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EVALUATION OF INTEGRATED LIGHTING SYSTEM PERFORMANCE IN A LARGE DAYLIGHTED OFFICE BUILDING

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ABSTRACT

The use of daylight for ambient illumination can substantially reduce this energy usage if the electric lighting system is properly controlled in response to available daylight. This paper evaluates the monitored performance of an integrated lighting system in a recently completed 56,000-m^2 office structure in the San Francisco Bay Area. Natural light serves 3,000 employees in open-plan offices throughout the five-story building. The architectural scheme includes: ceilings that slope from 4.25 m high at the perimeter to 2.75 m at the center; 3.5-m light shelves at the exterior walls; and a central atrium providing light to the interior spaces. The electric lighting system consists of fluorescent fixtures with continuously dimming ballasts controlled by photocells, which supplement available daylight when necessary.

The paper presents a summary of daylighting and electric lighting performance as monitored in several zones of the building. Analysis of detailed measurements on the third floor for four unoccupied days in May indicates that on the brighter south side, the potential for dimming during occupied periods is to 44% of full power. On the dimmer north side of the third floor, the potential for dimming during occupied periods is to 31% of full power based on an eight-day block of data in July. Analysis of detailed measurements during occupied periods indicates that on the third-floor south side the actual average power consumption is 75% of full power over nine-days in May. On the third-floor north side, the actual average power consumption during occupied periods is 50% of full power for eight days in July. Significant potential for daylighting is not being realized.

The paper discusses the potential benefits of daylighting in the context of the overall building electrical energy use. Analysis of annual electricity use indicates that the ambient lighting electrical circuits represent 23% of the total building electricity use. Present operation of the building is consistent with dimming of the ambient lighting electrical circuits to 85% of full power. There are significant opportunities for dimming that are not used. Proper integration of the electric light dimming system is essential for the realization of projected savings in electric power consumption.

This work was supported by the Energy Services Department, Pacific Gas and Electric Co. under agreement BG 83-42, and by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings and Community Systems, Building Equipment Division and Building Systems Division of the US Department of Energy under Contract DE-AC03-76SF00098.

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INTRODUCTION

A field study of the building's lighting and fenestration-system performance established a profile of daylighting and electrical lighting patterns and analyzed the relationships between daylight availability, interior illuminance, and electrical lighting power consumption [1,2,3]. This paper describes the relationship between daylighting and energy use for ambient electric lighting in representative zones and the annual building electricity consumption.

The Building

The structure represents a major advancement in daylighting use by a large U.S. corporation that seeks reduced energy consumption, lower peak demand, and improved employee productivity. The 56,000-m^2 office is occupied by 3,000 technical personnel in open-plan offices. The building design is strongly driven by daylighting criteria. The building plan, shown in Figure 1, is elongated on an east-west axis, producing major fenestration surfaces facing roughly north and south (the building is actually turned approximately 25 degrees west of south). Building functions lacking a strong relationship to daylighting (computer facilities, conference rooms, rest rooms, copy rooms, etc.) are gathered in opaque core groups placed on the east and west ends of the building.

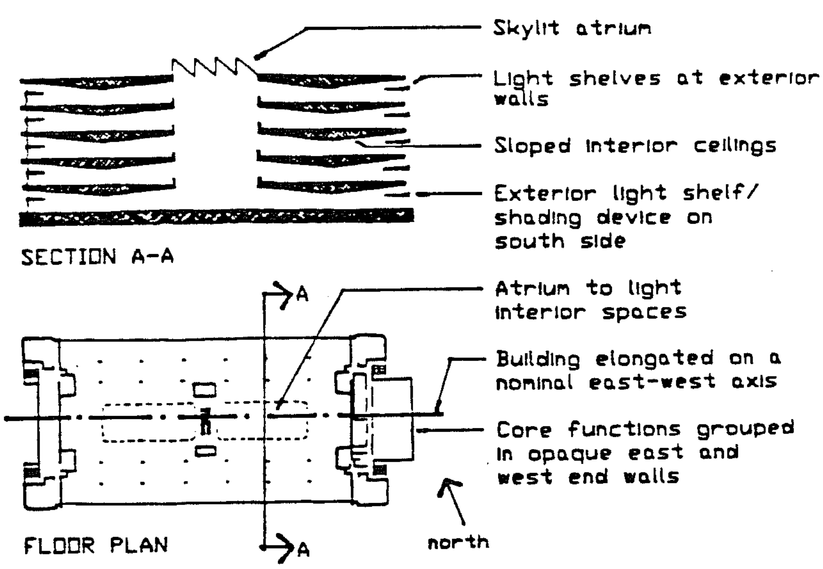


Figure 1. Section and Plan of the Building.

A central atrium was introduced to provide light, visual relief, circulation, and drama to the building's large interior zones. The building has a high floor-to-floor dimension (5.5 meters) to increase the depth of daylight penetration from exterior and atrium openings, with a sloped ceiling to intercept and reflect illuminance from the light shelves.

Large light shelves are located along both north and south exterior walls. The horizontal interior light shelves are approximately 2.3 meters above the floor and extend inward 3.75 meters from the exterior glazing to shield the perimeter zone from direct sunlight and to reflect daylight deeper into the space. The south side of the building has an additional exterior light shelf with a reflective white upper surface that serves as a light reflector and solar shading device. To further reduce glare and winter solar gain, the glazing below the light shelf has a relatively low transmittance (17% on the south side and 41% on the north).

Ambient illumination for circulation and casual tasks is provided by daylighting whenever possible and supplemented by indirect fluorescent ceiling fixtures. A photosensor provides the signal to control each circuit's continuous-dimming system. With a target of 350 lux for ambient illumination, the architect projected a significant decrease in electric power used for ambient lighting. A separate computer-based control system turns the lights off at scheduled periods of low occupancy. Task lighting is provided by individually controlled fixtures built into each workstation.

Field Measurements

The study of daylighting in an occupied building poses some interesting technical challenges. Instrumentation must be installed with minimal disturbance to the building occupants and with an orderly routing of sensor wiring. Our measurement strategy applied four independent battery-operated dataloggers to collect simultaneous readings at 28 sensor locations. The use of Campbell Scientific Model CR-21 dataloggers allowed short analog sensor wiring runs and flexibility in sensor placement. Data was stored on digital cassettes and downloaded in the field to a portable microcomputer for off-site evaluation. Characterization of interior lighting patterns was based on LiCor 210S photometric sensors placed across sectional profiles in representative daylight zones of the building. Ambient illuminance measurements in a horizontal plane were collected at partition height, 1.8 m above the floor. Additional photometric sensors were located in the volume above the interior light shelves. Lighting power circuits for corresponding light fixtures were monitored by Ohio Semitronic PC5-59C watt transducers in the local electrical closet.

Detailed field measurements were made at different times in three zones of the building from February 1985 until January 1986. Preliminary site visits with hand-held instrumentation established the third floor as a representative floor for daylighting. Data were collected for three-week periods across a horizontal section of the south side of the third floor, then across a similar profile of the north side, and finally in a vertical section across all floors along the atrium edge. Most of the data represent summer conditions, though detailed measurements for the south side were repeated for equinox and winter conditions.

Building Energy End-Use Data

In addition to the data from field monitoring of the building, data from daily manual readings of main electrical power circuits and hourly and daily readings from the energy-management system were used to construct a picture of overall building energy use. Hourly energy-use data for both the total-building electricity usage and the submetered circuits for ambient lighting and fans were obtained and plotted. Estimates of the annual building electrical end-use were made by analysis of the detailed data. The data were obtained on hardcopy printouts and manually entered into spread sheets for analysis and plotting. Because only a small sample of data was analyzed, this manual data manipulation technique was acceptable. However, for longer-term analysis, procedures should be developed to capture the data in a computer-readable form.

FIELD MEASUREMENTS

Performance of Daylighting System

To evaluate the performance of the daylighting system we have analyzed illuminance data from a series of unoccupied summer days with no electric lighting component, as confirmed by examining concurrent lighting power consumption data. Typical data for interior illuminance under summer clear sky conditions are shown in Figure 2. The south side of the structure, strongly influenced by beam sunlight, exhibits substantial variation in illuminance throughout the day. For this zone interior illuminance is low during the morning hours, but rises quickly as direct sunlight strikes the exterior light shelf. Peak illuminance readings 4 m from the exterior wall exceed 1200 lux, almost four times the target of 350 lux. Summer represents the darkest season for this area and winter levels exceed 2500 lux.

To prevent glare in the immediate vicinity of the window on the south side of the building, the architects used a combination of low-transmission view glazing and shading from the exterior light shelf. The area immediately below the south-side light shelf does not receive enough natural light to exceed 350 lux, thus there are lower levels of natural light in the zone closest to the window than in the interior zones. Illuminance levels 13 meters from the exterior wall peak at approximately 250 lux. Though this does not provide 100% of ambient illuminance, it does reduce the electric lighting load significantly.

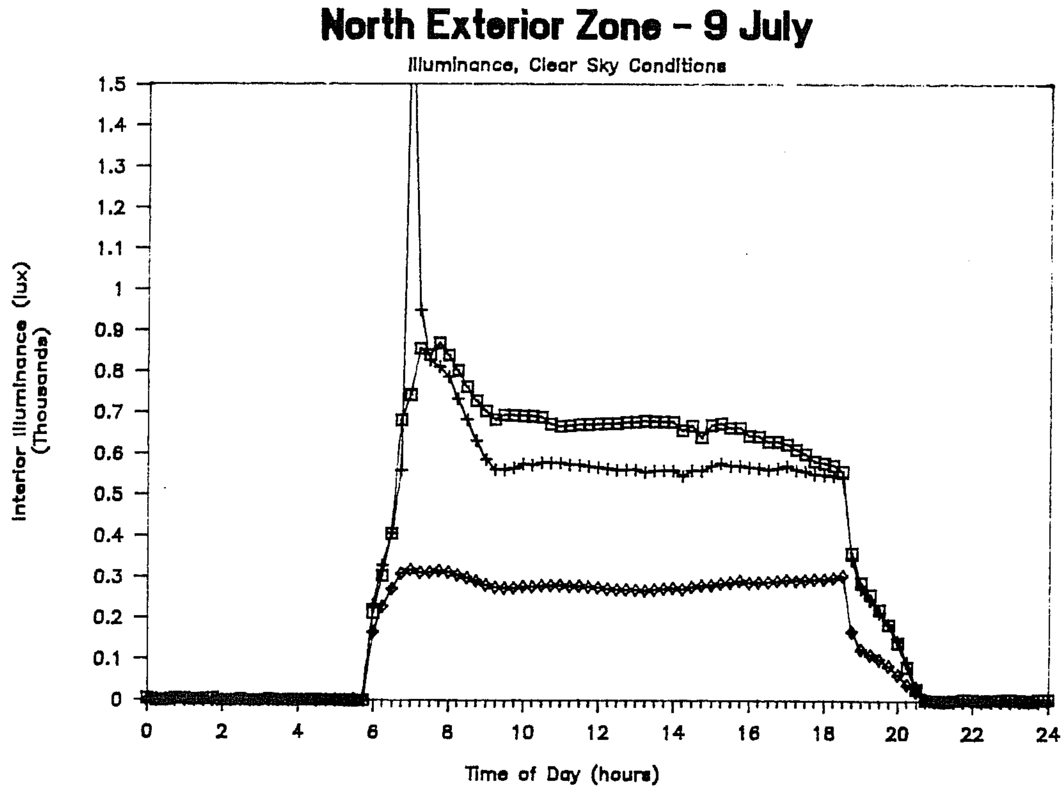
The north side of the building has an entirely different daylighting character. The north sky provides diffuse light to this zone, which has higher-transmittance vision glass and no exterior reflector on the light shelf. Interior illuminance here does not reach the high levels of the south side, peaking at 600 lux. The interior daylight levels, however, consistently exceed the 350-lux target and therefore provide substantial dimming potential. The area immediately beneath the light shelf has higher daylight levels than its south-side counterpart because of the higher transmittance of the view glazing. Like the south side, the regions near the center of the north zone do not reach target light levels.

Illuminance levels near the atrium edge on both sides are quite high and fall rapidly nearer the building's interior. A 6000-lux reading at the atrium edge drops to 700 lux at 3.5 m from the edge and 400 lux at 5.5 m.

Electric Lighting Power Measurements

A survey of ambient electric lighting on the third floor of the building indicated that the installed power was 10 W/m^2 (0.92 W/ft^2). Observations and manual testing of the fluorescent ballast dimming system at night indicated that it was operating within the manufacturer's specifications. The system can dim continuously from full output to a minimum of 27% of full power.

To establish an accurate profile of the dimming achieved by the building's current operation, 15-minute average power consumption readings were recorded for each lighting circuit corresponding to a row of fixtures within our monitored zones. This data, collected from Ohio Semitronic watt transducers mounted in the electrical closets, provides a direct measure of the power used by the indirect fluorescent lighting system under summer



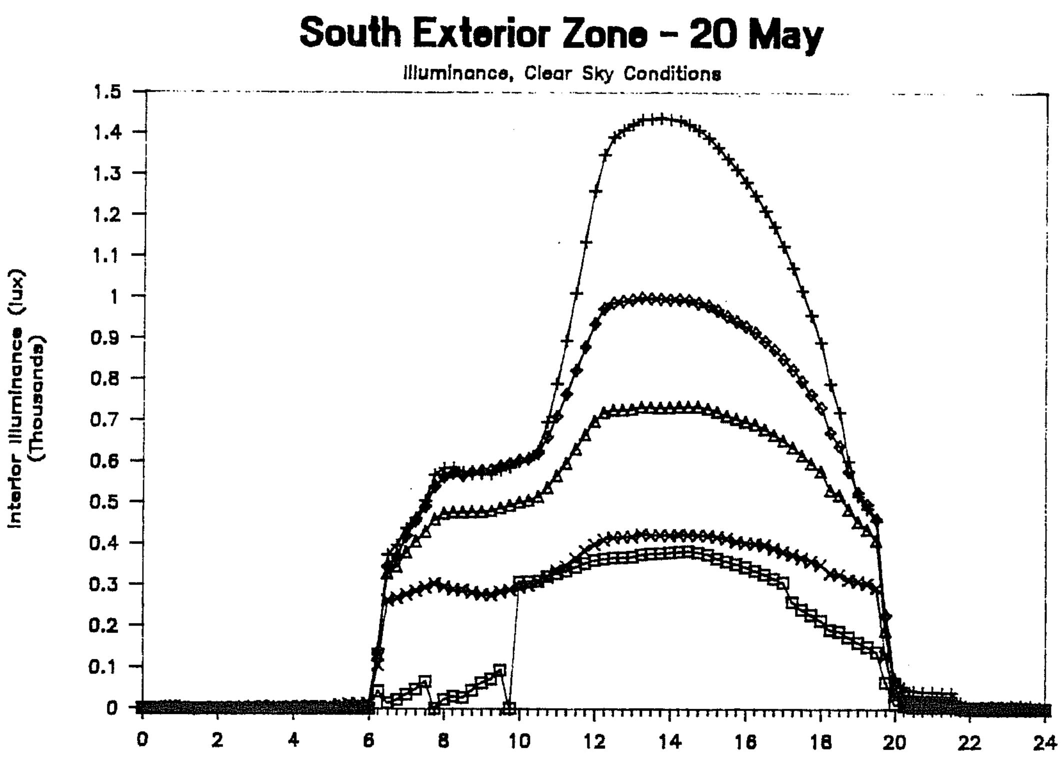


Figure 2. Interior Illuminance Values for a Typical Clear Summer Days: a) South Exterior Zone; b) North Exterior Zone.

conditions. From these measurements it is possible to define unoccupied days when the lights are off, and to determine the percentage of dimming of the lights during occupied days.

The actual dimming achieved in a representative zone during occupied hours was calculated by determining the percent power used for each lighting circuit in a cross-sectional profile of that zone. The data for each occupied day was checked to verify that occupancy patterns were normal. Lighting power data during the normal occupancy period of 8 AM to 6 PM was then assembled into an eight- or nine-day data block for each of the major daylighted zones. A microcomputer spreadsheet program (Lotus 123) was used to compile summary statistics for each lighting circuit including the number of individual 15-minute readings and their averages, totals, maximums and minimums. As a baseline we calculated the power consumption for the circuits at 100% electrical power for the full time period of the monitored data. This figure was defined for each lighting circuit as the maximum electrical power consumption times the number of time periods in the data set. The actual percent of electrical lighting power used was then calculated as the ratio of the sum of all actual power readings to the 100% power consumption figure.

The actual dimming achieved by the different electrical circuits that serve the lighting fixtures and the average over the entire zone on the north and south sides of the building are summarized in Table 1. An examination of the electric lighting power consumption in 14 locations across the third floor revealed significant dimming on only one circuit on the south side and six circuits on the north side. The correlation between interior illumination and electric power indicated that dimming to low electric light levels occurred on only four circuits. The other circuits exhibit either little dimming or no dimming at all at higher daylight levels.

Table 1.
Summary for Occupied Periods
Actual Electrical Lighting Power Consumed

			South Side					
Circuit	15B	13B	11	9	7	3&5	1B	Average
% Full Load Power Used	86.2%	73.0%	84.4%	92.8%	72.6%	30.6%	99.0%	75%
			North Side					
Circuit	16B	14B	12	10	8	4&6	2B	Average
% Full Load Power Used	54.6%	49.2%	42.9%	78.2%	46.9%	43.0%	45.3%	50%

Calculations of the actual dimming for the south-side zones are based on a nine-day data set. These occupied days represent typical summer conditions with a mix of clear, partly cloudy and cloudy conditions. The south-side data indicate that the actual average power consumption for occupied periods is 75% of full power. Calculations for actual dimming on the north side are based on an eight-day block of data. Again, these occupied days represented typical summer conditions with a mix of clear sky and partly cloudy sky conditions. The data indicate the average power percentage for the electric lighting system is 50% of full power, appreciably better than the 75% power consumption of the south side.

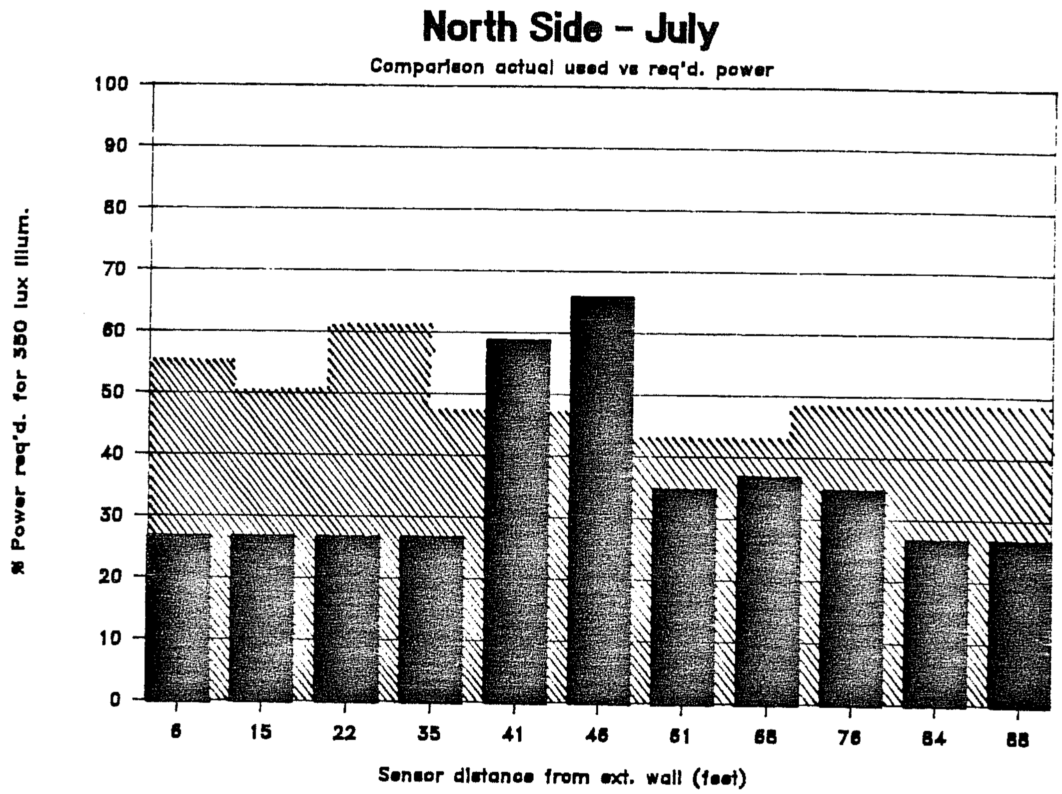
Dimming Potential

To evaluate the benefit of improved control system performance, the potential for dimming of the electric lighting system was calculated. Illuminance data was collected during weekends when the building was unoccupied and had no electrical lighting. Illuminance readings for 24 locations across the north-south building section were collected at 15-minute intervals for normally occupied hours (8 AM-6 PM) and sorted into bins with 70-lux increments. The number of occurrences in each bin was multiplied by the lighting power percentage required to raise that bin to the 350 lux target illumination level. Finally, a summation of electric energy required by each monitored location was weighted by the cross-sectional area represented by that location. The results portray the potential supplemental electric power required to meet target illuminance levels of 350 lux. From these figures the electric light dimming potential can be determined.

As might be expected, the south exterior zone with its relatively high light levels demonstrates considerable potential for dimming. The calculations indicate that for occupied hours during this summer period, the zone should require only 39% of full power from the indirect ambient lighting system. The area directly beneath the light shelf and the zone nearest the central corridor are each responsible for about a quarter of the required electric lighting. As expected, the central corridor area (13.7 m or 45 ft from the exterior wall) requires supplemental lighting. However, it is ironic that the area below the light shelf, the zone that could have the greatest access to daylight, requires continuous supplemental light because of the low transmittance of the view glazing, the deep lightshelf, and the exterior overhang.

The south atrium zone, receiving only diffuse daylight from the atrium, requires higher average levels of electric lighting (50%). When averaged with the south exterior zone performance, the average electrical power requirement for the south side is 44% of full power. The north side of the building, without the strong beam illumination and high daylight levels of the south side, consistently has enough daylight to meet the 350-lux target illuminance level and requires less supplemental electrical lighting than the south side. Our calculations indicate that the north exterior zone should only require 26% of the full power from electric ambient lighting as a supplement to daylight. The north atrium zone also compares favorably with the south side in requiring only 35% of potential electric lighting. A major portion of the north exterior zone requires no supplemental electric lighting during occupied hours while a corresponding area on the atrium side needs minimal assistance. Only the center corridor area of the north side requires substantial percentages of electrical lighting. The north exterior and atrium zones combined should require an average of 31% of full electrical power. The distribution of potential dimming across both the north and south side building sections is summarized graphically in Figure 3. Also shown in the figure is the observed dimming.

The observed and potential dimming for the third-floor representative zones are summarized in Table 2. The calculations indicate that the potential for dimming during summer occupied periods on the third-floor south side is 44% of full power, while the actual monitored consumption is 75%. On the third-floor north side the potential for dimming during occupied periods is 31% of full power while the actual average power consumption during occupied periods is 50%. Based on our summer data, the average energy consumption of the electrical ambient illumination system for north-side and south-side zones combined could be as low as 37% of full power.



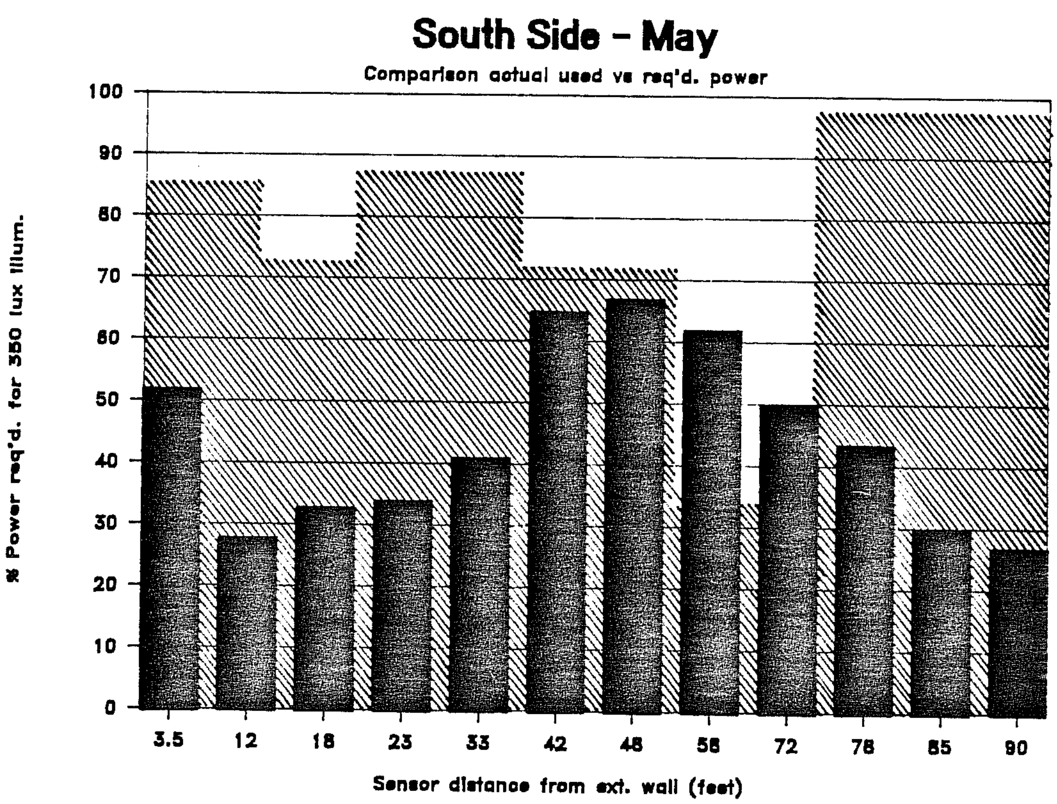


Figure 3. Potential dimming for daytime occupied hours. vs. observed dimming for the third floor south and north sides shown as a fraction of the full electrical lighting power

Table 2.
Observed and Potential Dimming as percentage of full power for third floor representative zones.

	Observed	Potential
South Atrium Zone		50%
South Exterior Zone		39%
South Side	75%	44%
North Atrium Zone		35%
North Exterior Zone		26%
North Side	50%	31%
Total Floor	63%	37%

The electric lighting control system has not been effective in capturing the energy savings inherent in the daylighting features. Some specific circuits dimmed well, but on the whole the dimming system is not performing up to expectations. The poor performance of the control system can be linked to improper placement and calibration of control sensors. The fourteen open-loop control sensors on each floor measure available daylight transmitted through the view glazing below the interior light shelf, and each one controls a different row of lamps. On the south side the view glazing has 17% transmittance, so the sensors see a relatively dark region. The north side's glazing, with 41% transmittance, provides a stronger relationship between the control sensor measurement and available daylight. In the atrium zones, the sensors are in the ceiling 2 m from the atrium edge and see a more representative illumination level. On the whole, the exterior-zone sensors are in poor locations to assess potential daylight, particularly for the beam component of daylight on the south side. This situation may be corrected by simply relocating the control sensors. Techniques such as direct readout of the lighting levels and percentage of dimming could also be helpful to give the operating personnel feedback as to how well the dimming system is working.

A survey of the dimming equipment indicates that while it is capable of dimming to 27% of full power, on the average the actual dimming on the third-floor south is to 75% of full power. On the fourth floor a spot check showed that the dimming was only to 84% of full power. This indicates that building-wide there is some uncertainty in projecting our measurements on the third floor to the whole building. As will be discussed in the following section on whole-building performance, an average reduction of the ambient lighting electrical circuits to 85% of full power is probably indicative of present building performance.

ANNUAL ELECTRICAL ENERGY USE

Whole-Building Electrical Energy Use

To evaluate the impact of the ambient electric lighting system on whole-building performance, the electrical energy use records have been analyzed. Potential annual energy savings from daylighting can be estimated by considering the total building electrical energy use and the fraction of energy used in electric lighting. The total electrical demand is shown in Figure 4, and is based on summing the hourly demand of five major utility meters: 1A, 1B, 2A, 3A, and 4A. These hourly readings were stored by the energy-management system (EMS), were printed out daily, and show good agreement with daily manual readings of the main utility circuits. The total building load is quite consistent from day to day, with a peak building electrical consumption of about 1,600 kW and with a minimum continuous load of about 700 kW. The cooling load in the building is served by a central chilled water plant and is not included in the building electricity consumption. At a gross building area of 56,000 m^2 (600,000 ft^2), the building peak electric power consumption is about 29 W/m^2 (2.7 W/ft^2). The minimum building load is about 12.5 W/m^2 (1.2 W/ft^2), which represents computers, fans, and other equipment that run 24 hours a day. Table 3 shows the disaggregation of the main utility circuits.

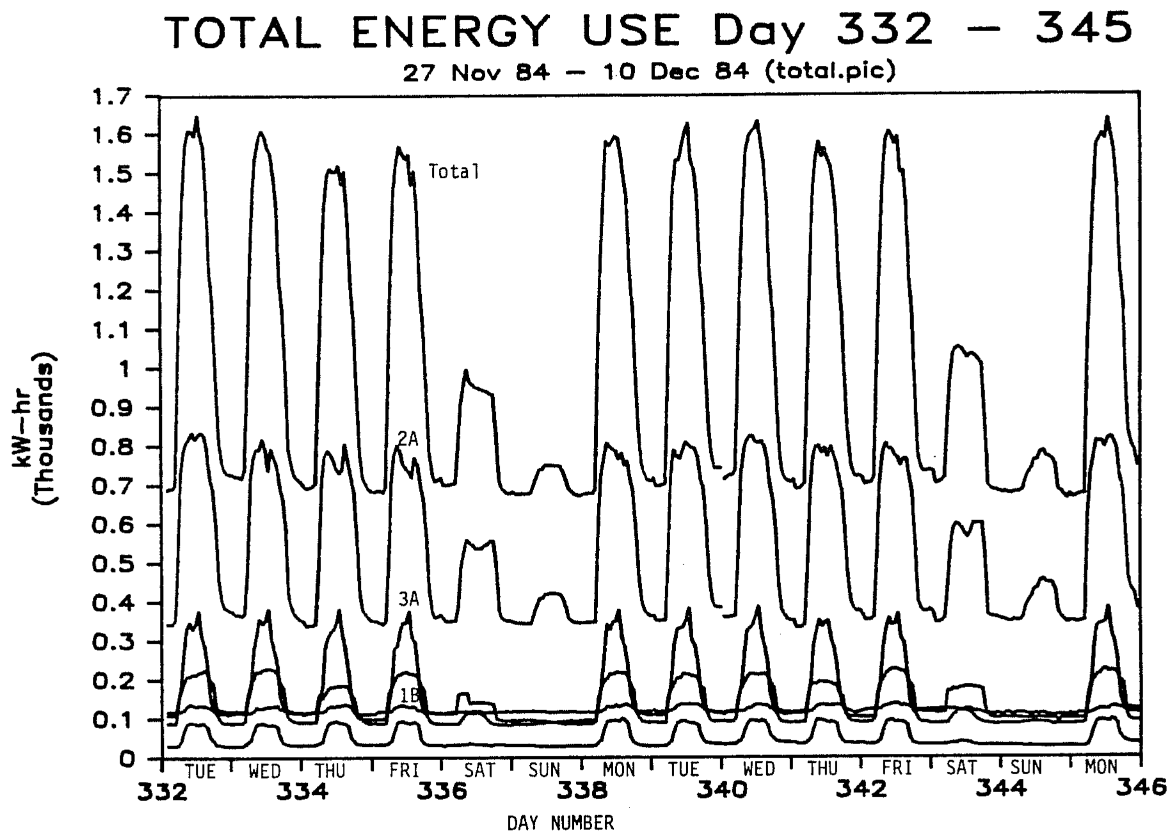


Figure 4. Hourly electrical energy use for the total building and main meters (1A, 1B, 2A, 3A, & 4A) for the period 27 November through 10 December 1984.

Manual meter readings of the main utility circuits over a period of 325 days indicate that the annual building electrical energy consumption is about 8,660 MW-hr/yr. The annual electrical energy use for the building is about 14.4 kW-hr/ft^2-yr (49 kBtu/ft^2-yr). This does not include cooling, which is provided by a district chilled-water system. Table 3 also shows the annual energy use estimates for major electrical circuits in the building.

Ambient Lighting Electricity Use

The major ambient lighting electricity use is on a submetered circuit, LK8, of meter 2A. The task lighting is on separate circuits and is not directly measured. There is also a much smaller ambient lighting load, LC2, that is a submetered circuit of meter 1A. The peak electrical lighting load on circuit LK8 is about 425 kW. There is a significant dip to about 330 kW around noon on clear days in the winter. Only the lighting circuit shows

Table 3.
Disaggregation of peak and minimum electrical power use by major circuit as measured by the energy management system. The estimated annual energy use is also shown.

METER	Submeter	Peak	Minimum	Annual Estimate
1A		96 kW	33 kW	415 MW-hr/yr
	LC2 Lights	39 kW	8 kW	137 MW-hr/yr
	Other			
1B		216 kW	115 kW	1,118 MW-hr/yr
	HVACSW fans	70 kW	35 kW	385 MW-hr/yr
	HVACNW fans	75 kW	39 kW	469 MW-hr/yr
	Other	79 kW	36 kW	
2A		825 kW	351 kW	4,802 MW-hr/yr
	LK8 lighting	423 kW	61 kW	1,873 MW-hr/yr
	HVACNE fans	56 kW	33 kW	658 MW-hr/yr
	HVACSE fans	82 kW	75 kW	419 MW-hr/yr
	Other	269 kW	175 kW	
3A		387 kW	88 kW	1,312 MW-hr/yr
4A		137 kW	110 kW	1,150 MW-hr/yr
	HVACCR computer	33 kW	32 kW	255 MW-hr/yr
	Other	104 kW	78 kW	
TOTAL		1632 kW	707 kW	8,662 MW-hr/yr

this noon-time dip of about 20%. The nighttime electric lighting load on this circuit is about 60 kW, which probably represents emergency lights.

Comparing ambient lighting energy use data for 27 November to 10 December 1984 with data for 30 September to 14 October 1985 indicates little variation in the overall peak lighting energy use. There is, however, a change in the observed pattern of dimming. In the fall the morning peak electrical usage is the same, but because of the longer period of daylight, the lights remain dimmed through the afternoon until the end of the business day. To disaggregate the contribution of ambient lighting to the total electrical usage on meters 1A and 2A, the daily energy use was examined in detail for a two-week period in October 1985. For this two-week period, the LK8 lighting circuit is about 39% of the energy use on meter 2A. The LC2 lighting circuit is about 33% of the energy use on circuit 1A. The peak and minimum electrical demand for these two circuits are shown in Table 4.

Assuming that the percentages for this two-week period are representative of the entire year, we can project the total electrical energy use for ambient lighting as shown in Table 4. The LK8 lighting circuit is about 39% of the energy use on circuit 2A, or about 1,873 MW-hr/yr. The LC2 lighting circuit is about 33% of the energy use on circuit 1A, or about 137 MW-hr/yr. The total lighting electrical load is then estimated to be about 2,010 MW-hr/yr. Thus, it is estimated that the ambient lighting circuits represents about 23% of the total building electrical energy consumption of 8,660 MW-hr. Assuming a total floor area of 600,000 ft^2, the electrical energy use for ambient lighting circuits represent about 3.4 kW-hr/ft^2-yr (11 kBtu/ft^2-yr).

Estimated Dimming Energy Savings

The installed ambient lighting energy density based on our survey of the building is about 10 W/m^2 (0.92 W/ft^2). Assuming a gross floor area for office space 416,000 ft^2 plus core and additional areas of 182,000 ft^2 for a total of 598,000 ft^2, the total installed ambient lighting load would be between 385 kW (based on office area) and 550 kW (based on total area). The observed peak demand on the ambient lighting circuits is 460 kW with a minimum usage of 70 kW, as shown in Table 4.

Table 4.
Estimate of Annual Energy Use for Ambient Lighting.

METER	SUB	Peak	Minimum	Annual Estimate
1A		96 kW	33 kW	415 MW-hr/yr
(33%)	LC2 Lighting	39 kW	8 kW	137 MW-hr/yr
2A		825 kW	351 kW	4,802 MW-hr/yr
(39%)	LK8 Lighting	423 kW	61 kW	1,873 MW-hr/yr
Total Ambient		~460 kW	~70 kW	2,010 MW-hr/yr

Daily estimate. The electric lighting system is normally on from approximately 6 AM until 8 PM, 14 hours. For circuit LK8 operating at a maximum of 425 kW for 14 hours and at the minimum of 60 kW for 10 hours gives a daily total of about 6550 kW-hr/day. Analysis of hourly electrical usage on circuit LK8 for a period in December 1984 indicates that some days have very little dimming and use roughly 6,000 kW-hr/day, or about 92% of estimated full power. Other days show significant dimming in the middle of the day on circuit LK8 and indicate a daily energy use of about 5,500 kW-hr, or about 85% of full power. In early fall 1985 the days show significant electrical peak electrical power use in the early morning, about 425 kW, and significant dimming in the afternoon. The typical week-day electrical use of circuit LK8 is 81% to 85% of full power, dropping to 74% on Saturday, and dropping to 31% on Sunday when the building is largely unoccupied.

Weekly estimate. The ambient lighting system is typically on 14 hours a day for 6 days a week, 84 hours/week. If the lights were operating at 460 kW during this 84-hour period (38,640 kW-hr) and at 70 kW during the remaining 84 hours (5880 kW-hr), then the total weekly electric use for ambient lighting would be about 44,520 kW-hr/week. The 14-day winter total for LC2 and LK8 is 37,600 kW-hr/week, which is 85% of the estimated maximum. The 7 day fall season total for LC2 and LK8 is 38,000 kW-hr/week, again 85% of the estimated maximum aggregated over the entire building. Thus analysis of detailed energy use data on the ambient lighting circuits indicates that the whole building is operating on a weekly basis at about 85% of full power output for ambient lighting.

Annual estimate. Extrapolating these results to 52 weeks/yr and 84 hours/week gives 4368 hrs/yr of full power operation of ambient lighting at 460 kW. The remaining 4392 hours the lighting system is operating at minimum of 70 kW. If the lights were operating at 460 kW during 4368 hours/yr (2,010 MW-hr) and at 70 kW during the remaining 4392 hours (308 MW-hr), then the maximum annual electric use for ambient lighting circuit would be about 2,310 MW-hr/yr, as shown in Table 5. If the average daytime power usage was reduced to 85% of the maximum, then the annual electric energy use would be would be about 2,015 MW-hr/yr, as shown in Table 5, consistent with our observed value.

Table 5.
Estimate of Electric Lighting Energy Use
based on dimming to 85% and 70% of full power.

Usage	hours	Power	Annual Usage
Background	4392 hrs	70 kW	308 MW-hr/yr
100% full power Total (100%)	4,368 hrs	460 kW	2,010 MW-hr/yr 2,310 MW-hr/yr
85% full power Total (85%)	4,368 hrs	460 kW	1,708 MW-hr/yr 2,015 MW-hr/yr
70% full power Total (70%)	4,368 hrs	460 kW	1,406 MW-hr/yr 1,714 MW-hr/yr

The additional energy savings from improved dimming performance can be estimated by considering the number of lamps in the daylighted area. The open plan office has approximately 8000 fluorescent lamps with a power of 40 W each, for a peak electric power of 320 kW. If these lamps are operated at full power for 3600 hours per year this would require 1,152 MW-hr/yr, which is about one half of the estimated peak power on the ambient lighting circuits, and about 13% of the annual electrical energy use. The observed average dimming over the third floor was about 63% of full power, which would require 726 MW-hr/yr. If the lamps were operated at the estimated average dimming potential 37% of full power, they would require 426 MW-hr/yr. Improving the average dimming performance from 63% to 37% of full power for 8000 lamps operating 3600 hours per year would save an additional 300 MW-hr/yr. The annual electric energy use on the ambient lighting circuits would then be about 1714 MW-hr/yr, or the average daytime power usage would be about 70% of the maximum. An additional savings of about 300 MW-hr/yr, would give an additional savings at on-peak utility rates of $0.10/kW-hr of $30,000 per year independent of any demand charge savings.

Dimming to 70% of full power on the ambient electric lighting circuits during occupied hours appears to be a readily achievable target, directly measurable on circuits LK8 and LC2 by the energy management system. The estimate of daylighting potential to reduce ambient lighting requirements to 31% of full power on the north side and 44% of full power on the south side in representative zones indicates that dimming to 37% of full power over the entire building is probably achievable with a well-controlled system. Further detailed measurement of the building would be required to confirm this estimate of savings potential.

SUMMARY

- This study has shown that the architectural daylighting features are performing well in providing the ambient lighting needs of this building and can potentially produce significant reductions in electrical energy consumption for ambient lighting. The differentiation of task and ambient lighting systems has been an effective energy-conserving strategy.
- The combination of very low transmittance glazing (17%) and shading by the exterior light shelf causes the south exterior zone under the light shelf to be one of the dimmest areas in the building. Though it potentially has abundant access to daylight, it requires continuous supplemental light in the summer months.
- The central atrium gives a definite dramatic flair to the space and offers a pleasant visual focus to this large-scale, open-plan office structure. At the same time, the

strong downward component of its daylight is less effective at providing light deep into adjacent interior spaces. The atrium edge is the location of a sharp gradient in natural light levels.

- Analysis of detailed measurements on four unoccupied days in May indicates that on the third floor south side the potential for dimming during occupied periods is to 44% of full power. On the third floor north side the potential for dimming during occupied periods is to 30% of full power, according to data from eight days in July.
- Analysis of detailed measurements during a nine-day occupied periods in May indicates that on the third floor south side the actual average power consumption is 75% of full power. On the third floor north side the actual average power consumption during an eight-day occupied period in July is 50% of full power. There is significant potential for dimming that is not being realized.
- Analysis of energy end-use data indicate that the total electrical energy use by the building is about 8660 MW-hr/yr, not including cooling provided by a district chilled-water system. Ambient lighting circuits currently represents 23% of the total building electricity usage.
- The building operation is consistent with dimming of the ambient lighting circuits on the average to 85% of full power. Considerable additional electrical energy savings and peak electrical demand reduction can be generated by modification and adjustment of the existing lighting control system.
- The electric lighting dimming system, with proper control, can effectively manipulate the electric lighting power. Based on the summer-period data reported here, potential energy reductions down to about 40% of full power could be obtained for the ambient lighting system.

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