits can be listed easily. Daylighting can 1) enhance the quality of the indoor luminous environment, 2) improve visual performance, 3) reduce electric lighting energy consumption, 4) reduce heating and cooling loads, and 5) reduce peak electrical demand. However, not all daylighting strategies will necessarily achieve all five of these goals; in some circumstances achieving several of these benefits can only be accomplished at the cost of reducing others. To properly evaluate the successes and failures of a particular design, it is necessary to establish clearly defined goals and objectives that explicitly address the five issues mentioned above. Ideally, comparing what was achieved in a design to what was intended will provide feedback that will prove helpful in subsequent building design exercises.

One reason for clearly distinguishing which design decisions apply to lighting quality, lighting energy consumption, peak demand impact, etc., is that the design and evaluation tools may be quite different for each of these issues. Furthermore, the requirement for design tools that will enable adequate analysis or evaluation of each of these issues will vary depending upon the stage in the design process. As one moves through the design process and then through construction and occupancy of building, one's concerns differ, one's perspective changes, and the quality and quantity of information required change significantly. Failure to recognize this often results in applying an inappropriate design tool that may produce incorrect or misleading results even if it is properly applied. Worse yet, when appropriate design tools are not available, one may tend to let the design tool output dictate design direction. When one's only tool is a hammer, every problem looks like a nail.

The sections that follow briefly review some of the design tools that are currently available to assist in designing pleasant, energy-efficient daylighted buildings. The discussion is not meant to be all-inclusive or definitive, but rather suggestive of many of the issues faced by designers today and some of the options available to solve them.

## PRE-DESIGN ASSESSMENT

One of the most obvious questions to be answered at the start of any project is, what is the role of daylighting as both an illumination source and an energy-saving strategy, given the design constraints for this building? Good daylighting design, like any other aspect of building design, requires an investment of time and energy and therefore money. Daylighting design thus competes for limited resources with other design issues that must be addressed. In some applications daylighting may not be appropriate, in others it may not be even remotely cost-effective. It is thus useful at the outset to evaluate the energy savings potential for daylighting. Nomographs (Figure 1) or other simple rules of thumb may be appropriate to help make quick decisions at this point. In the long run, intuition and experience may be one's best guide, but in 1982 those generally continue to be in short supply.

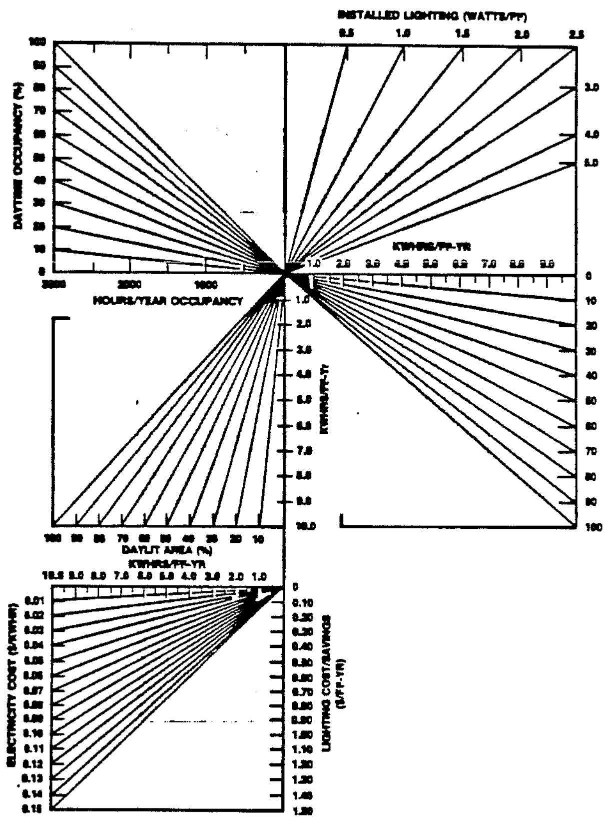

Fig. 1. The second in a series of four nomographs to determine potential daylighting savings.

## DAYLIGHT RESOURCE ASSESSMENT

To properly evaluate any daylighting design we need appropriate data on the availability of daylight. We generally want to know how much daylight is available and when it is available for various building orientations for a given geographic location. In some cases, we may want simple annual statistical data, in other cases data for design events or typical clear and cloudy days over the course of the year, and finally, for detailed energy analysis, we require hour-by-hour data. Although few of these data are now available in convenient form, a number of efforts are underway to develop the technical basis for a daylighting availability data base. Figure 2 shows a sample contour plot of average daylight values on an east-facing surface as a function of the hour and the day of the year. This permits a quick assessment of average conditions throughout the year.

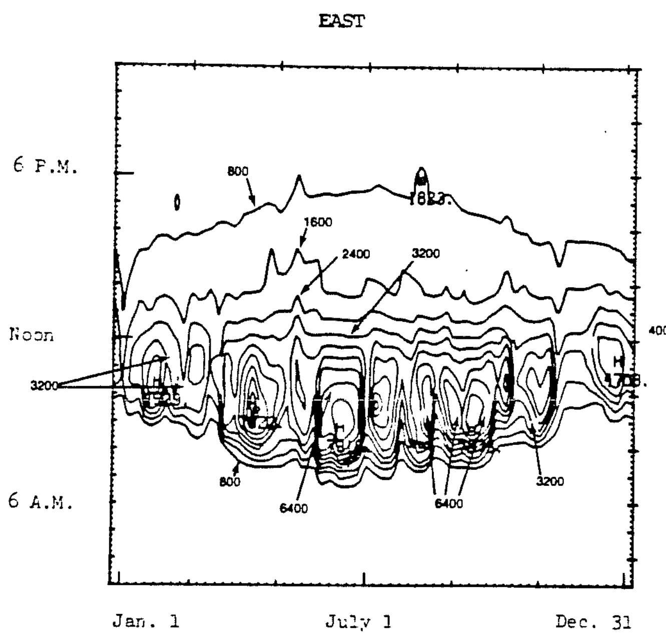


Fig. 2. Average daylight illuminance on an east-facing surface in San Francisco.

These data can also be manipulated to provide information on the frequency of occurrence of the full range of exterior daylight illuminance values. Hourly data for standard clear or overcast skies can be calculated using various algorithms and can then be presented in tabular form. Figure 3 shows numerical data converted into overlays for a sun-angle calculator. We can expect a number of the ongoing research programs to produce additional useful data for design purposes in the near future.

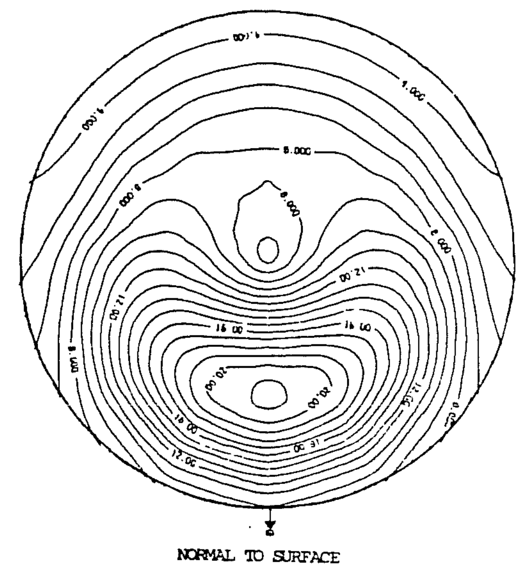


Fig. 3. Clear-sky, vertical-surface illuminance overlay for use with sun-angle calculator.

DETERMINATION OF DAYLIGHT ILLUMINATION IN BUILDINGS

Determining interior illumination requires considering four major sets of factors comprised of more than twenty variables (Figure 4). Each of these factors can influence the final determination of the daylight illumination level. Many design tools ignore or hold constant one or more of these factors, often at the sacrifice of accuracy or applicability of the model.

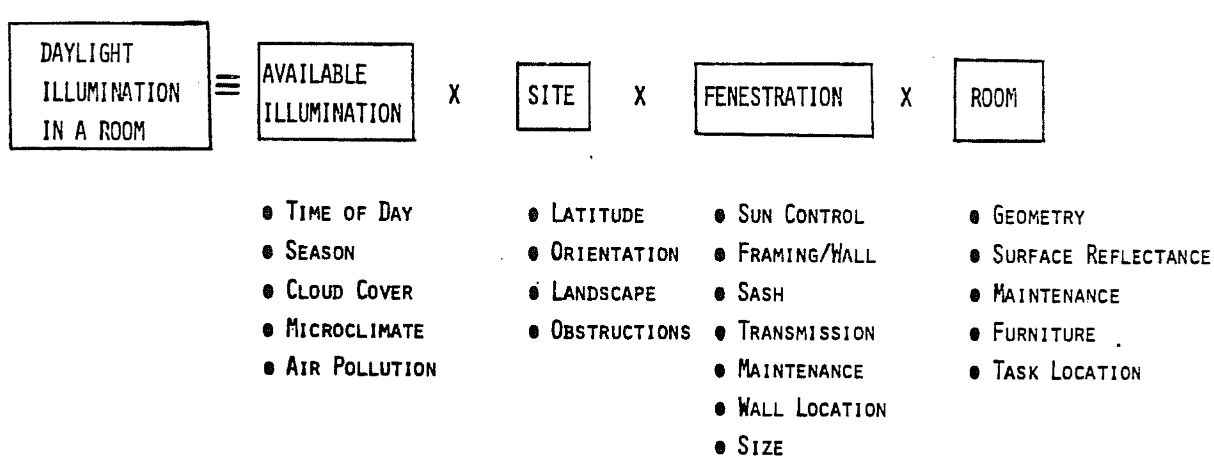


Fig. 4. Variables that influence determination of interior daylight illumination.

One of a designer's most difficult tasks may be not the use of a design tool but the selection of a design tool. Selection implies a) that the designer has a choice and b) that the criteria for making the decision are understood. Some of these criteria are listed in Figure 5. The first set of factors relates to the usefulness of the tool, while the second set relates to technical requirements for it.

DESIGN TOOL
CHARACTERISTICS

- Learning Curve
- Ease of Use
- Availability
- Cost

- Input Requirements
- Limits of Appliccability
- Transparency
- Sensitivity
- Stability
- Accuracy: absolute/relative
- Quanity/Quality
- Output Format

Fig. 5. Performance characteristics of daylighting design tools.

We have a tendency to lump daylighting design tools into general categories such as calculation methods, tabular methods, or graphic methods. However, these categories describe the presentation format of the tool rather than the basis for its predictive capability. Figure 6 shows a hierarchy of design tools based upon the procedure by which they were developed.

Understanding how a design tool was derived helps us understand its capabilities and limitations. For example, analytical approaches can be converted directly to calculation procedures for hand calculations or programmable calculators or can be converted into computer programs. However, the same analytical solutions might also be used to generate a set of data that can then be converted into a variety of other formats such as tables, nomographs, protractors, or other convenient forms. The final format of the tool may determine its ease of use. However, the technical constraints on the use of the design tool (such as accuracy) may be based mostly on the original technical derivation of the design tool. Thus it is important to understand how design tools have evolved and the technical basis for their predictive powers.

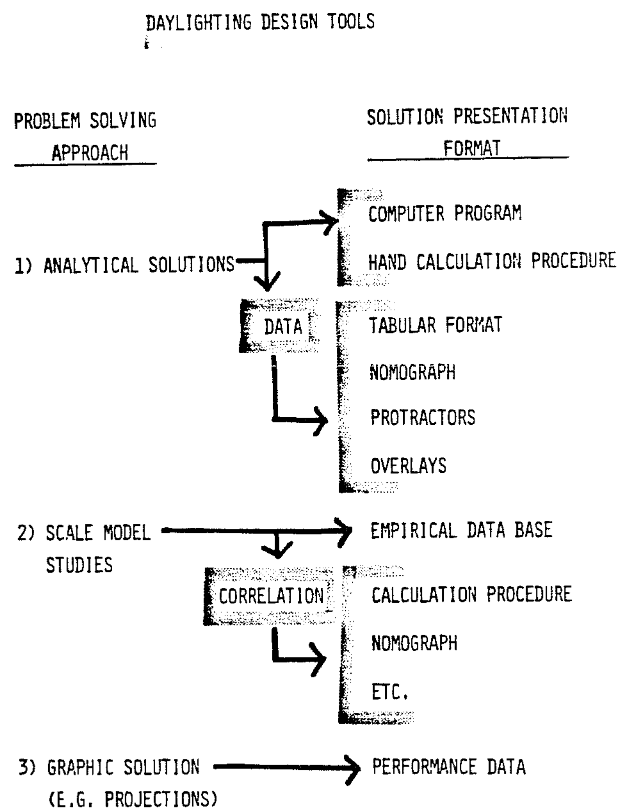


Fig. 6. Derivation of daylighting design tools.

A second major category of tools are those based upon physical model measurements. Once again, while model measurements can be used directly for design purposes, they can also be used to develop a data base from which other types of design tools can be developed. One of the best known approaches is the IES Recommended Practice of Daylighting.(1) This calculation method which has also been converted into a computer program, was based upon model measurements made in an artificial sky. A detailed discussion of the strengths and weakness of the lumen method analysis such as the IES Recommended Practice is beyond the scope of this review paper. However, designers should understand these attributes fully in order to make most effective use of the design tool.

In addition to the lumen method, the daylight factor approach has been used in many parts of the world. Because it has been used so widely for so many years, a variety of design tools have evolved based upon the daylight factor. The best known of these, besides some of the standard tabular data, are the set of protractors developed by the Building Research Station. Although originally developed for analysis of daylight illumination under overcast or uniform skies, the daylight factor approach can also be used, with some modifications, for clear skies. More recently, the somewhat tedious graphic and analytical approaches have been computerized for use on programmable calculators or microcomputers, thereby speeding the determination of interior room illuminance.

Computers will play an increasing role in any design process that is analytically based or that can be converted to an equivalent numerical basis. Computer programs can play two distinct roles. They can facilitate simple analysis that requires repetitious calculations of illuminance in different room locations under different sky conditions. Although the analytical model may be simple, these programs should be "user friendly," facilitating the designer's use of the program, and assisting in presentation and interpretation of results. Larger and more powerful daylighting computer programs permit analysis of sophisticated architectural solutions under any sun and sky conditions. Figure 7 shows sample results from a new main-frame computer model called SUPERLITE (2),(3). The program is capable of handling complex building geometries under any sun and sky condition; further development is underway to enable it to properly model complex sunlit shading systems. Figure 8 shows sample results for two skylights.

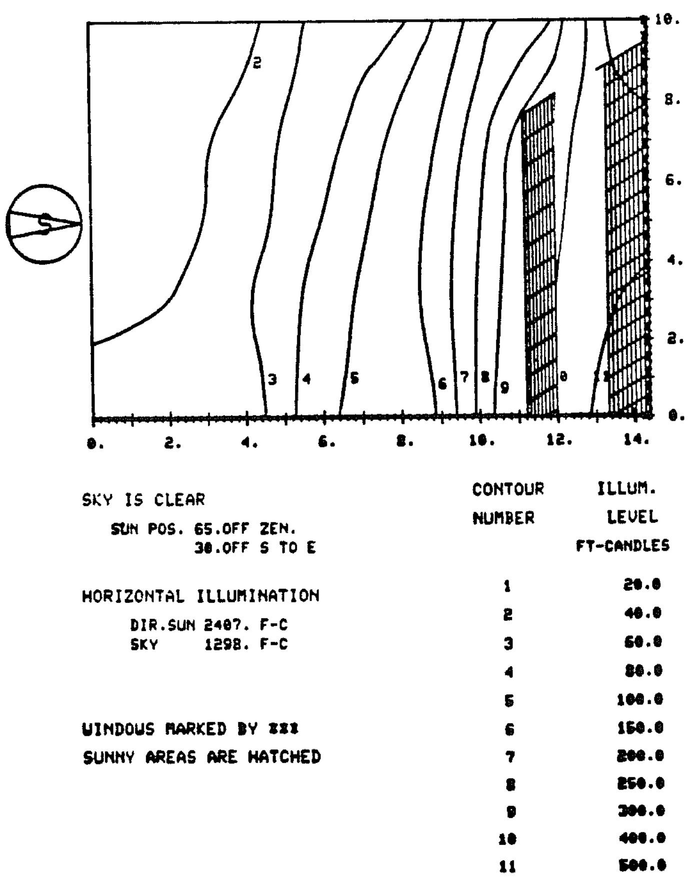


Fig. 7. Sample illuminance contour plot for a room with light shelf.

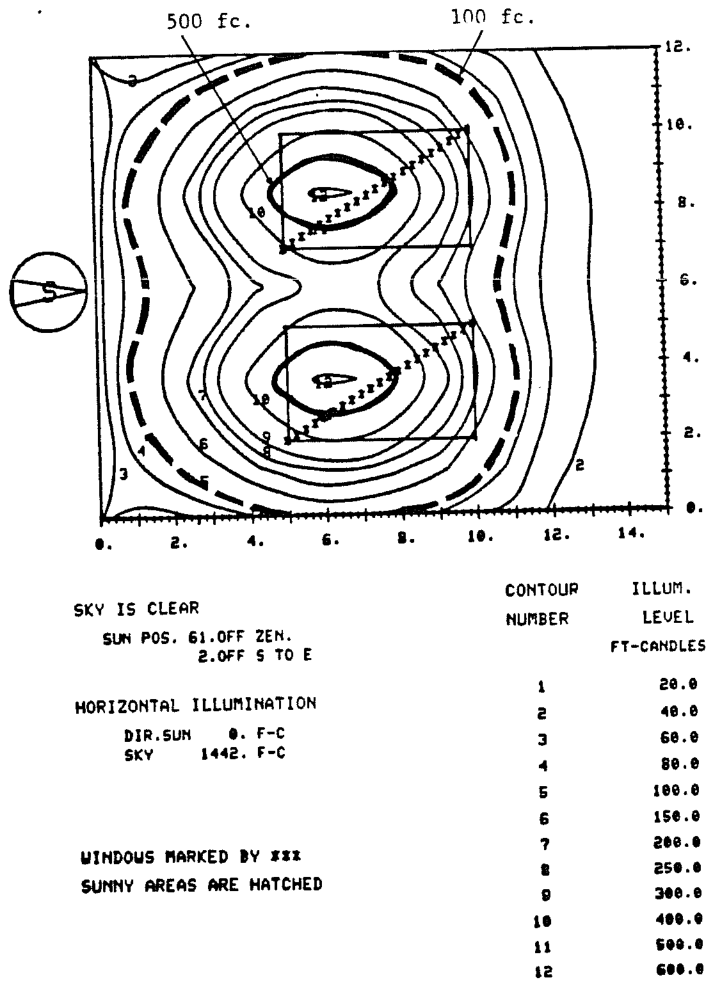


Fig. 8. Sample illuminance contour plot for a room with two skylights.

## SCALE MODELS

Architects have always used models in presentations, but the use of scale models for quantitative problem-solving is less routine. Lighting effects are scale-independent, so in principle a miniature of a large room will register the same daylighting response as the full-size room or building. Furthermore, illuminance values are additive, so lighting levels from daylight and from electric light can be determined independently and then added for the final result. Like other design tools, models can be used in a variety of ways. Rough models can be useful for making basic decisions about the size and location of window openings. At the other extreme, full-size mockups may be built to test occupant response, furniture systems, wall coverings, etc. Between these extremes lies the area of most interest, where carefully constructed scale models are used to make critical decisions on the design of a real building. Once again, the details and features incorporated in a model depend largely on the answers one is looking for. Models can be used not only to make quantitative measurements of illuminance levels, but also to investigate view, lighting quality, and, to some extent, the integration of electric lighting systems with daylighting.

As enticing as scale models appear, their effectiveness is limited. A practical concern is that extensive model testing requires an investment in photometric sensors and associated hardware. Some systems cost many thousands of dollars, although simpler, cheaper systems are adequate. Sensor size, dynamic range, accuracy, spectral correction, cosine correction, and hysteresis effects are all important in selecting photometric instrumentation. Sensor placement and movement in the model as well as many details of model construction all will influence the quality of measurement results.

Models can be tested outdoors under real sky conditions or indoors under controlled, simulated skies. Outdoor testing can be done at the actual building location so that microclimatic effects and site obstructions can be accounted for. Effects of direct sunlight can also be evaluated and, if the model is large enough and properly detailed, some information regarding view and glare can be obtained. But in order to compare the performance of various design alternatives, it is frequently necessary to compare model measurements made over a series of days, during which time sky conditions may change significantly. Even if appropriate adjustments are made to modify the collected data, it is very difficult to get highly reproducible results from outdoor model testing. This has provided the impetus during the last thirty years for researchers and practitioners to build sky simulators that allow specific sky conditions to be reproduced indoors. Very simple simulators based upon diffusing screens or mirror boxes can be constructed and used to accurately test small models under some sky conditions. However, to test the full range of clear, uniform, and overcast sky conditions, a larger facility such as illustrated in Figure 9 is required. This 24-foot-diameter hemispherical sky simulator was recently completed at Lawrence Berkeley Laboratory and is being used for a variety of research and design studies. Because the standard CIE sky luminance distributions are reproduced in this facility (these are the same distributions used in many computer models), results from the facility can be used as a basis for validating computer models, as shown in Figure 10. The facility is also being used for teaching purposes and to assist design firms in evaluating building design concepts.

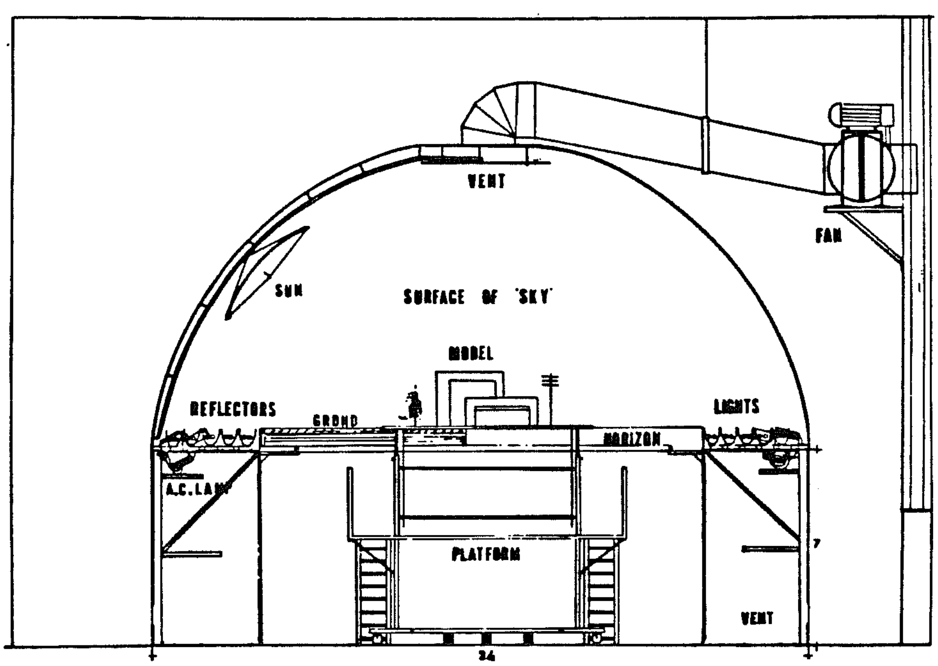


Fig. 9. Cross section of 24-foot-diameter hemispherical sky simulator.

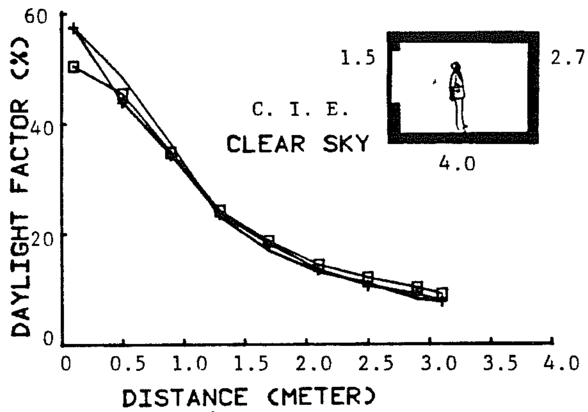


Fig. 10. Comparison of measured illuminance in model under simulated clear-sky conditions with SUPERLITE and DOE 2.1B computer predicitions.

LIGHTING ENERGY ANALYSIS

Having determined the daylight distribution in a proposed building using any of the methods described, we still will not have a good understanding of what the energy savings will be. Figure 11 suggests that determining annual lighting energy savings requires that the daylight illumination previously calculated be factored by the characteristics of lighting control systems. Only by summing this information over the zones in the building, the hours in the day, and the days of the year can one begin to estimate annual electric lighting energy savings.

During the past three years, lighting controls have been retrofit in several large office buildings to determine the daylighting savings (4). Figure 12 shows sample results for a perimeter zone in an office building in San Francisco.

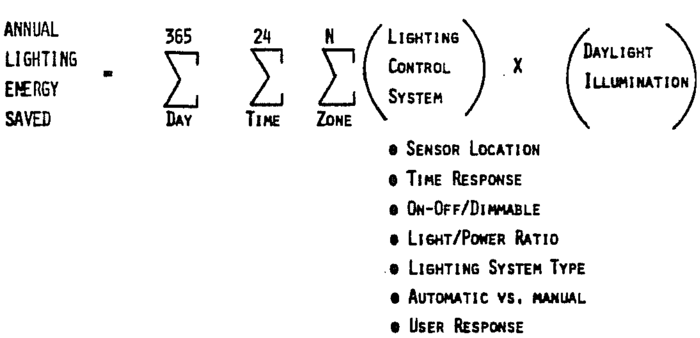


Fig. 11. Process for calculating annual lighting energy consumption.

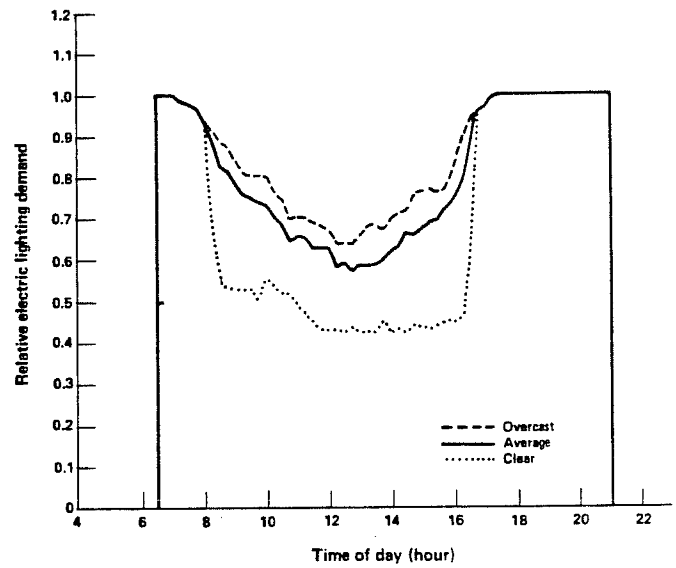


Fig. 12. Clear, overcast, and average day energy savings in a typical perimeter office.

Figure 13 shows sample results from an application in the World Trade Center in New York, which involves not only daylighting controls, but also adjustments to the operating schedule of the building.

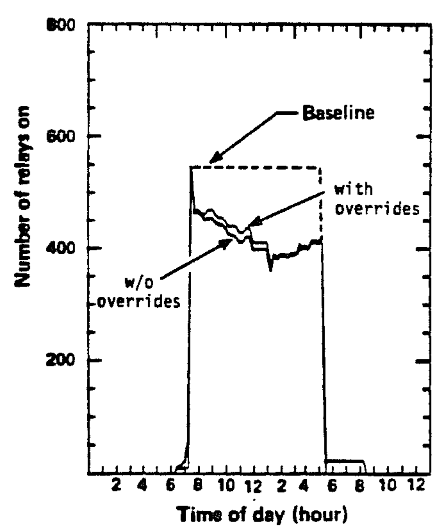


Fig. 13. World Trade Center lighting savings from use of daylighting and scheduling retrofit strategies.

To maximize cost-effectiveness, the same lighting control hardware may be used both for daylighting and for occupancy response, lumen maintenance, and fine-tuning light distribution. Results from these two demonstration projects suggest that daylighting can save between 15% and 40% of the electric lighting energy consumption in the perimeter zone in an existing building. They also suggest that the actual savings will depend upon the architectural design, the type of lighting controls, the design of the lighting system, and the operational characteristics of the hardware. Furthermore, occupant response to lighting control systems is critical to successful daylighting design. Controls can be manually or automatically operated, a choice that implies one understands the motivations of office occupants. Lighting levels can be switched discontinuously or can be dimmed smoothly from high to low levels. Switching systems are frequently cheaper but may produce sharp changes in light level. Dimming systems are much less noticeable but are more costly, representing a new generation of control hardware that is only now being proven in building applications. Current trends suggest that there will be a rapid increase in the complexity and sophistication of lighting control systems. To be successful as a daylighting strategy, the technical performance of these systems must be better characterized and the occupant response to both hardware and design issues must be better understood. If the performance characteristics of the hardware are known and adequate data on daylight availability and interior daylight distribution are available, annual fractional savings can be calculated.

In translating percent lighting energy savings to actual energy savings (kWh/$ft^2$) and thus cost savings, we need to consider the efficiency of the electric lighting system. Pre-energy crisis designs were consistently above 3 watts/$ft^2$, but recent practice is more typically in the range of 2 to 2 1/2 watts/$ft^2$ for office buildings. Task-oriented design strategies, improved lighting hardware, and more responsive electric lighting controls should push these levels even lower — it should be common to see electric lighting designed down in the 1 watt/$ft^2$ range within the next five to ten years. Given these possibilities for lighting design, the savings from daylighting may not be as large as we project today. If we account for the fact that much of this savings will occur during midday hours, however, the extra economic incentive from time-of-day pricing and from peak-load reduction will add to daylighting's energy savings.

## TOTAL ENERGY ANALYSIS

In addition to reducing electric lighting needs, daylighting strategies will impact the total energy consumption of a building by altering heating and cooling loads in two ways. First, reduced electric lighting energy consumption will alter the thermal balance of the building, which will tend to reduce net summer cooling loads and increase net winter heating loads. Second, the glazed area required for daylighting, which may not otherwise have been included, may have thermal impacts of its own. The next level of building energy analysis requires us to consider the total energy implications of daylighting, including heating and cooling effects. Because there are a large number of climate and building variables that influence total energy consumption, it is difficult to provide generalized conclusions. It is commonly assumed that daylighting will reduce cooling loads, but in fact that is not always the case. Results shown in Figure 14 indicate some interrelationship between daylighting savings and the heating and cooling loads from windows as a function of glazing area, type, climate, and orientation. These are a sample of results from a much larger glazing optimization study, which is beginning to define the desirable combination of glazing properties and daylighting strategies that will minimize total building energy use (5). One discovery to date is that it is almost always possible to find a glazing system based upon commonly available components which equals or outperforms a well insulated wall in almost any climate and orientation. For at least those solutions that prove to be cost-effective, the designer can then base fenestration decisions in large part upon non-energy issues without paying an energy penalty.

This type of analysis may require a detailed calculation of total building energy consumption on an hour-by-hour basis throughout the year. The DOE-2 model has recently been upgraded to include a first-generation daylighting model. DOE-2.1B is completing its testing phase and will soon be available to help users evaluate the energy implications of most of the common daylighting strategies. Additional modeling capabilities are being developed for DOE-2.1C which will allow the program to model light shelves and other more sophisticated architectural solutions. The current model allows the user to simulate various window management strategies based upon dynamic sun control and glare control. A broad variety of user-defined lighting control strategies can also be modeled. A new series of daylighting output reports provide a maximum of useful information with a minimum number of DOE-2 runs (see Figure 15). The goal of these ongoing modifications to the DOE-2 energy analysis program is to allow modeling of state-of-the-art architectural solutions from both thermal and daylighting perspectives.

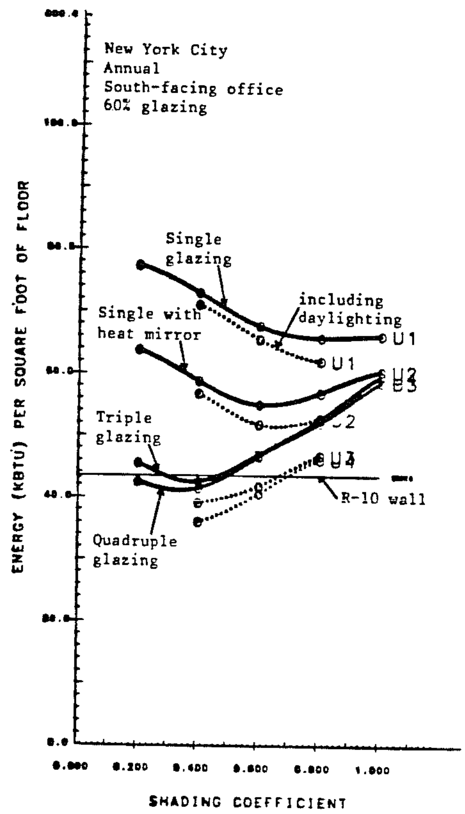


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Fig. 14. Total annual energy consumption vs. shading coefficient for a 90% glazed south perimeter office module in New York for five glazing U-values. Solid lines: without daylighting; dashed lines: with daylighting.

While the DOE-2 program is too large and expensive to be used extensively on small projects, we expect it to form the basis for a number of simplified design tools that are more readily usable for predicting daylighting energy effects and total energy consumption for smaller, less sophisticated buildings. For large projects, where the design budget permits and even may require extensive energy analysis, the modifications will enable evaluation of unique solutions such as special atrium designs. This ongoing series of developments in DOE-2 has been structured around the architect's need for flexibility in modeling design solutions that have more complex dynamic performance than the simple, static solutions frequently used.

## NEW FENESTRATION DEVELOPMENTS

New developments in the area of glazing technology and daylighting strategies will continue to add to the bag of tricks from which the architect can draw. However, the designer's ability to effectively use new products and technologies is governed in part by the availability of design tools that will adequately predict their performance. In the area of new glazing technology, new films and coatings are becoming available that increase the total transparency of the window system, reduce the U-value, act as selective filters to enhance daylight transmittance, or provide combinations of the above functions. Most of these can be adequately modeled with existing design tools and techniques. There is considerable interest in more sophisticated, operable shading systems, including devices such as exterior rollup shades and shutters and exterior venetian blinds.

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PERIMETER OFFICES DAYLIT TO 30 FEET TWO LIGHTING ZONES PER THERMAL ZONE CONTINUOUS DIMMING LIGHTING CONTROL
REPORT- LS-H PERCENT LIGHTING ENERGY REDUCTION BY DAYLIGHTING VS HR OF DAY

SPACE EASTZONE

HOUR OF DAY

| MONTH | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | ALL HOURS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JAN | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 25 | 46 | 54 | 57 | 46 | 41 | 35 | 31 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30 |
| FEB | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 37 | 45 | 54 | 54 | 52 | 47 | 42 | 36 | 27 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 34 |
| MAR | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 41 | 51 | 55 | 58 | 58 | 51 | 51 | 48 | 43 | 33 | 23 | 0 | 0 | 0 | 0 | 0 | 0 | 40 |
| JUN | 0 | 0 | 0 | 0 | 3 | 28 | 54 | 60 | 64 | 66 | 65 | 64 | 61 | 61 | 57 | 54 | 47 | 37 | 26 | 2 | 0 | 0 | 0 | 0 | 52 |
| SEP | 0 | 0 | 0 | 0 | 0 | 6 | 39 | 57 | 59 | 60 | 61 | 60 | 57 | 54 | 51 | 47 | 40 | 24 | 3 | 0 | 0 | 0 | 0 | 0 | 46 |
| DEC | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 31 | 42 | 47 | 47 | 40 | 37 | 34 | 24 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 26 |
| ANNUAL | 0 | 0 | 0 | 0 | 0 | 9 | 34 | 51 | 52 | 57 | 60 | 58 | 54 | 51 | 48 | 42 | 29 | 17 | 6 | 0 | 0 | 0 | 0 | 0 | 42 |

Fig. 15. DOE-2.1B report showing typical hourly and monthly pattern of electric lighting energy savings.

Devices such as venetian blinds that can be deployed or retracted automatically and that have the slant-angle tilt adjusted to minimize cooling load while maximizing daylighting contribution, present a new challenge to energy analysis tools. Because these systems tend to be expensive, proper analysis of the energy and load impact is essential to effective decisionmaking. Modifications now underway to the DOE-2 program will permit not only daylighting evaluation of these more complex systems but also an improved determination of the shading coefficient of complex operable shading devices and thus a better evaluation of their cooling load reduction.

Designers will continue to experiment with innovative daylighting schemes. A current trend that seems to have great potential is the use of translucent fabric structures to enclose large commercial building spaces. These structures generally have low daylight transmittance, but because light is transmitted by the entire roof area they provide effective daylighting throughout most of the year. Many of the structures tend to be geometrically complex, and thus represent a challenge for some of the daylighting and energy analysis models.

Technical approaches for introducing daylight deep within building interiors (e.g., beam sunlighting) remain largely in the experimental stage. Scale model studies are generally the best approach to characterizing the performance of these advanced systems. Designers should be extremely cautious in translating idealized model study results to hardware and performance requirements of actual buildings.

## VALIDATION AND FIELD MEASUREMENTS

However useful and accurate we believe a design tool may be, the final proof lies in the measured performance of occupied buildings. We need to strengthen the feedback loop between measured results in these buildings and the design approaches and design tools used to formulate those solutions. To properly evaluate the success of those design strategies, we need more data than will be collected by reading utility meters. Submetered data on the performance of the lighting systems is one requirement; net energy performance of fenestration systems is another. Some of the measurements can best be made in the buildings while others can better be made in test cells that simulate the outdoor and indoor environmental and building conditions. Figure 16 illustrates one such facility that will provide controlled measurements of the daylighting impact on fenestration performance.

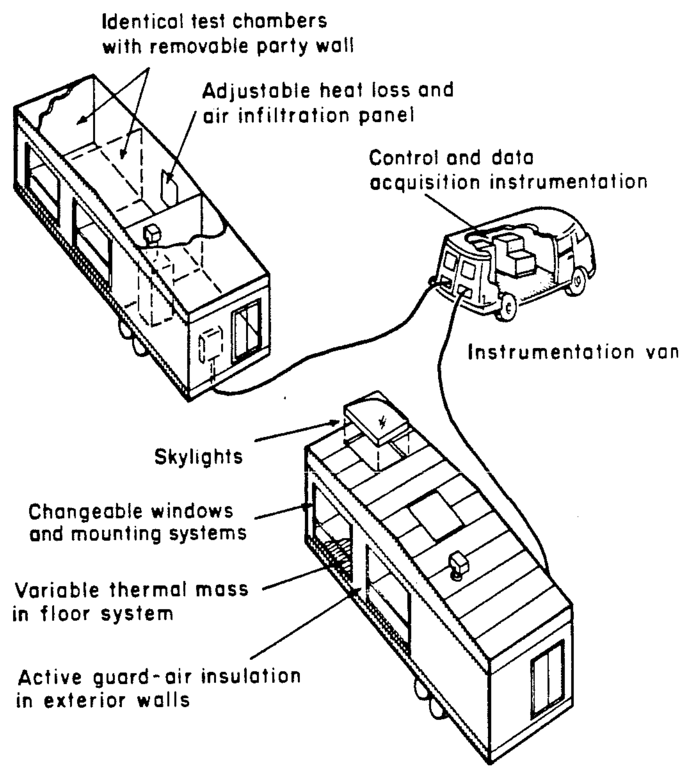


Fig. 16. Mobile Window Thermal Test Facility for measuring net energy performance of fenestration.

This test facility is designed to provide detailed data on the performance of the most complex window and skylight systems for any climate and orientation. A unique feature of these test cells is that the researcher can control their interior conditions to make them behave as various types of buildings having various thermal and lighting loads. Thus it would be possible to test the same fenestration system in side-by-side test cells, with one set up to simulate a low-mass, tightly insulated office building with low internal loads, the other a high-mass, high internal load building. Results from this facility will be used to validate the energy-analysis computer models, which in turn are used to generate simplified design tools.

Validation of design tools is not often seen as a high priority for a designer struggling to meet a short deadline for a nervous client. However, in the long run, the designer's ability to provide a cost-effective service to building owners depends upon the designer's ability to use the most appropriate, cost-effective design tools with the highest level of confidence. Proven design tools will never guarantee successful design solutions. But they certainly can assist the increasingly harried designer in developing and evaluating solutions that meet ever more stringent energy-efficiency targets while preserving and enhancing occupant comfort, productivity, and safety.

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REFERENCES

1. IES Daylighting Committee, RP-5, Recommended Practice of Daylighting. Illuminating Engineering Society of North America, New York NY, 1979.

2. M.F. Modest, "Daylighting Calculations for Non-Rectangular Interior Spaces wih Shading Devices." The Illuminating Engineering Technical Conference, Toronto, Canada, August 9-13, 1981. Lawrence Berkeley Laboratory Report, LBL-12599.

3. S. Selkowitz et al., The DOE-2 and SUPERLITE Daylighting Programs. PASSIVE '82, The National Passive Solar Conference, Knoxville TN, August 29-September 3, 1982. Lawrence Berkeley Laboratory Report, LBL-14569.

4. F. Rubinstein and M. Karayel, The Measured Energy Savings from Two Lighting Control Strategies. IEEE Industry Applications Society 1982 Annual Meeting, San Francisco CA, October 4-8, 1982. Lawrence Berkeley Laboratory Report, LBL-14651.

5. R. Johnson et al., "Glazing Optimization Study for Energy Efficiency in Commercial Office Buildings." Third International Symposium on Energy Conservation in the Built Environment, Dublin, Ireland, March 30 - April 1, 1982. Lawrence Berkeley Laboratory, Report, LBL-12764.