J. ENVIRONMENTAL SYSTEMS, Vol. 16(3), 1986-87

DAYLIGHTING

PART I: IMPACTS OF DAYLIGHTING ON ELECTRICAL AND COOLING PEAK DEMANDS IN COMMERCIAL BUILDINGS*

WILLIAM BOBENHAUSEN, A.I.A.

SCOTT LEWIS

Energy Design Collaborative, Inc.
Scarsdale, New York

ABSTRACT

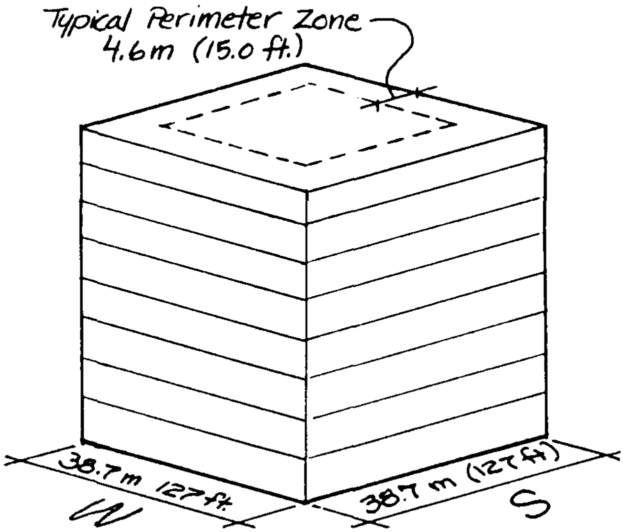
This article will illustrate the effects of daylighting as a major conservation and load management strategy for a theoretical eight-story office building of 120,000 gross square feet. Holding the basic building design constant, the benefits of daylighting will be analyzed for five different cities (New York City, Phoenix, Chicago, West Palm Beach, and San Francisco) and their utilities. For purposes of space, the detailed analysis will be limited to implications for New York City which has an existing stock of over 250 million square feet of office buildings.

Techniques for introducing controlled daylight (without excessive heat gain) into commercial buildings are becoming better understood and more frequently incorporated into state-of-the-art designs. Less well understood is the effect of daylighting on electric peak demands and cooling loads. Benefits are often manifold due to the way in which building energy loads interact, and the ways in which utilities structure their charges.

Savings begin when daylight is available and automatic electronic dimmers allow for the displacement of electrical energy for lighting. Of special importance is the fact that daylighting is usually most abundant at times when

*Paper presented at the 1983 International Daylighting Conference.

doi: 10.2190/2JA8-2M66-GJA1-VE9Q
http://baywood.com



TOTAL BUILDING AREA PER FLOOR	=	1,500 m^2 (16,140 ft^2)
TOTAL BUILDING AREA	=	12,000 m^2 (129,120 ft^2)
ASSUMED DEPTH OF PERIMETER ZONE	=	4.6 m (15.0 ft)
PERIMETER ZONE AREA PER FLOOR	=	627 m^2 (6,746 ft^2)
PERIMETER ZONE AREA FOR TOTAL BUILDING	=	5,016 m^2 (53,968 ft^2)
PERIMETER ZONE AS A PERCENT	=	41.8%
ASSUMED FLUORESCENT LIGHTING LEVEL	=	30 watts/m^2 (2.8 watts/ft^2)
LIGHTING POWER PER ZONE PER FLOOR	=	4,700 watts
TOTAL BUILDING PERIMETER ZONE LIGHTING POWER	=	150,480 watts

Figure 1. Description of base case building.

buildings experience peak cooling loads. This results in three significant benefits often not considered:

1. Substantially reduced peak cooling loads, since less energy used for lighting means less heat to remove from the building;
2. Reduced utility demand charges. Since maximum daylight availability coincides with peak cooling requirements, the effect is to level off overall electrical requirements; and
3. In the case of new or substantially renovated buildings, the reduced peak cooling loads can often mean capital savings due to reduced cooling equipment capacity. Not only chillers but often distribution components can be reduced in size for significant cost savings.

BASE CASE

Figure 1 is a description of the particulars for the theoretical eight-story office building which is the basis of this analysis. In particular, the assumed lighting level of 30 watts/m^2 (2.8 watts/ft^2) should be noted. Although such a level is indeed high for current, state-of-the-art office buildings, it corresponds exactly to the actual level for 1,000 office buildings in New York City as surveyed in an extensive study [1].

APPROACH

This evaluation is based on a simple, eight-story office building. It allows for presentation of a general methodology with results for a specific application. From such a starting point, refinement of the procedure to consider the impacts of surrounding buildings, reflectivity of ground surfaces, other orientations, different fenestration or glass areas and varying interior light levels can be accomplished.

Assumed in the calculations is a minimum daylight penetration throughout the depth of the perimeter zones equal to 2 percent of the quantity of daylight falling on the respective wall surfaces. Although beyond the scope of this article, serious attention must of course be paid to controlling the entry of overly abundant direct solar radiation along with its potential for glare.

Tables 1 and 2 provide Clear Day and Average Day Illumination for New York City arriving upon various surfaces during the summer months using correlations developed by the National Bureau of Standards while neglecting ground reflectance [2]. Although Clear Day values are of course applicable for peak cooling load evaluations, Average Day data is also provided to give an indication of typical illumination levels, and in particular the enhanced daylight availability on North facades under non-clear sky conditions.

Table 1. Clear Day Illumination Arriving Upon Wall Surfaces in Lux and (Footcandles)

	New York City at 2:30 p.m. EDST					
	May	*June*	*July*	*August*	*September*	*October*
West Wall	44,525 (4138)	43.911 (4081)	43,739 (4065)	43,534 (4046)	42,835 (3981)	40,339 (3749)
South Wall	47,096 (4377)	40,586 (3772)	42,620 (3961)	51,927 (4826)	65,646 (6101)	76,944 (7151)
East Wall	6,068 (564)	6,789 (631)	6,950 (646)	6,531 (607)	5,336 (496)	4,164 (387)
North Wall	6,068 (564)	6,789 (631)	6,950 (646)	6,531 (607)	5,336 (496)	4,164 (387)

Table 2. Average Day Illumination Arriving Upon Wall Surfaces in Lux and (Footcandles)

	New York City at 2:30 p.m. EDST					
	May	*June*	*July*	*August*	*September*	*October*
West Wall	30,720 (2855)	31,322 (2911)	31,903 (2965)	28,557 (2654)	28,535 (2652)	25,931 (2410)
South Wall	31,914 (2966)	29,708 (2761)	31,322 (2911)	32,193 (2992)	39,274 (3650)	42,846 (3982)
East Wall	12,879 (1197)	13,235 (1230)	13,073 (1215)	12,524 (1164)	10,878 (1011)	10,878 (1011)
North Wall	12,879 (1197)	13,235 (1230)	13,073 (1215)	12,524 (1164)	10,878 (1011)	9,210 (856)

Table 3.

	Total Lighting Kilowatts in Zone for all Floors	*Total Office Illumination Required*	*Daylight Arriving on Wall Surface*	*Minimum Daylight Available in Zone*	*Percent Electric Lighting Reduction in Zone*	*KW Lighting Saved in Zone for all Floors*	*Tons of Cooling Not Required, all Floors*
	KW	*LUX(fc)*	*LUX(fc)*	*LUX(fc)*	*Percent*	*KW*	*TONS*
West	36.6	1000 (93)	43,534 (4046)	870 (81)	80	30.1	8.6
South	37.6	1000 (93)	51,927 (4826)	1038 (96)	80	30.1	8.6
East	37.6	1000 (93)	6,531 (607)	130 (12)	13	4.9	1.4
North	37.6	1000 (93)	6,531 (607)	130 (12)	13	4.9	1.4
Totals						70.0	20.0

BENEFITS

In determining cooling loads, peaks are generally assumed to occur during late summer afternoons when high outdoor temperatures accompany clear skies. Table 3 summarizes the benefits derived by the base case building when located in New York City at the assumed cooling peak hour of 2:30 p.m. EDST (Eastern Daylight Savings Time) in August. Indicated is a peak hour savings of approximately 46.5 percent (70.0 KW of the 150.48 KW total perimeter lighting load).

In terms of economic benefits, daylight dimmer controls can save dollars in the following ways:

1. through reduced peak demand charges;
2. by dramatically lowering kilowatt hour consumption all year;
3. with cooling energy savings from less heat of light;
4. in new buildings, by requiring less cooling capacity.

For the base case building, current electric charges by the utility (Consolidated Edison Company) would be approximately $17 per KW during the Summer Billing Period and around $15 per KW during the winter. Thus, considering lighting demand reduction alone, monthly dollar savings would be about $1200 per month during the summer. Since daylighting works as a peak reducing strategy year-round, yearly savings for reduced peak demands of between $10,000 and $15,000 would be expected. In addition, a reduced kilowatt hour energy expense of over $13,000 per year would occur assuming 2500 hours of occupancy, an electric charge of $0.07 per kilowatt hour and an average lighting power reduction of 50 percent for the perimeter fixtures.

Dollars would also be saved on cooling energy varying greatly depending upon the air conditioning system employed. Perhaps more importantly, if cooling capacity is actually reduced in new building design, significant initial cost savings can be realized. For the base case building, $60,000 fewer construction dollars would be required if one assumes a cost of $3,000 per ton of installed capacity.

CONCLUSIONS

Buildings which utilize daylight availability can reduce electric and cooling peak demands and operational dollars. Initial costs can also be saved if cooling system capacities are fine-tuned and reduced.

While the economics of daylighting may be compelling for an individual building owner (especially in an area of high electrical consumption and demand charges such as New York City), the benefits to society at large are also worthy of analysis and discussion. For example, if 2.5 million square meters (27 million square feet) of New York City office buildings were retrofit with dimmer controls along the lines of the base case, the peak demand on the utility would be reduced by 32.5 million watts. Depending upon one's viewpoint, such a saving may be considered large or small alongside Con Edison's summer peak demand of about 7,276 Megawatts (in 1980). It may in fact be time for daylight to earn a spot in the electricity supply planning process which already ranges from nuclear power, to the environmental concerns for coal, to the economics of new plant construction of any type, to photovoltaics and ice making.

DAYLIGHTING

PART II: A COMPARISON OF DIFFERING STRATEGIES FOR TWO UNIVERSITY PROJECTS

INTRODUCTION

Experience with daylighting in commercial and institutional buildings has borne out the economic viability and improved user comfort associated with allowing natural daylight to penetrate the building envelope. Less attention has been given to the architectural attributes of *variety* and *flexibility* afforded building designers who understand fundamentally what daylighting requires, and that a varied choice of daylighting techniques is available to them. This article will compare daylighting strategies and analysis techniques employed in the design of two university buildings, to illustrate how similar levels of performance were achieved within the context of two very different sets of architectural aesthetics and client requirements. The point is not so much that daylighting works, but rather that it works by different means for different situations.

The two buildings discussed herein are to have similar hours of occupancy and are located in climatically similar cities. The Belfer Center addition to the John F. Kennedy School of Government, Harvard University is in Cambridge, Massachusetts.[1] The new library and computer center addition to Mart Science and Engineering Library, Lehigh University, is in Bethlehem, Pennsylvania.[2] Both new buildings will be occupied quite intensively seven days per week year-round, including all daylight hours after 8:00 a.m. In many other respects, however, the two buildings will be quite different. These differences are reflected in the energy conservation and daylighting strategies employed.

THE HARVARD PROJECT

The Harvard design is basically compact in form with a large auditorium space in the center, surrounded by small perimeter offices and some classrooms. Though some devices for enhancing daylight penetration in the small perimeter

[1] Architects for the Harvard building are Architectural Resources Cambridge, Inc., Cambridge, Massachusetts.

[2] Architects for the Lehigh library are Warner Burns Toan Lunde Architects, New York, New York.

offices were modeled (including lightshelves), the limited depth of these spaces showed little need or benefit from improved penetration beyond the use of highly reflective venetian type blinds. More effort in the analysis of the design was aimed at limiting window areas (to minimize heat loss), recessing the window glass back from the exterior wall plane with deep mullions (to shade the glass from direct solar radiation), and locating windows where they would be shaded by the building itself.

Lighting fixtures in the Belfer Center (the Harvard building) will be controlled by switches in each office to accommodate the frequent but varying use of those rooms and the need for individual user control to avoid wastefully lighting empty offices. Daylight-sensitive dimmer controls will be installed in each perimeter space, each dimmer controlling only the two to five fixtures of that space.

Evaluation

To evaluate the impact of daylighting and dimmer controls in the Harvard building, a method was devised to allow results of modeling a *typical* space to be applied to other perimeter rooms of similar size but various orientations.

Modeling of a typical office was done using a physical scale model at 1:12 (1″ = 1′-0″) scale, tested under a variety of sky conditions. Light (illumination) levels were measured for surfaces 76.2 cm (30 in) from the floor at 1.52 m (5 ft) intervals from the exterior wall. Readings were also taken of daylight impinging upon the vertical window glass.

Modeling determined that a desk surface inside the room would receive approximately 2 percent as much illumination as that impinging upon the glass. As long as each perimeter office space is assumed to have the same general size and window configuration, the 2 percent "window factor" can be generalized for all of the offices.

Savings attributable to daylighting were calculated from the average illumination contribution from daylight afforded each office, which displaces illumination from fluorescent fixtures. It was assumed that 500 lux (46 fc) would be maintained during office hours, and that lights would not be dimmed below 20 percent of full light output to avoid fluorescent flickering and negative psychological responses. Therefore, the maximum savings would theoretically be 80 percent.

Used in the analysis were correlations of solar radiation and available daylight developed by the National Bureau of Standards [2]. However, care must be taken in any such analysis which extrapolates day-long lighting savings from "average day" radiation and illumination data. After all, daylight is unlike thermal energy–it cannot be stored. Thus, an overabundance of available daylight at one period during the day cannot make up for an undersupply during other hours. Without sensitivity to this fact, greatly overstated savings will be projected.

Several other efforts were also undertaken to project daylight benefits from the 45,000 square foot addition to the existing 105,000 square foot existing School of Government. One was the installation of a demonstration dimmer control[3] with recording wattmeter in a typical west facing office (10 feet wide by 15 feet deep) in the existing building. Using correlations developed by the Smithsonian Institution, the manufacturer of the controllers put forth a total average savings of 56 percent for the lights in the existing perimeter offices after adjusting for orientation and glazing factors. In addition, a simple monitoring effort was conducted by the Building Manager of the school using an inexpensive light meter. For a period of several weeks typical readings were taken outside around the building, and inside in a variety of office conditions.

The selected dimmer control method involved one controller for the two fixtures in each office nearest the window, and another controller for the two fixtures furthest from the window. Yearly average savings of 50-55 percent are projected, with a payback on the dimmer controls of about three years.

THE LEHIGH PROJECT

For reasons of siting, the library and computer center addition to Lehigh University's Mart Library was conceived of as an elongated form, stretched along the east-west axis with long facades facing south and north. Daylighting the large continuous library spaces demanded approaches that are very different from those taken at Harvard. The width of the new building will be about fifty-five feet from North to South, requiring that daylight penetrate up to over twenty-five feet to be most effective. The long, narrow plan of the building, however, made it ideally suited for daylighting, coupled with the fact that most user activities (reading areas) were planned to be located nearest the perimeter with stacks and circulation areas planned for the less daylit interior areas.

Working within a modern "high-tech" design aesthetic, strategies to improve daylight penetration into the larger spaces could, in this case, enhance the architectural design. Visually reinforcing the articulated linear bands of window glass and spandrel wall, devices to control and reflect sunlight were added to the south wall. Projecting horizontal fins located between clerestory windows and lower vision glass, shade the vision glass to prevent direct solar gain and glare conditions. Outside of the clerestory glazings, operable aluminum louvers will reflect and beam daylight up toward the ceiling and deep into the library space. (See Figure 2).

[3] The "Flexiwatt" dimmer as manufactured by Controlled Environment Systems, Inc., Rockville, Maryland.

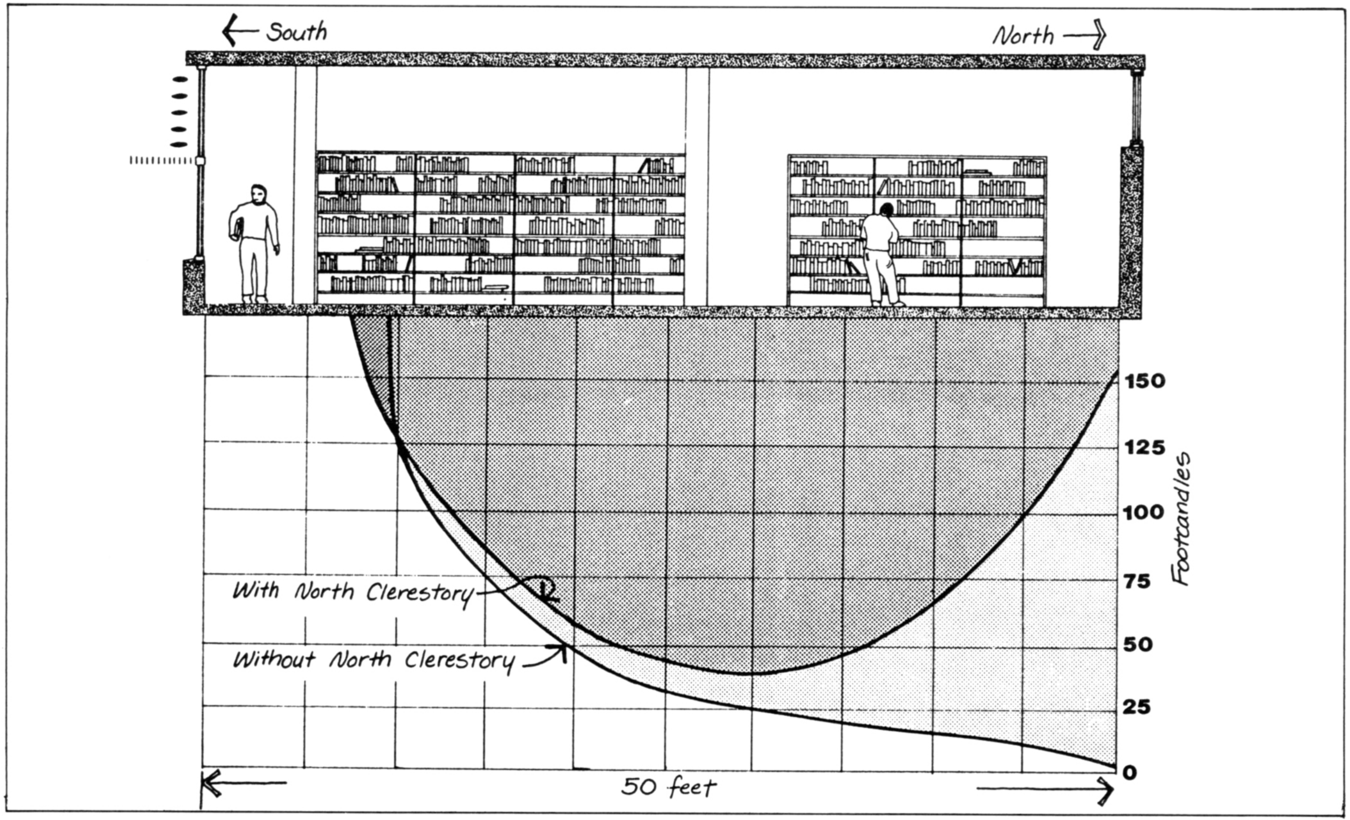


Figure 2. Daylighting design for Lehigh Library (Typical Floor).

Unlike the small offices at Harvard, successful daylight penetration could not rely upon windows and devices on a single wall. Clerestories were introduced into the north as well as the south wall despite concern over increased heat loss. In many instances, increased daylight benefits had to be balanced or restrained in deference to other energy concerns, though in some cases strategies worked in concert.

For example, in summer, at times when daylight intensity is often greater than can be usefully employed, direct solar rays can be blocked by the louvers; during winter months, when the heat gain is desirable, a greater percentage of the illumination available at the south clerestories can be deflected well into the space in a controlled and glare-free way.

It's important to note that the various energy-conserving strategies recommended satisfy aesthetic and functional concerns apart from simple daylighting. The projecting fins prevent unwanted solar gain for most of the year without obstructing the view at the perimeter where the loss of illumination is easily sustained. The louvers close at night to prevent heat loss, and can be adjusted to prevent glare during the day, as well as to maximize light penetration.

Analysis and Evaluation

Just as the type of space and daylighting strategies recommended at Lehigh were quite different from the small offices with punched windows designed at Harvard, so the means for evaluating performance were different.

Again a scale model was built to simulate daylighting conditions (See Figure 3). While a one-twelfth scale model would have to be only 138.6 cm(fifty-five- inches) wide, a complete model would have to be over 6 meters (200 inches) long! To effectively simulate light conditions throughout the many bays of the long library space, the model was built of two bays only. However, the east and west walls were covered by mirrors, creating the visual effect of endless bays. Daylight at Lehigh will enter from north as well as south fenestration, again owing to the larger size of the spaces and need for deeper penetration.

The Lehigh model simulated not a typical small space, but rather an entire floor of the library portion of the building. North and south facades of the model were specific to those orientations unlike the Harvard model, which could simulate offices facing a variety of directions.

CONCLUSIONS

Experience in the design process of two university buildings with different clients and design teams, has underlined the importance of accommodating specific client desires, architectural preferences, and programmatic requirements

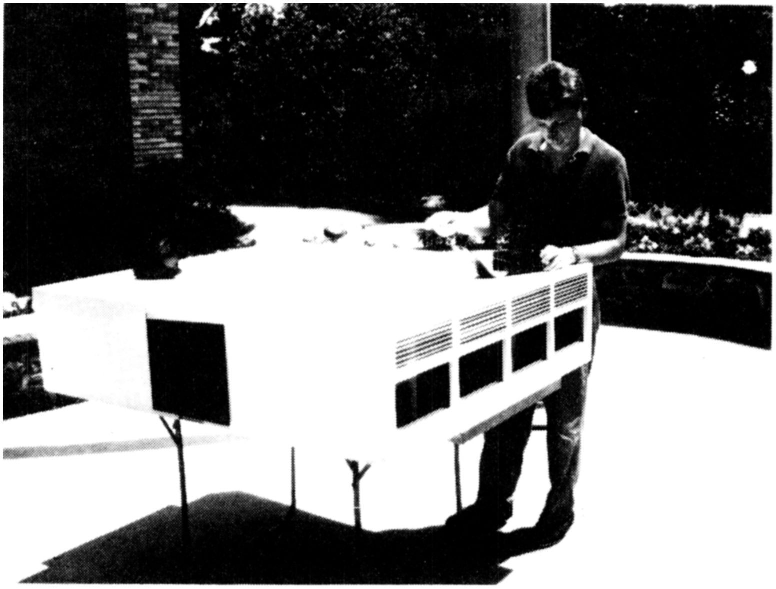


Figure 3. Testing of Lehigh Daylight Model.

of the building while integrating daylighting techniques successfully. The type of analysis performed to verify performance of the strategies employed, will of course vary accordingly.

REFERENCES

1. *Energy Conservation in Existing Office Buildings*, United States Energy Research and Development Administration, 1977.
2. S. Treado and T. Kusuda, *Solar Radiation and Illumination*, National Bureau of Standards Technical Note 1148, November 1981.

Direct reprint requests to:

William Bobenhausen
Energy Design Collaborative, Inc.
529 Central Avenue
Scarsdale, NY 10583