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Interior Partitioned Layout and Daylighting Energy Performance in Office Buildings

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Abstract

In this age of "Information", many people consider it a deterrent to information flow to provide a hierarchy with private rooms in a modern office layout. There are others, however, who insist that visual and acoustical privacy are more important than any other design factor in achieving higher productivity. The debate may never end, but the partitioned open plan, which is a new form of the vast open plan, has merits of each concept - open and closed layout. Consequently, office design has dramatically shifted to partitioned open planning, with shorter, temporary walls or partitions, originally intended for increasing privacy and diminishing hierarchy, yet still keeping flexibility in spatial organization. The introduction of low-level partitioned spaces in an office layout, however, produces a complicated lighting design problem. Obviously, accurately predicted daylighting performance data are needed not only for daylighting design but for artificial lighting system design. Scale models of 12 sets of unit partitioned spaces are constructed and extensive scale model measurements of both daylight and reflected sunlight have been performed within an artificial sky simulator. The prototype-building interior is modeled with different partition configurations, each of which is modeled using the different envelope geometry and exterior configurations, and then the variations in interior light levels are estimated. The result indicates that partitioned spaces employed in an open plan of modern offices still offer a large potential for daylighting and energy saving as well. Much of the savings may derive from the cumulative effect of reflected sunlight. Optimal design for building envelope geometry and exterior configuration promises additional savings.

Keywords: Partitioned Layout, Daylight, Sunlight, Lighting, Energy

1. INTRODUCTION

As the global economy evolves increasingly into a so-called post industrial knowledge and information economy, office environments take on ever increasing importance, and in the U.S., almost half the total employment is in the form of "office work." Office design over the last 30 years has shifted dramatically to open planning. By tearing down full height walls and replacing them with shorter, temporary partitions, what first appeared as a desirable approach to increasing office communication and diminishing hierarchy, quickly evolved into an approach to save money in both square feet and furnishings. Despite continuous complaints of acoustic and visual disruption, poor air quality and thermal discomfort, nightmarish "wayfinding" and hampered productivity, the vast open plan continues to predominate because of cost advantage, worker privacy, reduced noise levels and flexibility in spatial organization (HartKopf 1995).

Inherent with this type of office, the introduction of low-level partitioned spaces, which are the most significant design elements in interior layout, produces a much more complicated lighting design problem because of the unknown quantity of likely light attenuation and ununiformity in illuminance caused by the vertical obstructions (Briggs 1984). Nevertheless, lighting designers who predict daylighting performance have usually assumed that the space is empty and uncluttered.

In view of this situation, what is needed here is the basic daylighting illuminance data and design guidance to utilize the daylighting availability of the partitioned layouts with generalized standard obstruction losses. The main concern of this paper is the extent of evaluation to include the wide variations resulting from the correlated effect of daylighting, reflected sunlight, partitioned enclosure geometry, orientation and the relationships of these elements.

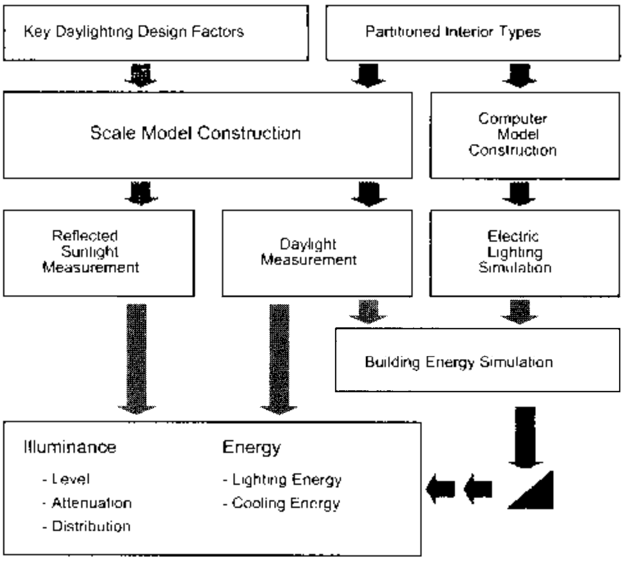


Figure 1. Overall Research Procedure

First, general daylighting concepts and features in office buildings are reviewed from related literature in order to formulate the framework of this study. In addition, previous studies on open plan lighting are reviewed in order to identify the relative importance of the key design parameters. Some of the findings of the previous studies about key design parameters are critically assessed to find what should be further investigated or considered with the target variables and some are just exemplified as a condition or assumption. At this stage, interior layout planning options in modern office buildings are reviewed to identify the role and usefulness of partition systems, which makes a new movement in offices toward a vast open plan. From this viewpoint, the prototypes of interior layout module are reviewed, generalized and categorized as a major variable.

This study is based upon a systematic series of measurements within the sky simulator at Texas A&M University by using an indoor sun simulator with a heliodon. Internal electric lighting controls for the partitioned open plan is also significant in estimating the ultimate performance of a daylighting system. By using ENERCALC developed by Professor Larry O. Degelman and his team at Texas A&M University (Degelman 1990), the amount of energy saving due to the integration of daylighting and electric lighting with proper lighting controls are evaluated. Finally, a design guideline for the partitioned plans is suggested in the view toward both environmental satisfaction and daylighting energy savings. Figure 1 shows the overall procedure of the study.

2. PARTITIONED OPEN PLAN

2.1 Interior Layout Options in Modern Offices

An interior office is typically designed according to three planning options; closed, open and combination. Each option is distinguished by the proportion of partitioned or enclosed to open space that exists in the layout. In the modern office, of course, the choice of planning options will depend upon the functional requirements of the task, equipment and storage. The closed plan is a system of ceiling height partitions that enclose and separate interior space and functions into private or semiprivate compartments. The closed plan is desirable for acoustical and visual privacy but blocks the admission of daylight into interior spaces. The open plan is a configuration of varying-height partitions or panels that are freestanding or integrated into furniture systems. This is, perhaps, the most typical planning option in the perimeter spaces of an office building. The open plan allows greater flexibility with furniture and personnel arrangements and expansion or contraction potential for future rearrangements, and it is often credited with fostering a spirit of team effort and community among the personnel.

2.2 Unit Partitioned Spaces

Partitioned space standards establish volume, area and the degree of enclosure which depends upon the design criteria for an individual, group or organizational function, both existing and future. These standards deal with desired task profiles, furniture, equipment, enclosure requirements and human factors. Six prototypes of unit partitioned space in common office buildings are selected as shown in Table 1.

Table 1. Units Of Partitioned Space Standard

	Profile	Config.	Size (ft²)
1	Typewriter the primary tool for processing paper		30 (6' X 5')
2	Data Retrieval		45 (7.5' X 6')
3	Shared Tasks		60 (10' X 6')
4	Word-processing + Guest		75 (10' X 7.5')
5	Technical/Systems Analyst / Programmer		104 (11.5'X9')
6	Administrative/ Managerial		126 (14'X9')

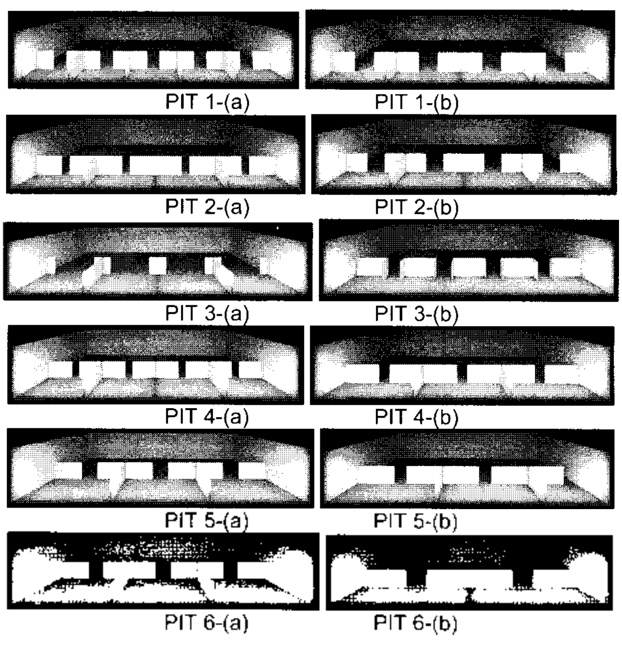


Figure 2. Configurations of the Partitioned Interior Type

In figuring out the occupants' satisfactions and work efficiency, thermal, acoustical, and visual comfort should also be considered. This, in combination with our increasing awareness and concern for the overall environmental quality of office interiors, creates the need for new directions in their design and management. The question of which partition system is the most appropriate over the long term, is dependent on the nature of many aspects. What is clear from the reference to the real design process is that the question is not which partition system is most appropriate to the workplace, but rather which physical, environmental and technological setting and guideline will allow the most effective workspace with the presence of the partition system type. From the viewpoint of lighting, it will become increasingly necessary to generate new concepts and improved data on the extent of the daylight potential and implications on interior space planning and building form.

2.3 Multi-Partitioned Interior Types

In the layout of multi-partitioned open space, a common design is to place the unit workstation modules in rows. This method will permit the use of bank-type partitions as a divider for those activities which require visual privacy, while still obtaining maximum utilization. The unit workstation should face the same direction unless there is a compelling functional reason to do otherwise. The use of this technique provides for straight workflow patterns, facilitates communications, and creates a neat and attractive appearance.

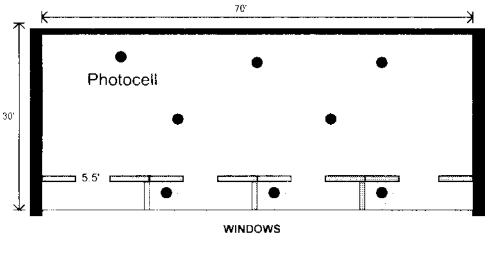


Figure 3. Measurement Locations

The space proportions are more important than any specific dimension. In spaces with unilateral openings such as a window on only one side, the illumination level at the end of the room opposite the window is reduced as the space depth increases. Generally, in multistory buildings a 15-foot perimeter zone can be fully daylit and another 15 feet beyond that can be partially daylit (Lechner 1991 p.320). Based on the unit partitioned spaces described in the previous chapter, various partition arrangements are placed within the identically-sized perimeter space, which is 30 feet deep and 70 feet wide.

As shown in Figure 2, twelve different partition arrangements are tested under various envelope/ground conditions. In more detail, Table 2 describes the variables related to the geometry of each partitioned interior type. The model perimeter consists of 3 different types of spaces, front, mid and rear space (See Figure 3). The daylighting performance is measured and analyzed separately in each space because they might have different daylighting levels because of both the presence of the partitions and the depth of the space.

Table 2. Geometry of Partitioned Interior Type

Partitioned Interior Type (PIT)		Distance from the Window	Partitioned Floor Area : ft^2 (% of total)	Totally-Open Floor Area : ft^2 (% of total)	Partition Vertical Area (ft^2)
1	(a)	6'	420 (20 %)	1680 (80%)	250
	(b)	5'	350 (16.7%)	1750 (83.3%)	240
2	(a)	6'	420 (20%)	1680 (80%)	300
	(b)	7.5'	525 (25%)	1575 (75%)	240
3	(a)	10'	700 (33.3%)	1400 (66.7%)	100
	(b)	8.5'	595 (28.3%)	1505 (71.7%)	250
4	(a)	10'	700 (33.3%)	1400 (66.7%)	300
	(b)	7.5'	525 (25%)	1575 (75%)	300
5	(a)	11.5'	805 (38.3%)	1295 (61.7%)	270
	(b)	9'	630 (30%)	1470 (70%)	287.5
6	(a)	14.5'	1015 (48.3%)	1085 (51.7%)	270
	(b)	9'	630 (30%)	1470 (70%)	280

3. DATA ACQUISITION

3.1 Experimental Design

The specific goal of this experiment is to evaluate the daylighting and reflected sunlighting performance of various interior configurations, and to investigate the architectural potentials of each different interior layout to enhance their daylighting effectiveness, and finally, to provide the architectural approaches and daylighting performance data to be used for the integration process of daylighting, electric lighting and the lighting control system.

Table 3. Key Research Variables and Conditions

Key variables		Assumption and Status
Building Type		Medium-size square office w/ deep interior
Space Configuration	Width and Depth	70' / 30' (fixed)
	Ceiling height	10' and 12'
	Layout type	12 different configurations
	Partition height	5' (fixed)
	Work plane height	2.5' (fixed)
	orientation	South, North, East, and West
Interior and exterior Treatment	Wall	60% reflectance/ diffusive
	Window	0% reflectance/ 100% transmittance (fixed)
	Ceiling	80% reflectance/ diffusive (fixed)
	Partition	50% reflectance/diffusive (fixed)
	Ground	20% and 40% reflectance
Fenestration	Window height	6.5' and 8.5'
	Window width	68' (70' - 1'-1' : fixed)
	Sill height	2.5' (fixed)
Location of the site		San Antonio (fixed)

Table 3 presents the outlines of the experimental design with key assumptions and simulated ranges of the research variables. San Antonio, Texas, is selected for the simulation of both real availability of reflected sunlight and building energy estimation. The height of the partition is fixed as 5 feet, which is common in real situations, and representative reflectances of interior surfaces are applied. In the scale model measurement, the open window has a reflectance of 0% which means the transmittance is 100%. The constants and variables which are set here are to be used for the estimation process of the electric lighting system performance which will be designed and integrated with the availability of daylight.

3.2 Building Envelope Type

The evaluation of a partition system must be in integration with the building envelope system as both the daylight admitting system and a thermal barrier between the interior and outdoors so that the daylighting measurement data can be used in the building energy simulation. In this process, the optimal building envelope can be inferred for maximized energy saving due to its thermal and lighting properties. A total of 10 different building envelope system types which consist of ceiling height, window size, shading and ground reflectance are defined as shown in Table 4. For this experiment, scale models of unit partitioned spaces which can be found in common office buildings and investigated in the process of literature review are constructed so that the partitioned interior complex can be easily established and readily changed.

Table 4. Building Envelope System Types

Type	Ceiling height	Window size	Shading	Ground Ref.
BLDG 1	10'	68' x 6.5'	No	20 %
BLDG 2	10'	68' x 6.5'	No	40 %
BLDG 3	10'	68' x 6.5'	Full	20 %
BLDG 4	10'	68' x 6.5'	Full	40 %
BLDG 5	12'	68' x 8.5'	No	20 %
BLDG 6	12'	68' x 8.5'	No	40 %
BLDG 7	12'	68' x 8.5'	Partial	20 %
BLDG 8	12'	68' x 8.5'	Partial	40 %
BLDG 9	12'	68' x 8.5'	Full	20 %
BLDG 10	12'	68' x 8.5'	Full	40 %

3.3 Daylight Measurements

The characteristics of each partitioned space type in terms of daylighting performance were determined from the measurements under diffuse overcast sky conditions without sun. Under the sky condition generated by the sky simulator, a total 130 different cases were carried out with 10 different building envelope systems, and Figure 4 shows the cases of the measurement. This measurement represents the performance results in terms of the *Daylight Factor (DF)* defined as follows:

$$DF = \frac{\text{Indoor horizontal illuminance from daylight}}{\text{Exterior horizontal illuminance}} \times 100$$

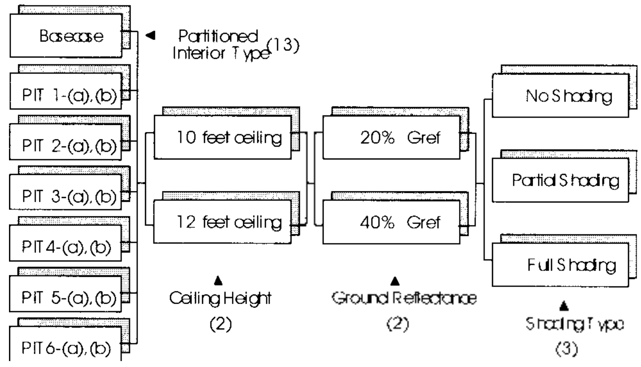


Figure 4. Measurement Cases under a Diffuse Overcast Sky

3.4 Reflected Sunlight Measurements

Ground-reflected or lightshelf-reflected components of direct sunlight on the sunny side, were treated as additional light sources for the multi-partitioned interior modules. However, the completely clear sky condition which is an extreme case, contains a wide range of variation in the amount of direct solar insolation on the basis of the given time, location and orientation. This has caused methodological difficulties in investigating the impact of direct component of natural light.

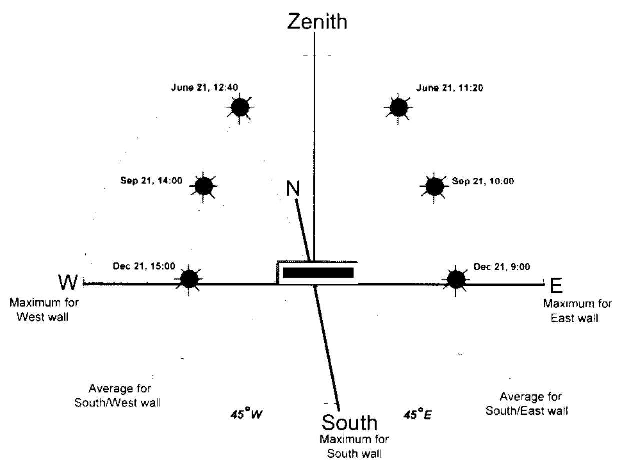


Figure 5. Representative Solar Positions for San Antonio, Texas, USA

For the purpose of generalization of sunlight availability, representative solar azimuth angles and time periods of occupancy were investigated for the whole year round for several building orientations. As representative dates, December 21, June 21 and September 21 were selected and the time when the solar azimuth angle becomes 45°W or 45°E were also selected, because the two cases produce representative average amounts of reflected sunlight simultaneously for each orientation of the window wall, even though the solar altitudes are different. An exception to this would be the north façade; Figure 5 illustrates the concept of the generalization process of reflected sunlighting performance for San Antonio, Texas, which is at latitude 30°N. To get the reflected sunlight only, eliminating direct sun light, two egg-crate types of shading device consisting of horizontal louvers and vertical fins were applied to the building envelopes.

In the same way, the measurement results were represented in terms of the *Reflected Sunlight Illuminance Ratio (RSIR)* defined as follows:

$$RSIR = \frac{RE_{uh}}{SE_{ouh}} \times 100\ (\%)$$

where RE_{iuh} = interior horizontal illuminance from reflected sunlight
SE_{ouh} = external horizontal illuminance from direct sunlight.

4. ANALYSIS AND RESULTS

To investigate the impact of each partitioned space type on daylighting performance, the three different depths of space, that is, rear, mid and front, were separately analyzed as illustrated in Figure 3, because each has a different potential of daylighting. Considering that the effective depth of daylighting is approximately 15' from the window wall, the mid space affected by partitions is the point of concern for attenuation of illuminance. In the rear space, which is 20 feet away from the window wall, whether the required light level can be acquired by daylight only is the main concern.

4.1 Daylighting Performance and Partition System

Figure 6 illustrates the variation in DF for the mid space caused by four representative partitioned space types. Comparing the performance with basecases which have no partitions, the range of reduction in the Daylight Factor in mid space was magnified from 2% to 3% and in the extreme case, a 5% drop was caused by the presence of the multi-partitions. In the front space, the Daylight Factor values become higher by 1% than the basecase due to reflectance from the partition surface. In the rear space, the reduction in DF averaged 0.5%, which is quite insignificant.

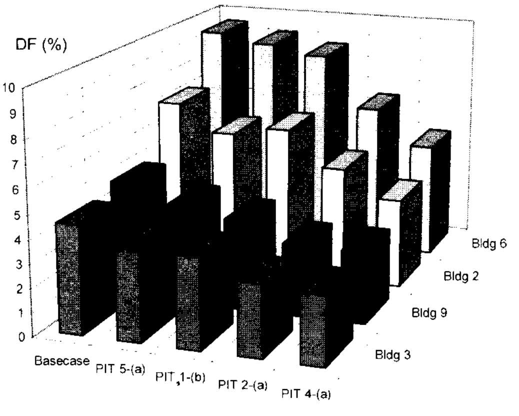


Figure 6. Variation in the DF for a mid space with 4 PITs

On the average, the Daylight Factor value is changed from 7% to 25%, depending on the building envelope features, which gives some idea about the key factor in daylighting performance in the office module. From the viewpoint of maximized daylighting benefit, the amount of reduction in the mid space can be minimized by using optimal envelopes.

4.2 Reflected Sunlighting Performance

Based on the measurement results of daylighting, PIT 2-(a) was selected as the representative partitioned interior type and examined to investigate the impact of the presence of the partitions on a reflected sunlit interior. Like the unpartitioned open plan, interior illumination levels by reflected sunlight were sufficient to obtain the required light level, 50 fc (550 lux) in spite of the presence of the partitioned space type 2-(a). Because of the partition, reflection from the ground does not produce noticeable improvement in lighting for the rear spaces.

As shown in Table 5, the reduction in the penetration of reflected sunlight was influenced by lower sun altitude angles during winter. Similar to the diffuse overcast sky situation, the front space had a higher light level due to reflection from the partitions' surfaces, making an extremely uneven distribution of light. In the winter and fall months, more than 10 percent reduction was detected in both the front and mid spaces by placing the partitions. The impact of partitions was also seen with higher reflectance of the ground.

Table 5. RSIR in partitioned open plan PIT 2-(a)

RSIR (%)	Ground Ref.	20%			40%		
	Location	Front	Mid	Rear	Front	Mid	Rear
SOUTH	Dec	12	3.55	3.87	17.3	4.46	3.87
	Sep	3.91	1.9	1.75	6.1	2.25	1.8
	Jun	2.15	1.96	1.47	3.16	1.96	1.47
EAST	Dec	17.9	6.12	4.2	20.3	6.38	4.49
	Sep	4.72	2.63	1.83	5.81	2.63	1.83
	Jun	3.18	2.26	1.49	3.38	2.32	1.77
WEST	Dec	13.8	5.17	3.47	14.4	5.17	3.47
	Sep	4.84	2.59	1.55	5.31	2.59	2.02
	Jun	3.51	2.21	1.35	3.8	2.21	1.35

4.3 Accumulated Performance

In the final process of estimating the practical usefulness of natural light, reflected sunlight and daylight should be considered simultaneously, which calculates the accumulated benefit of natural lighting. Figure 7 shows the interior illuminance derived from reflected sun and diffuse overcast sky light in a totally open plan located in San Antonio, Texas. Like the totally-opened plan, the overall interior illumination from reflected sunlight and diffuse overcast sky light are sufficient in obtaining the required light level, 50 fc in spite of the presence of the partitioned space type 2-(a).

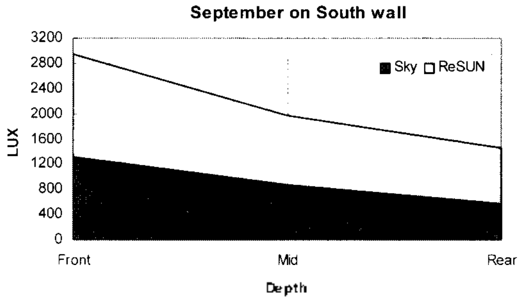


Figure 7. Accumulated Performance (South, Open plan)

Figure 8 shows the variation of illuminance in PIT 2 -(a) with different depths of the space and time periods of the year. The most significant impact of partitions occurred in the mid space just behind the partitions. Also, the biggest reduction in light level was detected during winter when the solar altitude is relatively low. As expected, the partition plays a big role in causing uneven distribution of illumination in the interior. Briefly, the partitions caused a noticeable reduction in the range of 5 through 20 percent the year round.

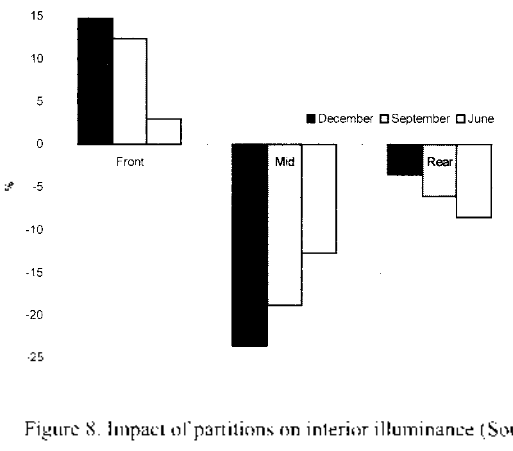


Figure 8. Impact of partitions on interior illuminance (South)

5. DAYLIGHTING ENERGY SAVINGS IN A PARTITIONED OPEN PLAN

5.1 Overview

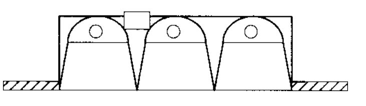
The quantity of light available for a space can be translated in terms of the amount of energy savings through a process of building energy simulation. A number of computer programs provide the capability to calculate the level of daylight, which can decrease the need of electric lighting. To get significant energy savings in general illumination, the electric lighting system must be incorporated with a daylight - activated dimmer control. That is, the design of dimming controls is a major factor in the determination of the ultimate energy saving amount.

A conventional luminaire system is used for the partitioned area in an open-plan office. The light attenuation by the vertical partitions and the impact of the partitioned configuration on the overall performance of the electric lighting system are predicted by a computer program, Lumen Micro 6.03. Alternative layouts of the electric light source are suggested so that the desired light level can be achieved. The resulting amount of energy savings due to the daylight dimmer is calculated by a building energy simulation software, ENERCALC.

5.2 Conventional Electric Lighting System Design

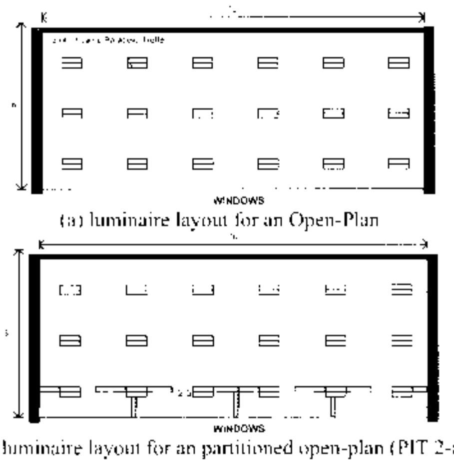
The most important factor in designing an electric lighting system is the selection of the light source and its layout. In the former literature, general considerations for the design of an artificial lighting in both open and partitioned open plans have been reviewed. In brief, the design of an electric lighting system for partitioned open-plan requires additional considerations to compensate for the likely loss of illuminance caused by the vertical obstructions. The amount of light attenuated and the behavior of light in the space are likely to depend on the configuration of each interior space. To estimate the impact of the partition system on the general illumination environment, representative partitioned interior types which have been used for extensive experiment in this study are selected, and then a conventional approach to designing an electric lighting layout is applied for the partitioned space. The impact of the presence of the partition system is expressed in terms of light reduction by comparing to a totally open plan.

Table 6. Luminaire Description

Description	2' x 4' 3 Lamp Parabolic Troffer
Configuration	
Lamp	Fluorescent (F40cw)
Lamp Watts	40.0 W
Total Watts	120.0 W

Presently, a high percentage of office lighting utilizes fluorescent rapid-start lamps and low efficacy magnetic ballasts (IESNA 1993, p. 524). A typical fluorescent lighting system consists of a three-tube fixture with cool white 40W bulbs (F40cw). Parabolic fixtures, the selected light source for general illuminance in this study, are linear parabolic troughs with lamps positioned at the focus. These fixtures came into widespread use during the 1970s for offices in the United States. Most parabolic fixtures are louvered luminairies with parabolically shaped white or metallic troffers. The louvers are open grids of opaque, semi-translucent or reflective shielding and diffusing media that collimate down-coming light rays. These fixtures reduce glare commonly associated with poorly designed or positioned lensed fixtures, and permit cooler luminaire operation (Mills and Piette 1993, p.81). This recessed lighting equipment is the most common application which is used for general lighting in offices, especially where computer terminals are present. The specifications of the luminaire are described in Table 6.

To get an average 50 fc (550 lux) of ambient illumination in a totally open plan, a luminaire layout is proposed based on the conventional design method of electric lighting and is illustrated in Figure 9. Eighteen lighting fixtures are asymmetrically arranged forming a 3 by 6 rectangular matrix on the 12-foot high ceiling without suspension. In this 3x6 layout of the luminaries, on the average, a total of 2,196W is required to get an average illuminance of 50 fc and to generate a power density of 1.05W/ft^2 for electric lighting only. The layout of the luminaries is also applied to the selected partitioned open-plans so that the impact of the presence of partitions on the electric lighting performance can be estimated in terms of light reduction. An example layout is illustrated in Figure 9.



(a) luminaire layout for an Open-Plan

(b) luminaire layout for an partitioned open-plan (PIT 2-a)

Figure 9. Luminaire Layouts

The performance of the electric lighting system design for the totally open-plan is calculated by Lumen-Micro 6.03 and the contour of light distribution shows fairly even distribution of illuminance through the interior space, generated by electric lighting only. The results show that the average, maximum and minimum levels are 54.5, 67.1 and 31.5 fc, respectively. In spite of even distribution of the luminaries, some degrees of fluctuation with a standard deviation of 6.67 in the illuminance level is unavoidable. The impact of the partition arrangement on the illuminance level and distribution under a electric lighting environment is also examined, and the illuminance behavior in the partitioned space are illustrated in Figure 9.

On the average, a reduction of 4 fc occurred through the whole space but more attenuation is detected around the partition, showing an about 15 percent drop, compared to the basecase open plan. Previous studies mentioned in the literature review have revealed almost the same amount of reduction in the case of multi-partitions arrangement under an electric ambient lighting environment (IESNA 1993, p. 531). Various approaches can be proposed to compensate for the light attenuation. Rearrangement or increase of the luminaries can be easily attempted, which intensifies the lighting for the partitioned area.

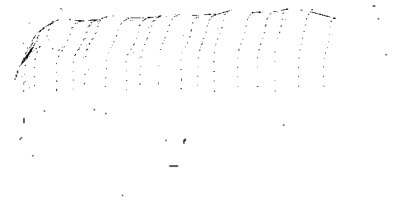
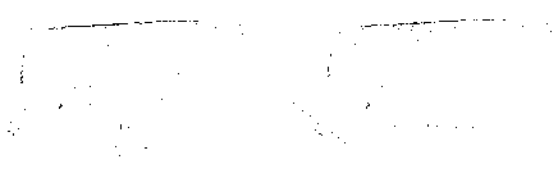


Figure 10. Electric Light Distribution in a Partitioned Open Space (PIT 2-a)

5.3 Electric Lighting System Design for Partitioned Plan

It is suggested that the attenuation in light level and the deterioration in qualitative lighting by the shadow effect may be mediated by both increasing the number of luminairies and more dense arrangement of the luminaries on the ceiling in a partitioned open-plan. The feasibility test for the implementation is performed by the Lumen-Micro, which is an experimental approach to overcome the impact of partitions with 21 luminaries in a 3 by 7 array.



(a) PIT 2-(a) (b) PIT 5-(a)

Figure 11. Electric Light Distribution in Partitioned Spaces

As shown in Figure 11, when a 3 by 7 array of the luminaries is designed in PIT 2-a, the average, minimum and maximum illuminance become 60, 29 and 75 fc, respectively, consuming an increased amount of electricity by 15%. The layout produces the average illuminance of 60 fc for the whole space, but 50 fc of illuminance is typical in partitioned areas because of the impact of partitions. It can be said that approximately 15 % increased power density per unit foot area would be required to acquire an increased level of 10 fc in the spaces. Consequently, the experimental layout using 21 luminairies in a 3 x 7 rectangular form, which produces an average of 60 fc, is to be used in the process of the whole building energy simulation.

5.4 Building Energy Simulation

Perimeter spaces of an office building typically benefit from daylight. It is assumed that the specimmen for simulation is a one-story building without any outdoor obstructions. Figure 12 shows the geometry of the one story office space with dimensions of 70'x30'x12'. Four representative types of PIT are considered and the luminaire layout provides an average illumination of 60 fc in the case of the presence of partitions as examined before. On the process of energy simulation by the ENER-Win, a continuous dimming system located at the back of each daylit zone reflects the variation of daylight level in the partitioned spaces.

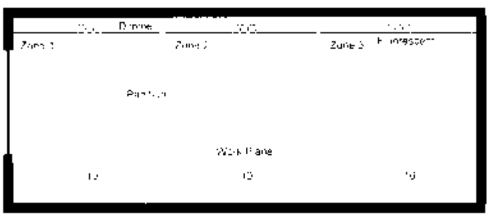


Figure 12. Model Building Section and Luminarie Layout with Controls

A total of 11 cases were selected as representative configurations and examined to determine the impact of both daylight and partitioned space types on the building energy performance. Table 7 describes the properties of the building element and equipment for the building energy simulation. Comparing with the extreme case which has no daylight, on the average, daylight plays a big role in reducing 25 % of the annual cooling load and 70 % of the lighting load for general illumination.

Table 7. Description of Building Properties

Building Envelop.	Area (ft²)	Description	U-value	Solar Abs.
South Wall	840	Precast Concrete	0.079	0.57
East Wall	360	Precast Concrete	0.079	0.57
North Wall	840	Precast Concrete	0.079	0.57
West Wall	360	Precast Concrete	0.079	0.57
Roof	2100	Built-up Roof w/ Mtl. Deck	0.058	0.75
Floor	2100	R-11 Floor Effec-tive. R-19	0.1	1.0
Window on South	500	Double Plate Heat Abs	0.55	0.57 (SHGF)

Light Type	Lighting (Watt/ft²)	Equipment (Watt/ft²)	Target (fc)	Daylit Depth (ft)
Fluorescent	2.5	0.5	60	30

Infiltration Rate (ACH)	Ventilation (CFM/person)	A/C	Heating
0.7	7.4	V.A.V	Gas

Figure 13 illustrates the amount of energy required for general illumination in each partitioned space type. The different partition configurations experience about 4 % reduction in daylighting saving, which depends on the area of partitioned space in the open-plan. However, the extra lighting demand for the partitioned space can be mediated by using proper building envelopes and ground situation. It should be stressed that the amount of daylight savings is for a perimeter space only, and thus, the effects for an entire building must adjust this in relation to how much space is perimeter and how much is interior space.

In spite of the presence of the various types of partitions, the partitioned open plan has almost energy same potential to utilize daylight for not only general illumination but also for building energy savings. Unless daylight availability of a building is extremely higher than usual, however, other design factors, such as windows or the outdoor environment must be well incorporated with the interior condition in order to compensate for the blocking effect of the vertical partitions.

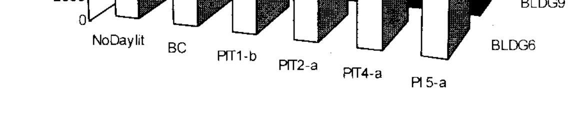


Figure 13. Annual Energy Consumption for Lighting

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1) With the presence of the partitions, an approximately 5 to 20 percent reduction is experienced in daylighting performance when both daylight and reflected sunlight are simultaneously considered the year round. The reduction should be translated into the practical impact on the interior illuminance based on the local daylight availability analysis. The measured daylighting data should be incorporated in

the design process of the electric lighting system including lighting control devices for maximum energy saving and visual comfort. An optimized electrical lighting system can provide the required light level and mediate the uneven distribution of natural light interrupted by the vertical objects.

2) When reflected sunlight is introduced into a space, its impact on general illumination is what is of interest. Reflected sunlight may help the general illumination in almost the same level of significance as daylight from diffuse overcast sky. It is also summarized that the contribution of reflected sunlight to general illumination through the year round may be even and uniform regardless of the season. Consequently, the introduction of reflected sunlight should be regarded as one of the most successful means to enhance the visual environment in a quantitative and qualitative way.

3) Building envelope features intended as light admitting systems should be designed to compensate for the light attenuation caused by the presence of partitions. Besides other criteria like aesthetics in the design of the facade, the fact that a 7% to 25% variation of daylight factor can occur with different envelopes should also be remembered.

4) Results from the evaluation of electric lighting performance show that, on the average, a reduction of 20% was experienced in the partitioned area, compared to the non-partitioned area. In the daytime, the attenuation can be easily compensated by the introduction of daylight. For the period when daylight is not available, however, the electric power density should be increased by 20% to provide more light, resulting in an increased number of luminairies. In the building interior model for the study, an extra power density of about $0.25W/ft^2$ is demanded for the partitioned area.

5) Finally, the carefully designed features of a multistory office building can successfully permit most of the space to be daylighted and electric lights to be dimmed by a cost effective operated system. The results from the building energy simulation with measured daylight illumination levels and the performance of the lighting control system indicate that daylighting can save over 70 percent of the required energy for general illumination in the perimeter zones through the year. A 25 % of electric energy for cooling may be saved by dimming and turning off the luminairies in the perimeter zones.

6.2 Recommendation

With all of these data available, how can it be effectively applied to the real design process of an office lighting system? With general lighting design methods, the drawback of working with a partitioned environment is the extra time required to evaluate the location, orientation and reflectance of all the partition systems in the space. There is no specific approach that always provides the best design, and there is no formula that will always give the best answer. Proper analysis and a design process that includes both general and specific considerations on illuminance for partitioned open-plans may be the best formula for success. These considerations generally translate the findings of the study into several design recommendations as follows:

1) Analysis of the climatic characteristics of the site and its daylight or sunlight availability must be established to predict the localized availability of natural light with the building geometry. This analysis also includes other design factors, such as the orientation of the building, opening and shading, formulating the design criteria for the site.

2) As a basis, the exact information for the interior condition in the office layout must be acquired. If partitions must be planned for the space, it is clear that the actual illuminance will be lower than in the totally-open space. To accurately predict the ultimate illuminance or design an optimal electric lighting system, the location of partitions must be included in the lighting calculations for the space.

3) Compared to the totally open plan with no partitions, the quantitative performance of daylighting varies from a high of over 25 % to a low of 5 % for different types of partitioned spaces. Regardless of the presence of partitions, however, results show that the contribution of daylight on the general illumination of the space and on energy conservation are still practically promising. An approach to moderate the impact of the partitions on daylighting performance is to use an ideal building envelope and ground condition. Under the condition that the daylight availability is relatively lower with small windows, the light attenuation cased by the partitions may create difficulty in the visual environment, which cannot be solved by other architectural considerations. Hence, it is recommended that as much availability of daylight as possible is provided in designing the building envelope and ground condition.

4) Reflected sunlight penetrates into the interior and enhances the daylighting efficiency in both quantitative and qualitative ways. To get a more desirable reflected component of direct sunlight, diffusive and moderate reflective materials are recommended for the ground surface rather than high reflectives. In a multi-story building, the upper surface of a overhang for downstairs or a lightshelf which is intentionally designed for reflection of natural light can play that role. However, the glare problem from the still luminous surface must be kept away from the field of the occupants' view.

5) To provide the desired level of light for a partitioned area in a vast open plan, it is simply recommended that the amount of electric light is increased by 20 %. Not by using higher intense luminairies, however, it should increase the total number of lighting fixtures and arrange evenly the luminairies in the form of a rectangular and symmetrical layout. This will compensate for the attenuation of general illumination and the shadow effect due to the partitions, proving both quantity and quality lighting.

6) The integration of general illumination with task lighting can be effectively used, as is reflected in the mix of lighting system to meet various criteria as follows: a lot of multi-partitioned spaces are planned within an open plan so that daylight is not expected to provide enough light and then, the need of electric lighting exists through all of the daytime; different types of partitioned spaces house different tasks and activities, which may demand different light levels. For example, daylight or electric lighting plays a

limited role for general illumination and task lighting provides the additional light for the tasks with localized control of lighting. The advantage of this approach is that the highest illuminance is provided at the task and it can be more responsive to the daylight level available for both quality lighting and energy savings since the general illumination does not provide the major portion of the task illuminance, although the occupants' behavior on the control of the personalized lighting devices is another significant issue.

7) Improvements in the energy efficiency of lighting should be made with due consideration of their impact on human visual performance and health because the ultimate goal in lighting design is to provide good visual performance itself. The use of daylight can improve the visual performance without compromising efficiency of an electric lighting system. In the daytime, it is revealed that daylight can provide most of the required light for general illumination, in spite of the presence of the partitions. However, this quantitative approach may simply give a rise to the glare problem by the striking contrast between the window itself and the back surface of the partitions. An accent lighting can be effectively used to reduce the contrast ratio in the far field between the back of the partitions and the luminous window. It is important to recommend that some accent lighting on the back surfaces of the partition with some inserts such as drawings or pictures should be considered for the purpose of both visual performance and aesthetics.

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