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Evaluating Office Lighting Environments: Second Level Analysis

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National Institute of Standards and Technology
(Formerly National Bureau of Standards)
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April 1989

Prepared for:
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New York, New York

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New York State Energy Research and Development Authority
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U.S. DEPARTMENT OF COMMERCE
Robert Mosbacher, Secretary
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
Raymond G. Kammer, Acting Director

Abstract

Data from a post-occupancy evaluation (POE) of 912 work stations with lighting power density (LPD), photometric, and occupant response measures were examined in a detailed, second-level analysis. Seven types of lighting systems were identified with different combinations of direct and indirect ambient lighting, and task lighting and daylight. The mean illuminances, with body shadow, at the primary task location were within the IES target values for office tasks with a range of mean illuminances from 32 to 75 fc, depending on the lighting system. The median LPD was about 2.36 W/ft^2, with about one-third the work stations having LPD's at or below 2.0 W/ft^2. Although a majority of the occupants (69%) were satisfied about their lighting, the highest percentage of those expressing dissatisfaction (37%) with lighting had an indirect fluorescent furniture mounted (IFFM) system. The negative reaction of so many people to the IFFM system suggests that the combination of task lighting with an indirect ambient lighting system had an important influence on lighting satisfaction, even though task illuminances tended to be higher with the IFFM system. Concepts of lighting quality, visual health, and control were explored, as well as average luminance to explain the negative reactions to the combination of indirect lighting with furniture mounted lighting.

Keywords: Contrast, daylighting, environmental assessment, illuminance, lighting, lighting power density (LPD), luminance, post-occupancy evaluation, photometric measurement, task lighting, VDT's, work station.

Foreword

This report is a follow-on to the post-occupancy evaluation project sponsored originally by the U.S. Department of Energy and the New York State Energy Research and Development Authority under a contract to the American Institute of Architects Foundation. The present project was initiated and managed by the Lighting Research Institute. Co-funding for the present project came to Mr. Fisher, Mr. Gillette and Dr. Marans from the Lighting Research Institute, Electrical Power Research Institute, and New York State Energy Research and Development Authority, while funding for Dr. Collins was provided by the U.S. Department of Energy under contract No. 88CE21027.000. Although the authors are listed in alphabetical order, each contributed equally to the present report.

Acknowledgements

Assistance was received from several sources. In particular, the authors wish to thank Dr. Pieter von Herrmann, Mr. Richard Vincent, and the members of the review committee for their contributions and advice. Mr. Xiaoying Yan, a doctoral student at the University of Michigan, provided invaluable assistance to Dr. Marans in the data analysis and figure preparation for section 5.

Disclaimer

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Executive Summary

- This report is a second level analysis of data obtained in a Post Occupancy Evaluation (POE) of 13 office buildings performed between 1984 and 1986 (See Marans, 1987; Gillette and Brown, 1987).

- Some of the principal conclusions to be drawn from this evaluation are noted below, together with references to the parts of the report which document them. Some of these conclusions are different from earlier published reports on the POE study.

- The present analysis demonstrates strongly that overall conclusions relating lighting power densities to levels of satisfaction are NOT meaningful, but that analyzing the data in terms of specifc lighting systems provides useful information about lighting satisfaction.

- The average lighting power density (LPD) for the work station areas of the thirteen buildings was 2.48 W/ft^2 while the mode was 2.0 W/ft^2. (See section 3.1 and figure 1.)

- The direct recessed fluorescent luminaires appeared to be a highly efficient lighting system. The data indicated that they produced acceptable illuminances and luminances at modest power densities. (See section 3.1.1 and figure 4.)

- The majority of occupants (about 70%) were satisfied with their lighting and believed that it was of high quality. Dissatisfaction with the lighting could be related to specific lighting system type, however. (See sections 4.2.3, 5.1, and figure 19.)

- The generally held belief that individual task lighting is energy conserving and advantageous was not borne out in this analysis. Work stations with furniture integrated task lighting and indirect ambient lighting (and darker surroundings) not only had higher lighting power densities but also produced significant dissatisfaction with the lighting. (See sections 3.1.2, 4.3.1, and figure 8.)

- Occupants clearly preferred surroundings perceived as bright and rated them as having high lighting quality. (See section 5.1, figure 26, and table 14).

- Ratings of work station lighting satisfaction were higher for those work stations that were rated as having less glare from task lights, ceiling lights, and work surfaces. Reflected glare from work surfaces was rated as being the most bothersome of the three glare measures for all types of lighting systems. (See section 5.2 and table 16.)

- Lighting quality was rated as higher when the ratings of the ability to control the lighting were higher. (See section 5.3 and figure 37.)

- Within the very narrow range of parameters of the present evaluation:

    1) When people liked the basic lighting system (such as the general area lighting provided by the direct systems), then overall lighting satisfaction was higher and tended to increase with more illuminance on the task. (See section 4.1.1 and figures 17 and 18.)

    2) When people disliked a lighting system, such as the furniture integrated task lighting system used for many work stations in the present POE, then satisfaction tended to decrease with more illuminance. (See section 4.1.1 and figures 17 and 18.)

    3) Daylight raised the average luminance in the space and thus made an unpopular lighting system more palatable. (See section 4.1.2.3 and figures 18 and 20.)

- The fact that ratings of satisfaction, brightness, and lighting quality were consistently lower for the furniture integrated task lighting system with indirect ambient lighting suggests that the pattern of luminances in a space may be more important to occupant satisfaction and perception of brightness than the amount of light on the primary task, if adequate levels of task illuminance are also provided. (See section 4.3.1 and table 12.)

- Work stations that were larger were rated as being more spacious and more satisfactory in general. (See section 5.5.2 and figure 40.)

- Increased privacy was the most desired change that occupants wished to have made to their space. Improved lighting, however, was a close second for spaces with furniture integrated lighting (See section 5.5.1 and table 17.)

1. Introduction

In a post occupancy evaluation (POE) sponsored by DOE and NYSERDA during 1984-1986, data were collected on lighting power densities, photometric measurements, and user attitudes toward work stations in 13 office buildings which contained lighting systems typical of current lighting practice.[1] The present report describes a second level, in-depth evaluation of these measures.

The purpose of the detailed evaluation was to examine the relationships between individual lighting system type, photometric data, lighting power density data, and occupant response data, as well as to resolve discrepancies in earlier reported data (Marans, 1987; Gillette and Brown, 1987). The present report is the fifth in a series of published reports on the data collection and analysis with earlier reports by Gillette and Brown (1986) Marans and Brown (1987), Gillette and Brown (1987), and Gillette (1988). Detailed documentation of the collection procedures can be found in these companion reports; what follows is a fresh analysis of the data.

1.1 Energy Recommendations

The project began in 1984 as an attempt to document existing lighting power density (LPD) levels in buildings in support of the recommendations for Unit Power Density (UPD) levels being developed concurrently by committees within the Illuminating Engineering Society of North America (IES) and American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). The thrust in recent years to conserve energy has led to suggestions that lighting power (and consequently lighting levels) be reduced, sometimes quite drastically. Conflicts about the impact of these reductions arose, in part, because of lack of information about the range of power densities to be found in office buildings, and their impact on both photometric levels and user responses. The present analysis is an attempt to provide some baseline information on LPD's, photometric levels, and user response to lighting variables.

Major reductions from IES recommendations made before the energy crisis have been suggested in the unit power density (UPD) figures contained in different energy standards. As an example, the base UPD suggested by the draft ASHRAE/IES Standard 90.1R (1986) is 18 percent lower for reading and typing tasks, and 53 percent lower for drafting tasks than the earlier IES Lighting Energy Management Document LEM1 (1983). The problem is that these figures are based either on computer simulations which did not evaluate the

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[1] The data collection was sponsored by the Department of Energy, and the New York State Energy Research and Development Authority, with additional support from the Lighting Research Institute, and the National Electrical Manufacturers Association. Oak Ridge National Laboratory was the project monitor, and the work was performed by the American Institute of Architects Foundation and the Institute for Social Research, University of Michigan.

resulting visual environment, or on committee consensus which relied on judgments from practicing professionals. Neither approach relies on knowledge of the impact of LPD's or photometric conditions on occupant attitudes or ability to do visual work.

Over the years, the IES recommendations for the amount of light needed to perform given tasks such as reading in offices have varied from a low of 2 fc (20 lux) in 1910 to a high of 70 fc (750 lux) in 1959, depending on the state of the art in research and lamp technology. Current recommendations (IESNA, 1987) set forth a range of levels which depend on the type of task and weighting factors determined by the occupant's age, room/task surface reflectances, and desired task speed and accuracy (where appropriate). Consequently, recommended levels for office tasks (including VDT tasks) now vary from 4.7 fc to 186 fc (50 to 2000 lux) depending on the type of visual work, desired level of speed and accuracy, occupant age, and either room surface reflectance or task background reflectance.

1.2 Human Requirements for Lighting

Recent research by Rea (1986) indicated that task contrast is an important determinant of relative visual performance, particularly for low contrast tasks. Relative visual performance changes very little for task contrasts between 0.5 and 1.0, but does change quite a bit at lower levels (below a contrast of about 0.3). In addition, at low levels of contrast, such as 0.15, increasing task luminance has a much greater impact on visual performance than it does at higher levels of contrast. Rea concluded that:

> "...visual performance will be relatively high and stable for medium to high contrast tasks, but veiling reflections and reduced illumination levels can be very important for low contrast tasks." (Rea, 1986, p. 49).

Rea's research was conducted in a laboratory and so does not reflect occupant preference or actual conditions (including luminance levels, contrasts, and power density data) in real buildings. Documenting task contrasts and luminance levels under actual office conditions, or the occupant response to these variables, has rarely been done. For these pieces of the puzzle, it is necessary to turn to post-occupancy evaluations.

2. Approach

Data for power density, photometric conditions, and occupant responses from a total of 912 work stations in 13 office buildings for which complete power data were collected were analyzed in the present effort.[2] The data collection procedures were fully described by Gillette and Brown (1986).

As noted earlier, the aim of the project was to collect data on working conditions in existing office buildings to determine the relationship between physical conditions and perceived lighting satisfaction and quality. Data included physical measurements (including photographs) of photometric, acoustic, and thermal conditions; measurements, tabulations, and calculations of lighting power densities and physical characteristics of the office space; and measurements of occupant response using a questionnaire. Although ratings of environmental conditions were obtained from experts for a subset of three buildings, the present report deals only with the occupant response, power density, and photometric data.

2.1 Data Collection Procedures

For each of the 912 work stations, the following lighting measurements were made as documented in Gillette and Brown (1986):

illuminance at both the primary and secondary work surface;

luminance at ten locations within the work station (white paper task, task surround, ceiling between luminaires, brightest light source in field of view, brightest ceiling area in field of view, darkest area in field of view, wall area straight ahead, wall area 90° to the right and 90° to the left, and brightest area of the sky); and

luminance contrast and contrast rendition factors for a printed task for four positions at the primary work surface (three fixed positions, 45°, 90°, 135°, each at a 25° viewing angle, with the fourth position determined by the location of lowest contrast measurable on the working area of the desk).

At the same time, questionnaire data were collected from about 150 respondents in each of the first three buildings and from approximately 50 people in each of the remaining ten buildings as documented in Marans and Brown (1987). The questionnaire assessed occupant responses to a number of environmental features, including structured responses to the following:

rating of lighting for each task;
rating of the overall amount of lighting available;
satisfaction with the lighting;
rating of the office arrangement and appearance;

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[2] The full data set contains occupant response data for a total of 1217 work stations. The 912 work stations are a subset in which complete photometric and lighting power density data were also recorded.

- time spent in their office and building;
- normal type of work and time spent at individual tasks;
- problems with VDT's;
- bothersomeness of office characteristics such as reflected glare, noise, temperature, etc;
- frequency of health-related symptoms and absences;
- attitude toward the work space;
- four most desired improvements to the work space;
- rated characteristics of the office;
- attitudes toward the window and view out;
- ability to control environmental characteristics such as temperature, lighting, ventilation, and daylight;
- overall satisfaction with the space;
- attitudes toward the actual work and work requirements; and
- general demographic characteristics such as age, sex, job title, and eye condition.

Lighting power density (LPD) data were calculated after determining the actual lamp and ballast characteristics for all the luminaires in a work area, assigning fixture wattages, and calculating the floor areas associated with these wattages. Once the lamp, ballast, and fixture characteristics were determined for each luminaire, a series of tables (Gillette, 1988) providing wattages for both source and ballast for each unique fixture category were generated using ANSI correction factors from ANSI C82.2. Lighting power density for each work station was then computed from the wattage data as follows:

$$LPD = \frac{\text{Wattage for Zone Ambient Lighting}}{\text{Zone Floor Area}} + \frac{\text{Wattage for Task Lighting}}{\text{Work Station Floor Area}}$$

where,

LPD = Total lighting power density associated with the specified work station,

Zone = Space enclosed by walls, such as a fully enclosed office or bay containing work stations,

Work Station = Personal space area occupied by the occupant (see Gillette and Brown, 1986).

2.2 Description of the Lighting System Types

For the present analysis, the impact of different lighting systems (defined primarily by mounting type) on LPD, photometric, and occupant response variables was examined. Seven unique lighting systems - three direct, three indirect, and one direct/indirect - were defined, with additional sub-groupings based on the presence and type of task lighting and daylight.

The three direct systems included 313 work stations with direct recessed fluorescent systems with parabolic louvers (DRFLV), 162 work stations with direct recessed fluorescent systems with prismatic lenses (DRFLN), and 45 work stations with direct surface mounted fluorescent systems with egg crate louvers (DFSM). The indirect systems included 166 work stations with indirect fluorescent furniture mounted systems (IFFM), 73 work stations with indirect fluorescent pendant mounted (IFP), and 37 work stations with indirect metal halide pendant mounted systems (HIDP). The direct/indirect system included 78 work stations with pendant mounted direct/indirect fluorescent systems (DIFP).

As shown in table 1 the data for the 912 work stations could also be subdivided by the presence of task lighting or daylighting. In these subdivisions, 355 work stations had no task lighting, 376 had furniture integrated task lighting, 121 had desk movable lighting, and 22 had some other type of task lighting, such as floor mounted units. In addition, 334 work stations had some daylight, while 518 had very little daylight. The presence of daylight was defined by the adjacency of a work station to a window. Virtually all the work stations which were less than 10 ft (straight line distance) from a window were considered to be "adjacent". The photographs were examined to ensure that windows in all work stations considered to be "adjacent" were not blocked by partitions or furniture.[3]

The primary light source for the seven ambient systems was warm white or cool white fluorescent, although the HIDP system used metal halide sources. Virtually all the furniture mounted sources were cool white, but a variety of fluorescent and incandescent sources were used in the desk movable units. The 38 work stations with wall wash lighting or a composite of lighting types were put in a separate category ("Other Configurations").

The various subdivisions allow one to select portions of the database for detailed analysis. One such subdivision is those work stations in which neither task lighting nor daylighting were part of the lighting system. This particular subset provides the "purest" way of evaluating the effects of the ambient lighting system alone, free from the effects of task lighting or daylighting.

Table 2 describes the general configuration of offices and lighting systems in the thirteen buildings. Several lighting systems were installed in more than one building: the DRFLV system was present in four buildings, the DRFLN system in four, the DFSM system in one, the IFFM in two, the DIF-P system in two, the IFP in one, and the HIDP in one. Six buildings had primarily open plan or open pool (open plan but with no partitions) offices, three had primarily enclosed offices, and four had all three types of offices. This converts to a total of 910 work stations for which the type of work station was known, with 627 (68.9%) being open plan with partitions, 42 (4.6%) open pool, and 241 (26.5%) enclosed offices.

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[3] Measures of daylight availability, separate from illuminance supplied by electric lighting, were not taken as they were not considered to be within the original scope of the project.

Table 1. Breakdown by Type of Lighting System.

Total		TYPE OF AMBIENT LIGHTING SYSTEM		TYPE OF TASK LIGHTING	DAYLIGHT PRESENT	LITTLE DAYLIGHT
912 work stations	313	Direct recessed fluorescent w/parabolic louvers (DRFLV)	108	No Task Units	17	91*
			163	Furniture Integrated Units	39	124
			35	Desk Movable Units	1	34
			7	Other	-	-
	162	Direct recessed fluorescent w/prismatic lenses (DRFLN)	121	No Task Units	97	24*
			13	Furniture Integrated Units	0	13
			22	Desk Movable Units	17	5
			6	Other	-	-
	45	Direct fluorescent surface mounted w/egg crate (DFSM)	38	No Task Units	33	5*
			1	Furniture Integrated Units	1	0
			5	Desk Movable Units	4	1
			1	Other	-	-
	166	Indirect fluorescent furniture integrated (IFFM)	2	No Task Units	1	1
			146	Furniture Integrated Units	53	93*
			17	Desk Movable Units	5	12
			1	Other	-	-
	73	Indirect fluorescent pendant mounted (INDFP)	30	No Task Units	26	4*
			14	Furniture Integrated Units	9	5
			26	Desk Movable Units	25	1
			3	Other	1	2
	78	Direct/indirect fluorescent pendant mounted (DIFP)	34	No Task Units	6	28*
			30	Furniture Integrated Units	21	9
			11	Desk Movable Units	8	3
			3	Other	-	-
	37	Indirect metal halide HID pendant mounted (HIDP)	22	No Task Units	12	10*
			9	Furniture Integrated Units	1	8
			5	Desk Movable Units	0	5
			1	Other	-	-
	38	Other configurations				

* refers to the pure case, without supplemental task lights or daylight

Table 2. Building and General Lighting Description

Building Location	Office Type	Building Height	Lighting System Type	Task Lighting Type
1. Tampa, FL	All N=149	8-story	DRFLV WW DIF-P WW	FI CW DM *
2. Richmond, VA	All N=149	3-story	DRFLV WW DIF-P WW	DM *
3. Cincinnati, OH	Open N=149	11-story	IFFM WW	FI CW DM *
4. Asheville, NC	All N=51	2-story	HID-P MH	
5. Washington, DC	Open N=46	8-story	DRFLN CW	DM *
6. Appleton, WI	Open N=49	2-story	IF-P W	DM IN
7. Gaithersburg, MD	Enclosed N=48	11-story	DFSM CW	DM *
8. New York	Enclosed N=26	High-rise	DRFLN WW	DM CW
9. Ann Arbor	Enclosed N=50	4-story	DRFLN CW	DM IN
10. New York	Open N=51	High-rise	IFFM WW	FI CW DM *
11. New York	All N=50	21-story	DRFLN CW	
12. New York	Open N=49	High-rise	DRFLV WW	FI CW
13. Hopewell, NJ	Open N=49	Low-rise	DRFLV WW	FI CW DM *

Notes:

WW = warm white fluorescent lamps
CW = cool white fluorescent lamps
W = white fluorescent lamps
IN = incandescent
* = various sources
FI = furniture integrated units
DM = movable desk units (various types)

Open = open plan with partitions
Enclosed = fully enclosed offices
All = combination of above
N = number of work stations studied

3. Lighting Power Density, Illuminance, and Luminance Evaluation

3.1 Lighting Power Density Data

The first topic to be covered is that of the lighting power densities in the different work stations. The following section presents the range of LPD values which characterize the 912 work stations and relates these values to current energy recommendations. Subsequent sections present the photometric data and the user response data. Where possible, the user response data will be related to the physical characteristics of the space to provide greater understanding of the reasons for the response.

Figure 1 which presents the frequency of occurrence of the LPD's for the 912 work stations demonstrates a great deal of variation in the LPD data for all lighting systems. The range of LPD's was from a low of 0.37 W/ft^2 (3.4 W/m^2) to a high of 7.41 W/ft^2 (79.7 W/m^2). Nonetheless, almost 170 work stations had LPD's at about 2.0 W/ft^2. The average lighting power density for all work stations was 2.48 W/ft^2 (26.7 W/m^2) with a median value of 2.36 W/ft^2 (25.4 W/m^2). About half the data fell between 1.93 W/ft^2 (20.8 W/m^2) and 2.87 W/ft^2 (30.9 W/m^2), with the mode at 2.0 W/ft^2, however.

Closer examination of figure 1 suggests that the distribution of the LPD data was really bimodal, with one distribution peaking at 2.0 W/ft^2 and the second peaking at 2.8 W/ft^2. Inspection of figure 2 confirms that the direct and indirect lighting systems had very different distributions of LPD's. Thus, the direct lighting systems, such as the direct recessed fluorescent with louvers (DRFLV) had a modal LPD of 1.86 W/ft^2 (20.0 W/m^2), while the indirect lighting systems such as the indirect fluorescent furniture integrated system (IFFM) had a much higher mode of 2.97 W/ft^2 (32.0 W/m^2).

3.1.1 Lighting Power Density for Each Lighting System

As noted earlier, seven ambient lighting systems were identified for detailed analysis. Figure 3 presents the summary data (means, range, and standard deviation) for the LPD's for each of the seven individual lighting systems, including both daylighting and task lighting. Although this figure reveals substantial variability for each system, it also indicates that the means and standard deviations for the DRFLV and DRFLN systems were generally lower than those for the DFSM, IFFM, and INDFP systems, but similar to those for the DIFP and HIDP systems. The DRFLV category (which had the largest number of cases) also had the most extreme values.

Figure 4 indicates that the mean and range of LPD's were considerably reduced for those work stations in the DRFLV and DRFLN systems which did not have task lighting. (The IFFM system contained task lights as an integral part of the system.) Figure 5 indicates that the effect of excluding work

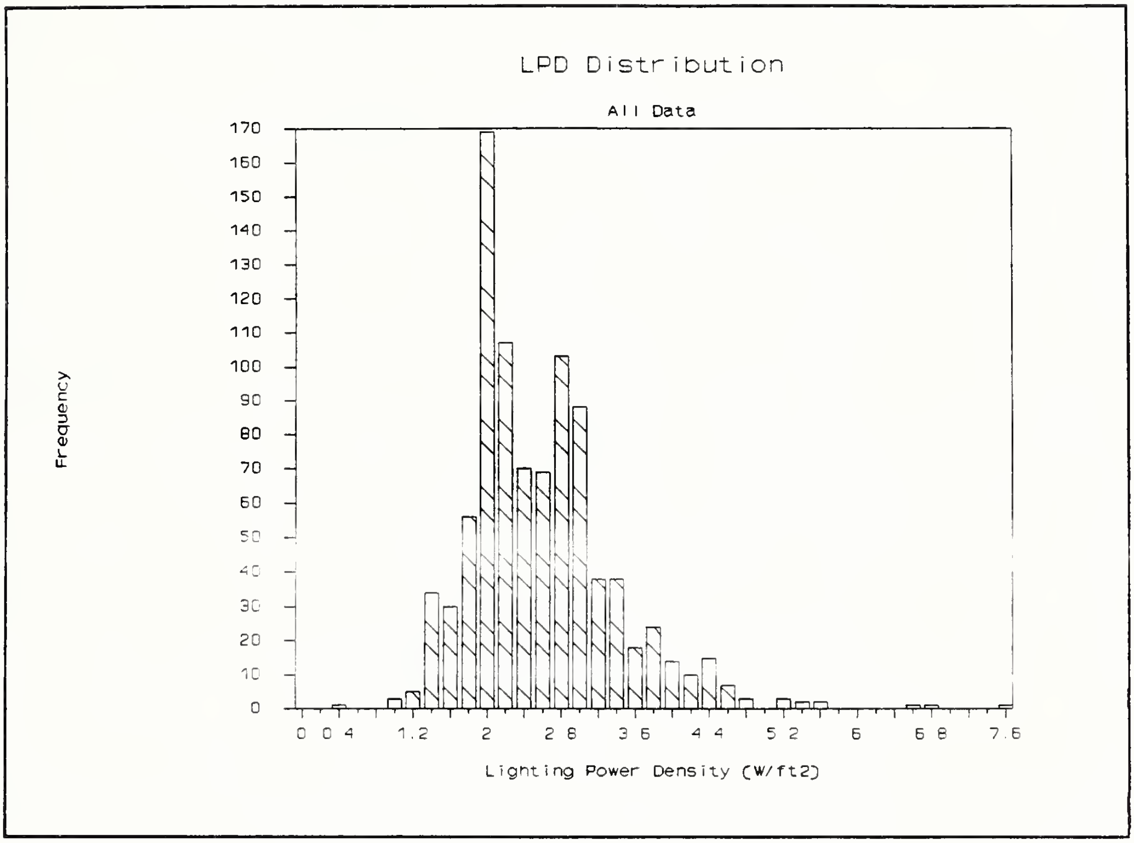


Figure 1. Frequency of occurrence of lighting power densities (LPD's) for all work stations.

This figure indicates that the most frequently occurring LPD was 2 w/ft^2 or (20 w/m^2), but that the overall distribution was bimodal, with a secondary peak at 2.8 w/ft (30 w/m^2).

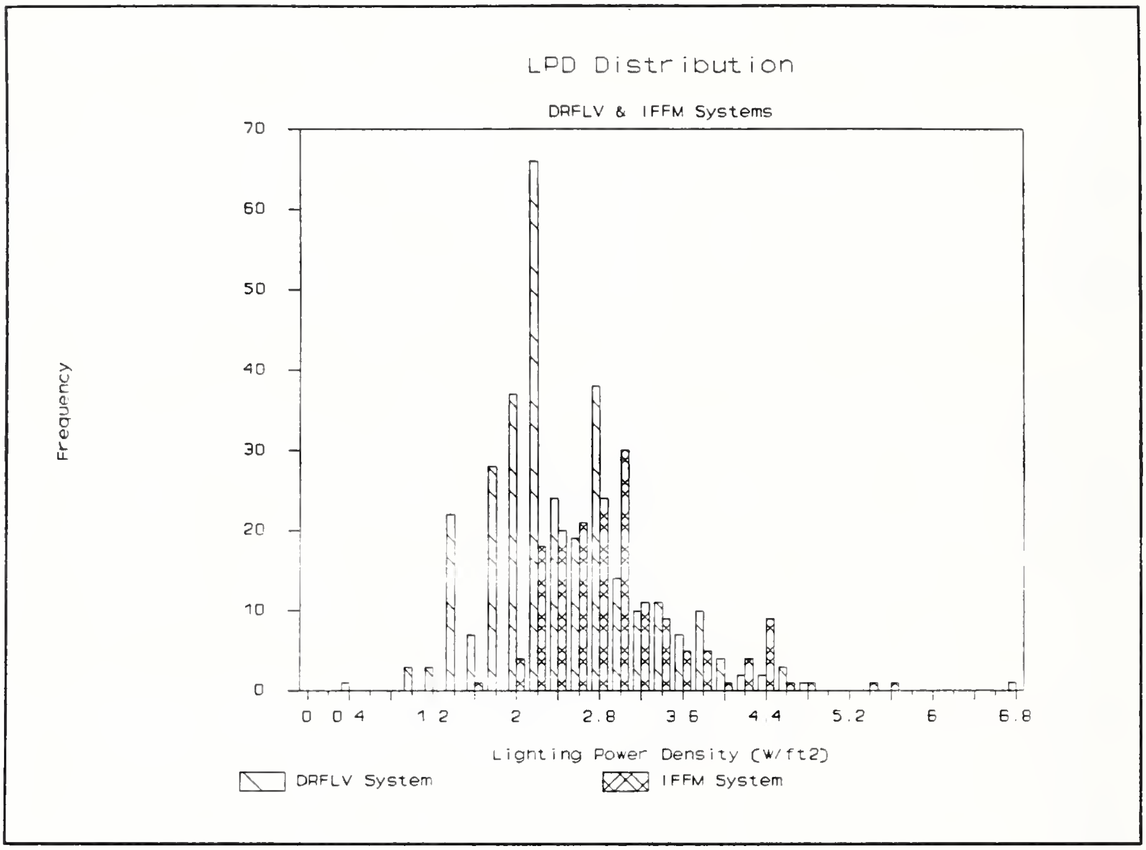
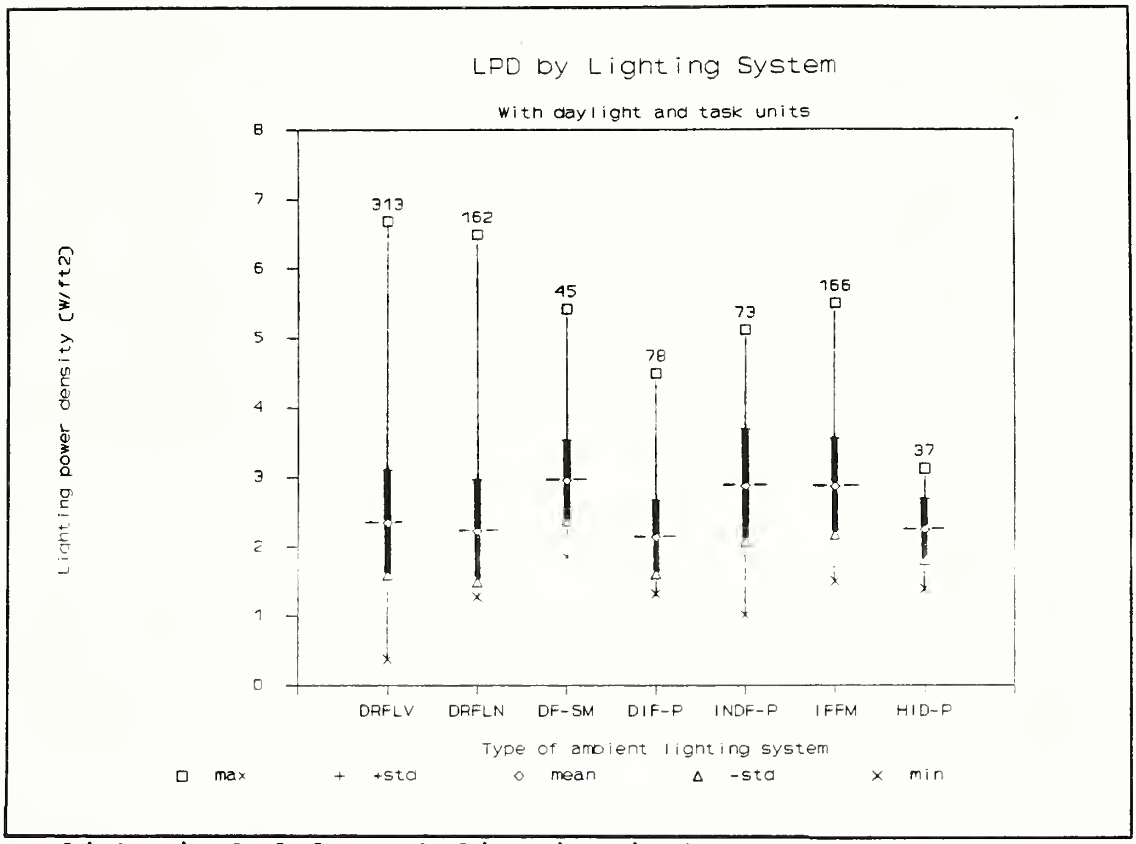


Figure 2. Frequency of occurrence of lighting power densities for two different lighting systems - direct recessed fluorescent with louvers (DRFLV), and indirect furniture mounted (IFFM).

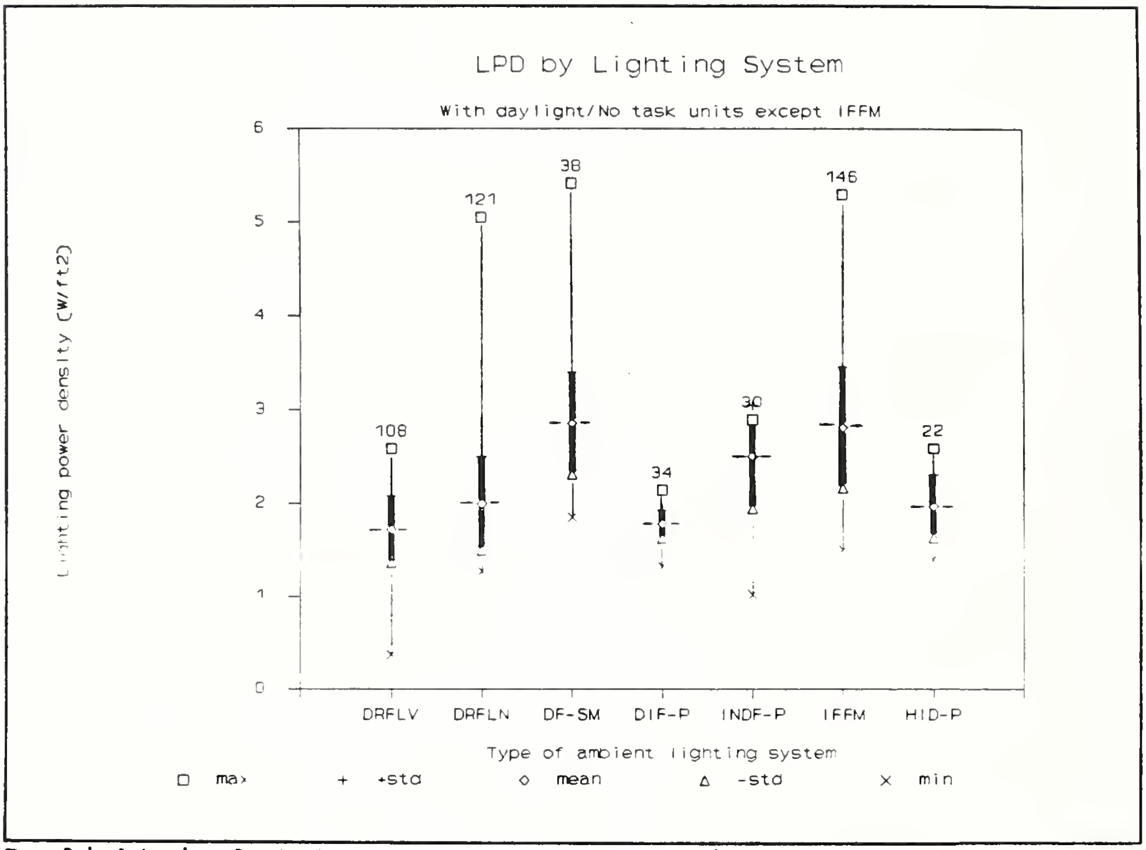
This figure suggests that the bimodal distributions observed in figure 1 were the result of marked differences in performance between the DRFLV and IFFM systems. The LPD's for the DRFLV system were consistently lower than those for the IFFM system.



Daylight included; Task lighting included.

Figure 3. Distribution of lighting power densities for the seven different lighting system types.

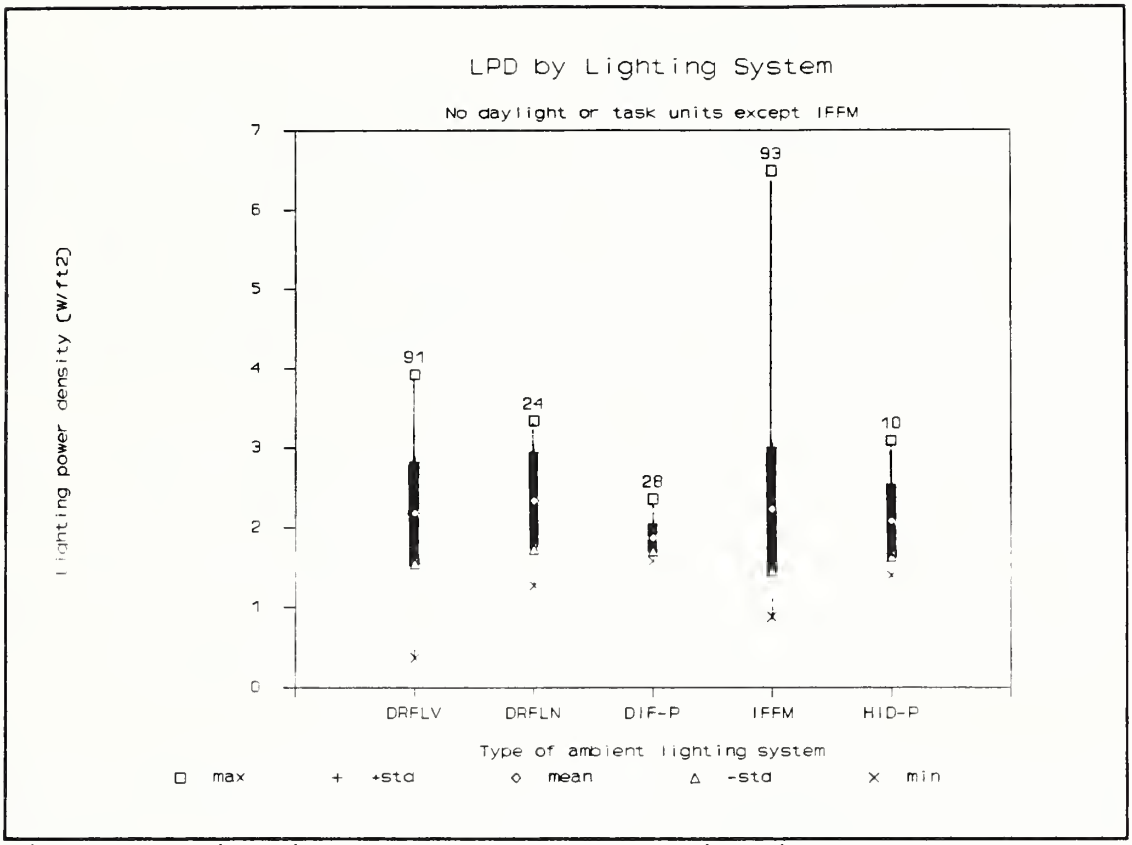
This figure provides the LPD data for each of the seven lighting systems in terms of mean, maximum, minimum, and plus and minus one standard deviation. It demonstrates that the mean LPD's were greatest for the DFSM, INDFP, and IFFM systems. Although the range was greatest for the DRFLV system, the standard deviation was comparable to other systems - about 1.5 w/ft^2.



Daylight included; non-system task unit excluded.

Figure 4. Distribution of lighting power densities for the seven different lighting system types for work stations without task lighting.

This figure indicates that the mean, range, and standard deviation of LPD's for three systems, DRFLV, DIFP, and HIDP, were noticeably lower than for three other systems, the DFSM, IFFM, and INDFP. The range of LPD's was particularly large for the DFSM and IFFM systems. Although the mean for the DRFLN system was similar to that for the DRFLV system, the range was much greater. In this figure, the center point represents the mean, the black bars represent plus and minus one standard deviation, the x represents the minimum point, and the square represents the maximum point (with these two points defining the range of values). The number above the square is the total number of measurements for an individual lighting system.



Little daylighting; non-system task lighting excluded.

Figure 5. Distribution of lighting power densities by lighting system type for work stations without either task lighting or daylighting (insufficient data for the DFSM and INDFP systems).

This figure demonstrates that the LPD's for the IFFM system were higher than for the other systems when work stations with neither task lighting nor daylighting are included in the analysis.

stations with both daylight and task light was to increase the LPD's slightly for the IFFM and DFSM systems[4].

Figures 4 and 5, which focus only on the effect of the ambient lighting systems, indicate that the variability shown in figure 3 for the entire database is reduced somewhat. Both figures demonstrate that the highest average LPD was found for enclosed offices with the surface mounted system with egg crate baffles (DFSM), the indirect furniture integrated system (IFFM), and the indirect fluorescent pendant mounted system (IFP). The lowest LPD's were found for the direct recessed fluorescent system with parabolic louvers (DRFLV), the direct/indirect system (DIFP), and the indirect metal halide pendant (HIDP). The direct recessed system with prismatic lenses (DRFLN) had similar but slightly higher lighting power densities as shown in figure 6.

When daylight was excluded from the analysis of LPD data as shown by figure 5, the indirect fluorescent furniture integrated system (IFFM) had the highest LPD, while the direct fluorescent recessed system with louvers (DRFLV) had the lowest LPD of all the systems studied. A comparison of figures 4 and 5 suggests that daylight may have contributed to the usable illuminance in the offices labeled as adjacent since the LPD's were somewhat lower than for those offices with daylight. (It is not known whether the LPD's were deliberately lowered by design to compensate for daylight.)

Finally, figure 7 reveals that for open plan offices using similar partitions and furniture integrated task lighting, work stations with the indirect furniture integrated ambient lighting system (IFFM) had higher mean lighting power densities than the direct ceiling system (DRFLV). This was true for those work stations with supplementary daylight and those without. In this report, frequent comparisons will be made between the results for the DRFLV and IFFM systems. For example, a t-test (statistical comparison of the differences between means) of the difference between the DRFLV mean of 2.34 W/ft^2 (25.2 W/m^2) and the IFFM mean of 2.87 W/ft^2 (30.9 W/m^2) systems was significant ($p<.001$).

The distributions of lighting power densities were quite different for the two systems, with the IFFM system having significantly higher LPD's than the more conventional DRFLV system.

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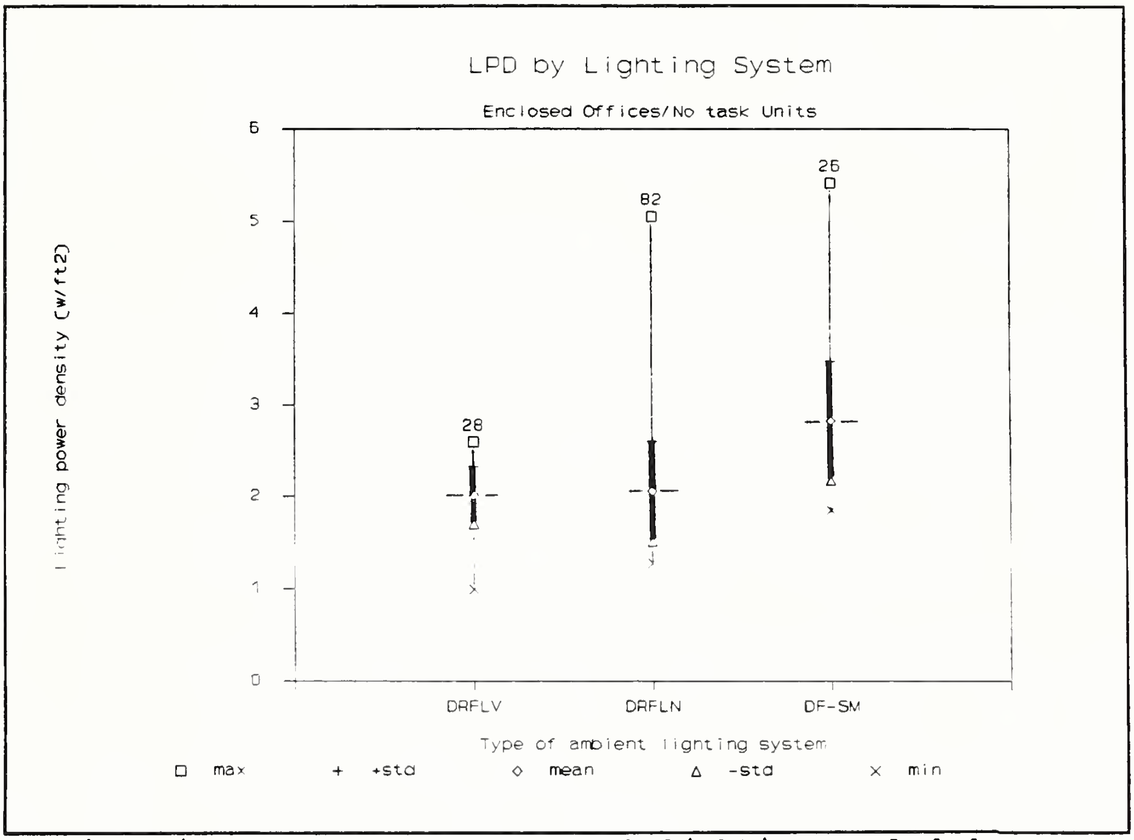
[4] The surface mounted system with only 5 work stations had insufficient data for detailed analysis.



Daylight included; non-system task lighting excluded.

Figure 6. Distribution of lighting power densities for three different lighting systems in enclosed offices without task units.

This figure demonstrates that the mean LPD's for enclosed offices were quite similar - between 2 and 2.5 w/ft2, although they were higher for the DFSM system. The variability for the DFSM and DRFLN systems remained high.

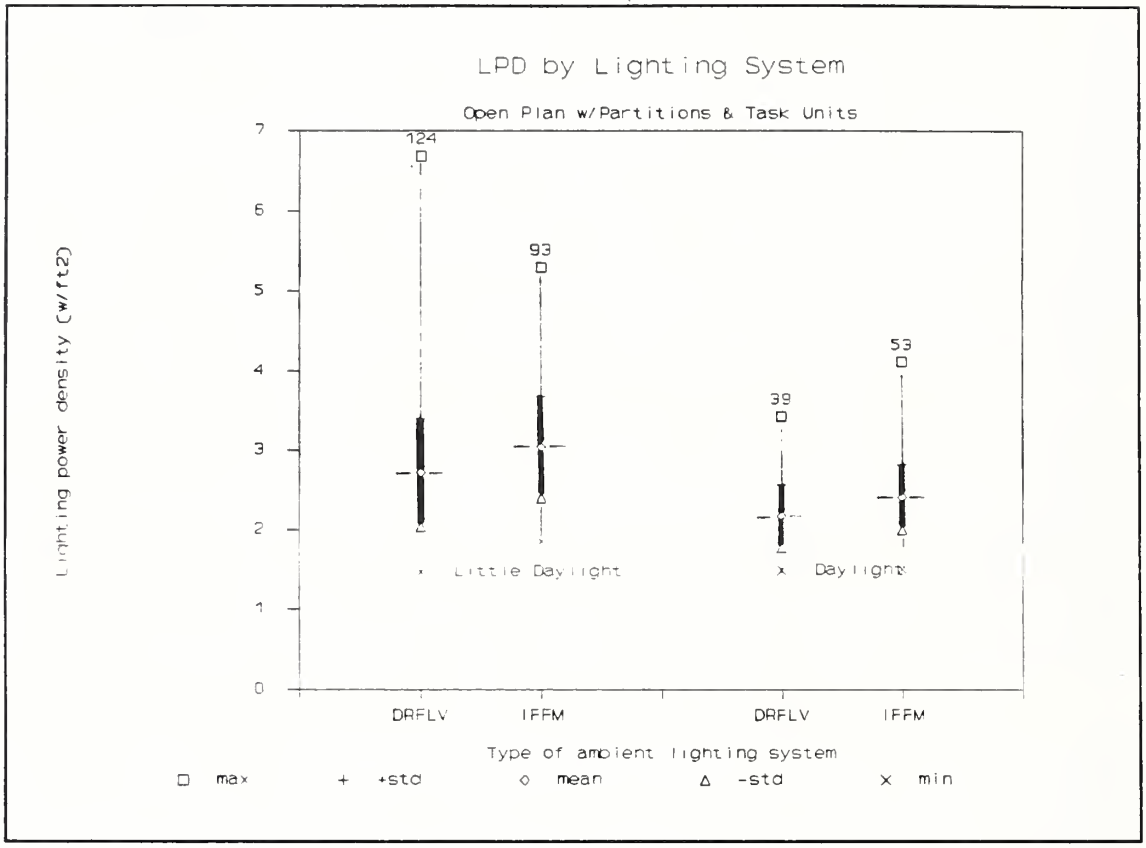


Figure 7. Comparison of lighting power densities for two lighting system types in open plan offices with partitions and task units with and without daylight.

This figure shows that the LPD's were consistently higher for the IFFM system than for the DRFLV system when the same furniture systems with integrated task lighting were used. In addition, the LPD's for the DRFLV system with task lighting were higher than those shown in figure 4 where task lighting was excluded. Figure 7 also indicates that the presence of daylight reduced the range and mean of the LPD's for both the DRFLV and IFFM systems. This finding suggests that occupants may have usefully employed daylight to supplement the lighting in workspaces with furniture integrated task lighting.

3.1.1.1 Reasons for Variations in Lighting Power Density

Several factors which may have accounted for both the absolute values and the differences in LPD's seen in figures 3, 4, 5, 6, and 7.

These factors include variations in:

1. Light source efficacy and ballast efficiency of the systems which were specified for use in the thirteen buildings.

   Not much of the difference observed here can be attributed to this factor, since all the lighting systems were fluorescent, except the HIDP system in building 4 which had indirect metal halide lighting (similar to fluorescent lighting in efficacy). Some of the desk movable task lighting systems were incandescent systems which have lower efficacies, however.

2. The efficiency of the luminaires and their light distributions characteristics from system to system.

   Luminaires with direct lighting distributions tend to have higher utilization of light than indirect types.

3. Characteristics of the room in which the lighting is employed.

   These include floor area and geometry, ceiling height, light reflectance of the walls, floor, and ceiling, and the presence of obstructions to the distribution of light such as partitions or high office furniture. These factors would affect the Coefficient of Utilization (CU) for a specific luminaire in a particular room.

4. The target value of illuminance appropriate for the employees and their visual tasks established by the owner and lighting designer.

   This will affect the number of lamps and luminaires necessary to provide the illuminance.

5. The presence or absence of task lighting for different work stations, with the type of illuminant varying from fluorescent to incandescent to metal halide, all with different efficacies.

6. The size of the "lumen package" employed, such as two-lamp, three-lamp, or four-lamp luminaires.

   In addition, the physical spacing of the luminaires in the building structure may have varied, as determined by the ceiling module, room or bay size, layout of work stations and other variables. Thus, the ceiling module of a particular building may not have allowed the installation of luminaires on seven-foot centers to provide the target illuminance, so either a six foot or an eight foot spacing had to be used. This would affect both the delivered illuminance and the LPD. Another alternative is that a small office may have required only three two-lamp fixtures to provide the desired illuminance, but four fixtures were installed to provide a better distribution of light and symmetry of appearance. The latter situation could work in the reverse direction as well, if five luminaires were needed but only four were practical to install.

3.1.1.2 Differences in LPD with the IFFM System

The indirect fluorescent furniture integrated (IFFM) lighting system was used in buildings 3 and 10 of the present study. These systems provided indirect ambient lighting by using fluorescent light sources built into the top of the office furniture. Task lighting was supplied by a fluorescent luminaire built into the furniture and concealed under shelving close to the work surfaces. In the present study, this type of systems furniture with integrated task lighting was also used in buildings 12 and 13, but the ambient lighting was furnished by DRFLV luminaires located in the ceiling rather than by indirect lighting mounted in the furniture. The combination of task and ambient lighting has been advertised for the past decade as being an energy saving lighting solution. Yet, the examples observed in the present study showed that the installed LPD's for this system were among the highest of the systems surveyed. Why should this have occurred?

One contributing factor to the higher LPD's may have been that the indirect lighting commonly used for the ambient lighting was lower in utilization than a direct lighting system. Another factor may have been that the LPD's in the space resulted from unanticipated modifications to the "lumen package" (and, therefore, the power package) built into the work station furniture by the manufacturer due to changes in the final layout of the work stations by the building owner or operator. For example, it was found that the (movable) furniture systems were often moved and placed much closer together than anticipated by the manufacturer. This repositioned the lighting system, and in turn, modified the power distribution resulting in higher LPD's than originally intended. Thus, the use of systems furniture with built-in lighting appears to have altered the customary approach to lighting design and did not permit the designer to "fine-tune" the lighting as closely to desired illuminance targets, or to control the lighting power values as precisely as more conventional approaches would allow.

3.1.2 Lighting Power Density for Local Task Lighting

Figure 8 indicates that work stations with local task lighting (either furniture integrated or desk movable) had higher LPD's than those without any task lighting. Although cool white fluorescent sources were usually used for the furniture integrated task units, the sources for the desk movable units varied from a single fluorescent to multiple incandescents. Work stations with movable desk lighting had the highest mean LPD of 3.20 W/ft^2 (34.4 W/m^2); those with furniture integrated lighting had a slightly lower mean LPD of 2.69 W/ft^2 (28.9 W/m^2); and work stations without local task lighting had the lowest mean LPD of 2.02 W/ft^2 (21.7 W/m^2)]. The lower efficiencies of incandescent sources would explain some of this variability.

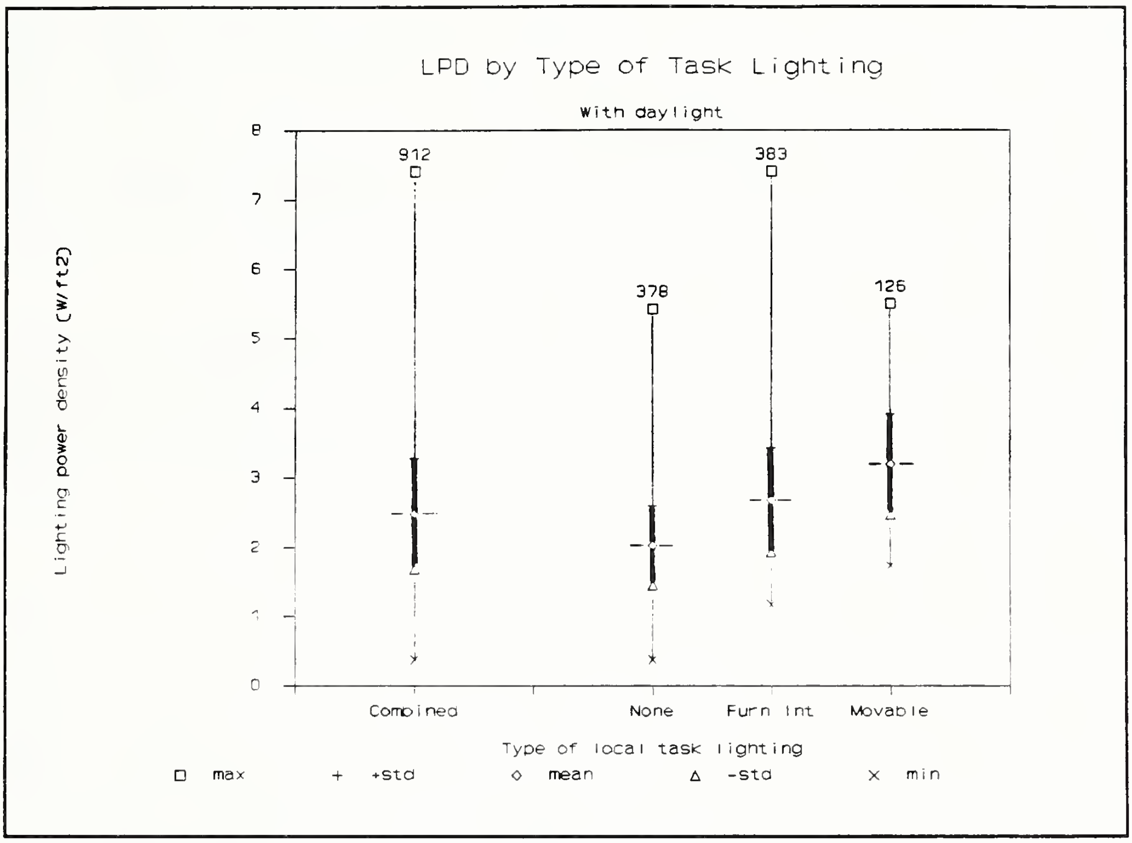


Figure 8. Comparison of the distribution of LPD's for all lighting systems combined with three task lighting systems.

This figure indicates that the mean LPD was lowest for systems with no task lighting and highest for those with movable units. The LPD's for systems with furniture integrated lighting were intermediate, but noticeably higher than for systems with no task lighting.

In current design practice, task lighting is not intended to be used exclusively in lieu of ambient lighting. If this were done, the result would be extreme imbalance in the luminances throughout an environment and a visually chaotic appearance for the space. Principles that have been developed for acceptable task-ambient lighting are to design the ambient to supply about one-third of the light needed for the task, distributed with reasonable uniformity throughout the space. The task lighting then should provide the remaining two-thirds of the light directly on the task. In theory, this will provide some general luminance to the room, and prevent the brightness relationships from becoming unbalanced.

The higher LPD's for work stations with task lighting suggest that lighting designers and furniture manufacturers have not yet learned how to work together to design properly for this potentially energy conserving application. (See also section 5.3.) For many of these work stations, task lighting was apparently added to the usual base of general ambient lighting, but designed as if it were to be the sole source of task illumination. Furthermore, additional task units were often added by occupants to areas not originally intended to be task areas. The result was higher LPD's.

The lighting power density was also strongly related to the type of office enclosure (open, open w/partitions, or enclosed), at least for the direct ceiling systems[5]. Fully enclosed offices tended to have higher lighting power densities than either completely open offices or open offices with partitions, for the same type of direct lighting system as shown in figure 9. This outcome illustrates directly the variation in utilization of light between large and small offices. The enclosed offices tended to be small, often private, offices in which the utilization of light was lower than in large rooms: hence, more lighting power was needed to supply the target level of illuminance. Open offices tended to be larger, and if there were no partitions, either full or partial height, the utilization was higher, so that lighting power could be lower. Where partitions were added to an open space to provide visual privacy and sound attenuation, they also absorbed light and interfered with its distribution, requiring more lighting power to supply the needed illuminance.

Work stations with local task lighting (either furniture integrated or desk movable) had higher lighting power densities than those without task lighting. This finding indicates the need for more careful design for task lighting systems to avoid unnecessarily high LPD's.

3.2 Illuminance

The next question to be considered is the relationship between LPD and photometric variables such as illuminance. Two sets of illuminance data, with and without body shadow, were collected for the primary and secondary work surface at each work station. In the following pages, however, illuminance data will be presented <u>with</u> body shadow, since this measure

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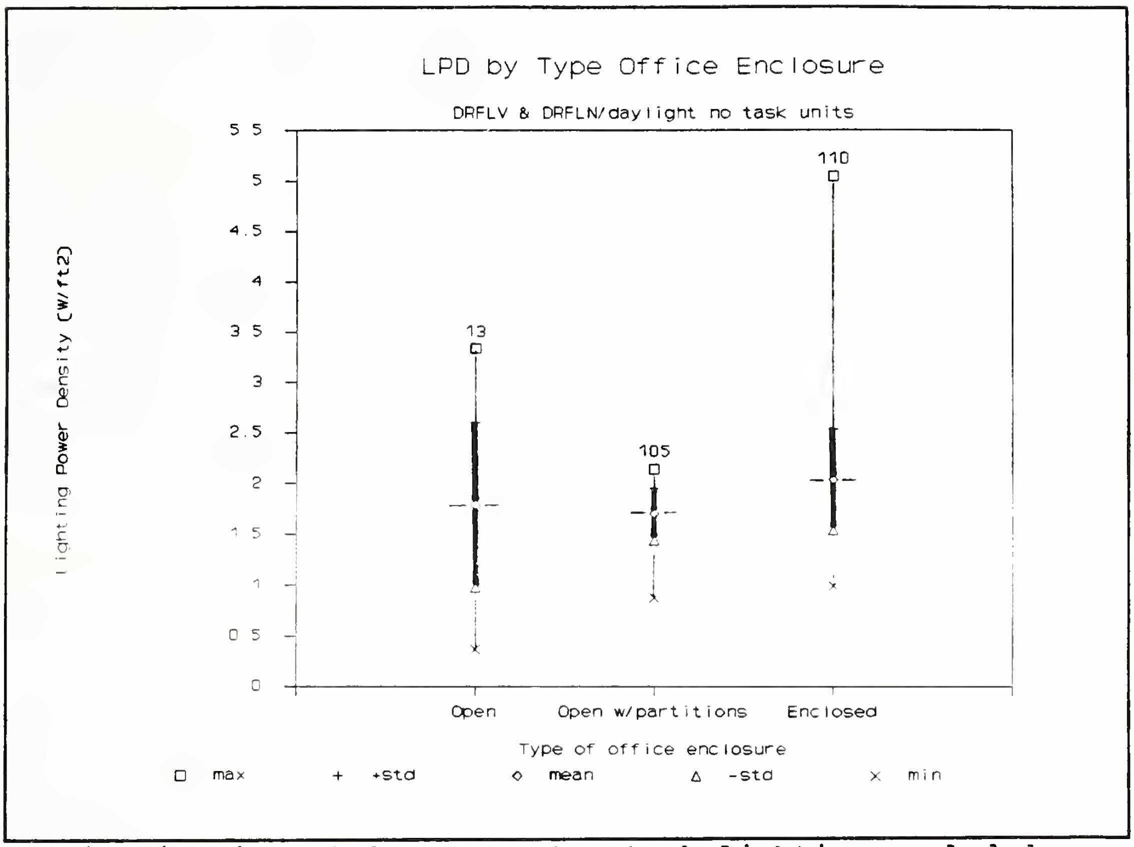
[5] There were insufficient data for the indirect and the direct/indirect systems in enclosed offices for this analysis.



Daylighting included; non-system task lighting excluded.

Figure 9. Distribution of LPD's for different types of office enclosures.

This figure compares LPD's for different types of offices <u>without</u> task units. It indicates that the lowest mean LPD's with the smallest variability were found for open offices with partitions.

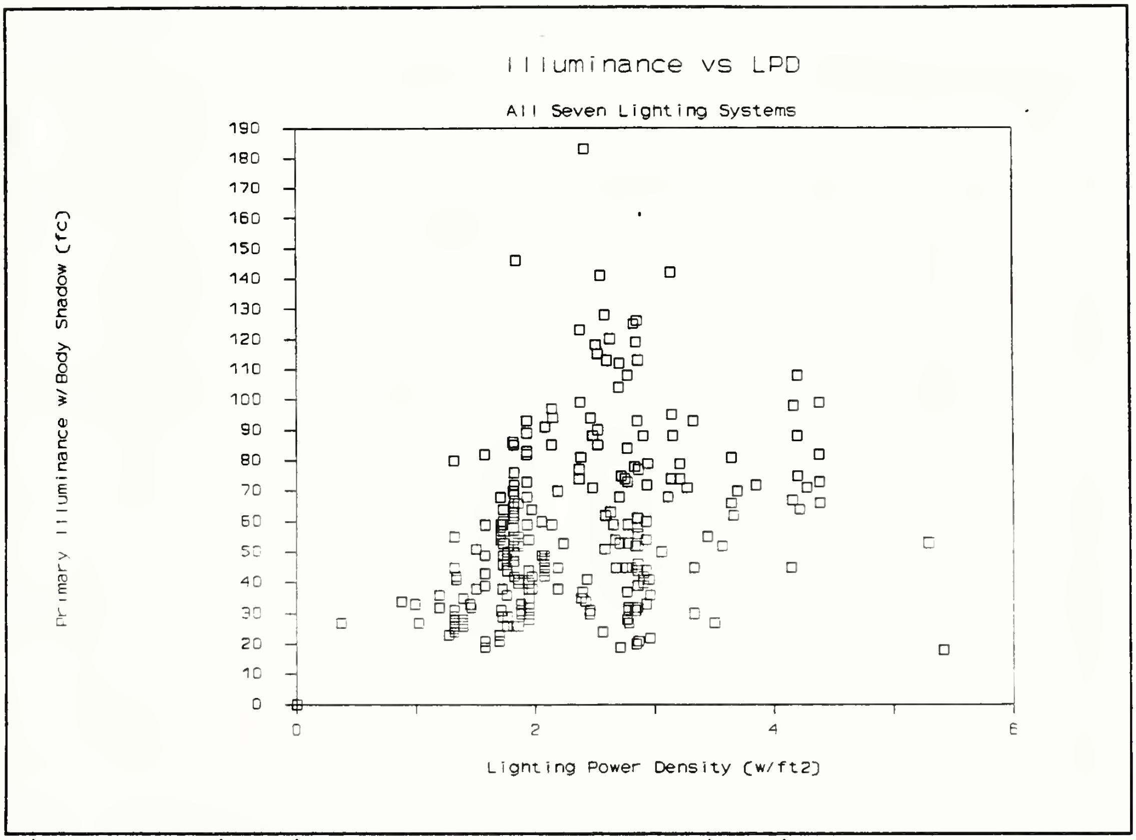
relates more closely to the way occupants see the work surface. Figure 10 indicates that there was a broad scattering of data points relating illuminance to LPD. The relationship appears to be anything but linear, making it difficult to make general statements about the relationship between illuminance and LPD's.

Several factors immediately come to mind to explain the scattering effect. First, part of the scatter was due to work stations at the perimeter of the buildings which received part of the lighting on their tasks from daylight. The daylighting portion of the illuminance required no lighting power, and hence did not add to the LPD. As a result, higher illuminance was achieved with lower LPD's. A second reason is the use of task lights which supplied high illuminance to only a small part of the work station. Yet the lighting power was attributed to the total area of the work station. A third major factor is the effect of room size on the utilization of illumination. Since large rooms, particularly those without partitions, are much more efficient in the utilization of light than small ones, considerably less lighting power was required to produce illuminance in them than in smaller spaces.

Even when the data are segregated into groups of similar lighting systems with no daylighting or supplemental task lighting (eliminating factors 1 and 2 from above), figure 11 indicates that the data still contained substantial scatter. The scatter is principally due to the effect of room size discussed above, and to several other factors which will be discussed below. In addition, data for the IFFM system which contained task lighting as the primary lighting system are included in figure 11. Yet, although no simple relationship is seen for the data as a whole in figure 10, figure 12 suggests that there was a somewhat linear relationship between increasing LPD's and illuminance, when the data for only a single lighting system (DRFLV) are considered. Nonetheless, there was still much scattering of the data points.

In addition to the three factors cited above, there are several other reasons for the non-linear relationship between illuminance and LPD. First, illuminance as measured at the work surface varied because of non-uniform ceiling lighting. Because some work stations were located directly under fixtures, they could have higher illuminances for a given LPD. Second, partial-height wall partitions and other furniture obstructions caused shadows on some work surfaces so that the full possible illuminance from all fixtures was not realized. Third, the various types of luminaires varied in efficiency (as well as in scheduled maintenance). (The light <u>sources</u> themselves had similar efficiencies except for the metal halide system and the incandescent task units, which were treated separately, but the the luminaires varied extensively.) Finally, although the LPD was calculated for an entire work station as discussed in section 2.1, the illuminance was measured at only two locations in the work station. These might not have received the full benefit of the power supplied to the luminaire.

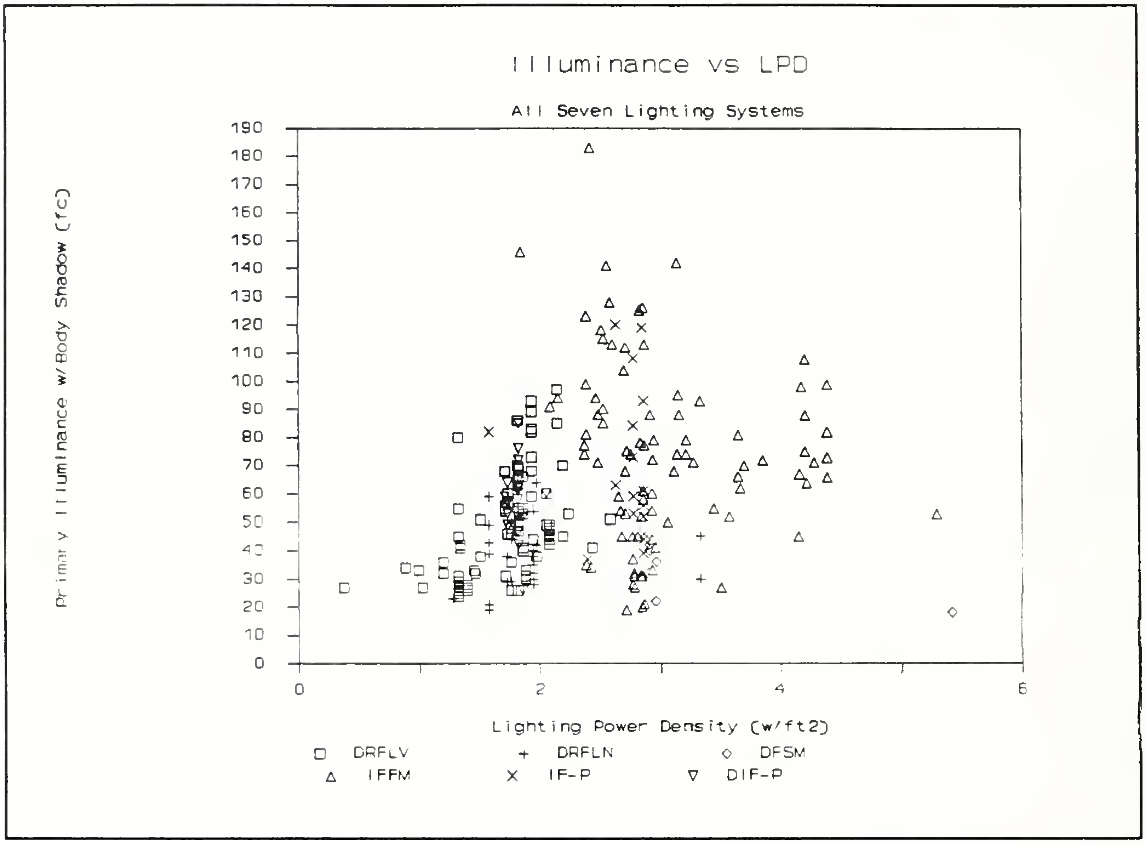
In addition, the type of ambient lighting system in the work station influenced the relation between illuminance and LPD. Figure 11 shows that the greatest variation in LPD's occurred for the indirect lighting systems in general, and the IFFM system in particular. For the direct systems, such



Little daylighting; non-system task lighting excluded.

Figure 10. Distribution of illuminance as a function of lighting power density for all lighting systems.

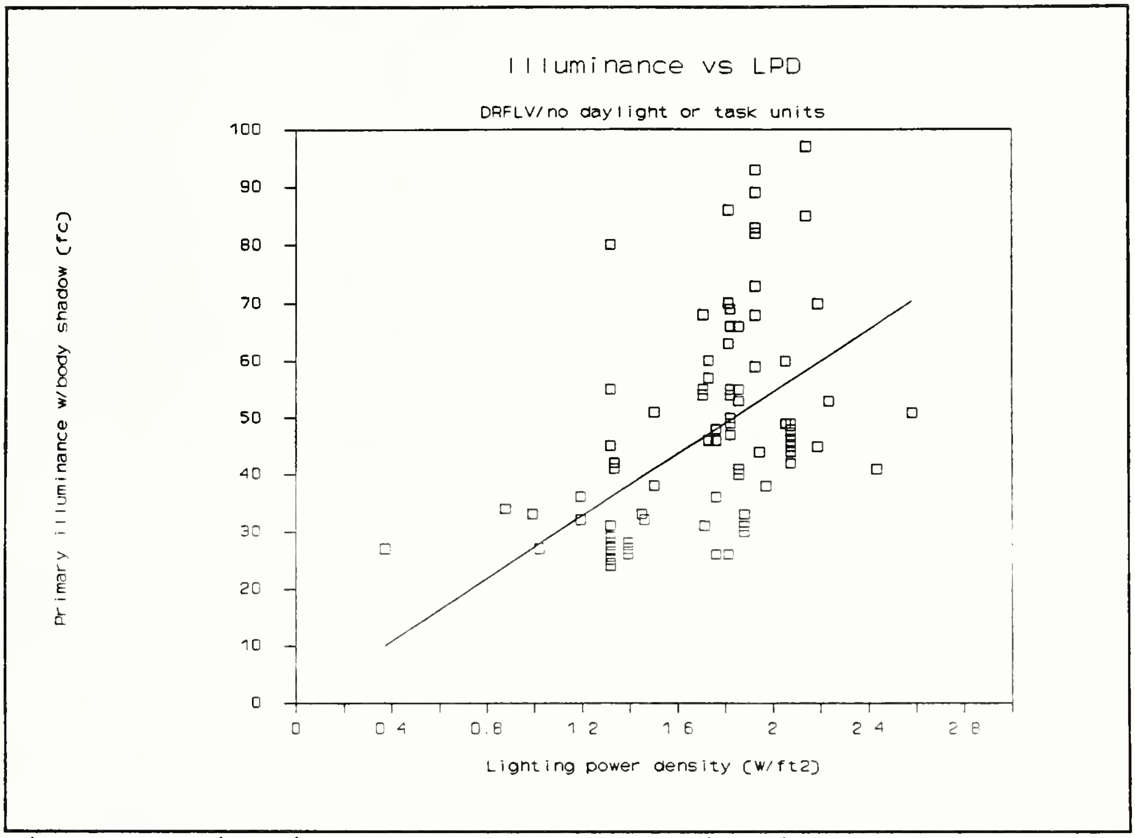
This figure presents the distribution of illuminances at the primary work station as a function of lighting power density. It suggests that illuminance generally tended to increase with LPD but that there was considerable variability in the illuminance obtained at any given LPD.



Little daylighting; non-system task lighting excluded.

Figure 11. Distribution of illuminance as a function of lighting power density for each of six lighting systems.

This figure presents the distributions of illuminances and LPD's for each lighting system. It demonstrates that the greatest variability, highest illuminances, and highest LPD's occurred for the IFFM system. For example, at about 2.5 w/ft^2, the illuminances for the IFFM system ranged from about 20 fc to about 185 fc. Conversely, LPD's varied from 2.5 w/ft^2 to about 5.5 w/ft^2 for an illuminance of about 50 fc. The scatter in the relationship between illuminance and LPD was much less for the other lighting systems.



Little daylighting; non-system task lighting excluded.

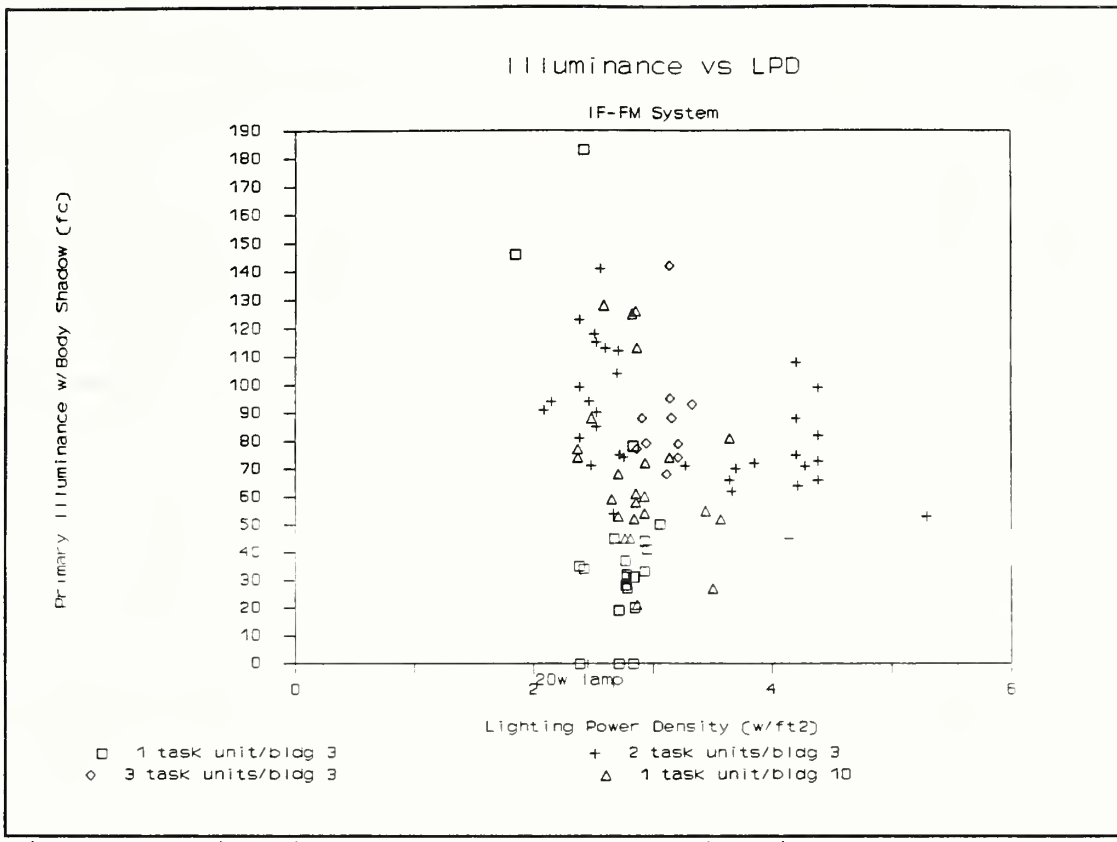
Figure 12. Distribution of illuminance as a function of lighting power density for the DRFLV system including regression line.

This figure demonstrates that there was a positive linear correlation between increasing LPD and illuminance for the DRFLV system. Nonetheless, there was still considerable scatter with a wide range of illuminances for any given LPD. Both daylighting and task lighting are included in this analysis.

as the direct recessed fluorescent system with louvers (DRFLV), figure 12 reveals that there was less scatter in the LPD's than with other systems. Figure 13 shows that the relationship between illuminance and lighting power density was definitely non-linear for the furniture integrated (IFFM) systems. This lack of linearity may have arisen because the task lighting was highly localized with separate units employed for each task location for these task/ambient environments. In fact, figure 13 indicates that additional task units were often added to a work station to provide needed illumination for a secondary task location. Because the additional units did not contribute to the illuminance at the primary task location, the reported illuminance for the work station did not increase, but the total power density of the space did. On the other hand, the opposite situation could have arisen in which a space had a single task unit located directly over the work area which provided high local task illuminance, but only for that small area. As a result, the resultant lighting power density would be lower than might be expected for the reported illuminance. Finally, because the work stations with integrated task lighting were likely to have partitions shadowing the task surface, the illuminance distributions may have been especiallly non-uniform. As a result, the relationship between LPD's and illuminance was likely to be particularly non-linear for the task/ambient lighting systems, as seen by the range of illuminances for a single LPD for the IFFM systems. For example, in Building 3, ten work stations had three task units each, all with fluorescent sources and indirect ambient lighting. These IFFM systems had an LPD of about 3 W/ft^2.

Figure 13 also reveals that all the LPD's above 3.72 W/ft^2 (40.0 W/m^2) were for work stations with more than one task unit. This finding provides confirmation of the idea that separate task units were often used for each task surface area - thereby increasing the overall LPD but not necessarily increasing the illuminance for the task surface. In addition, both the highest and the lowest illuminances occurred for work stations with a single task unit; confirming the idea that the reported illuminance was strongly related to the location of the task with respect to the local lighting.

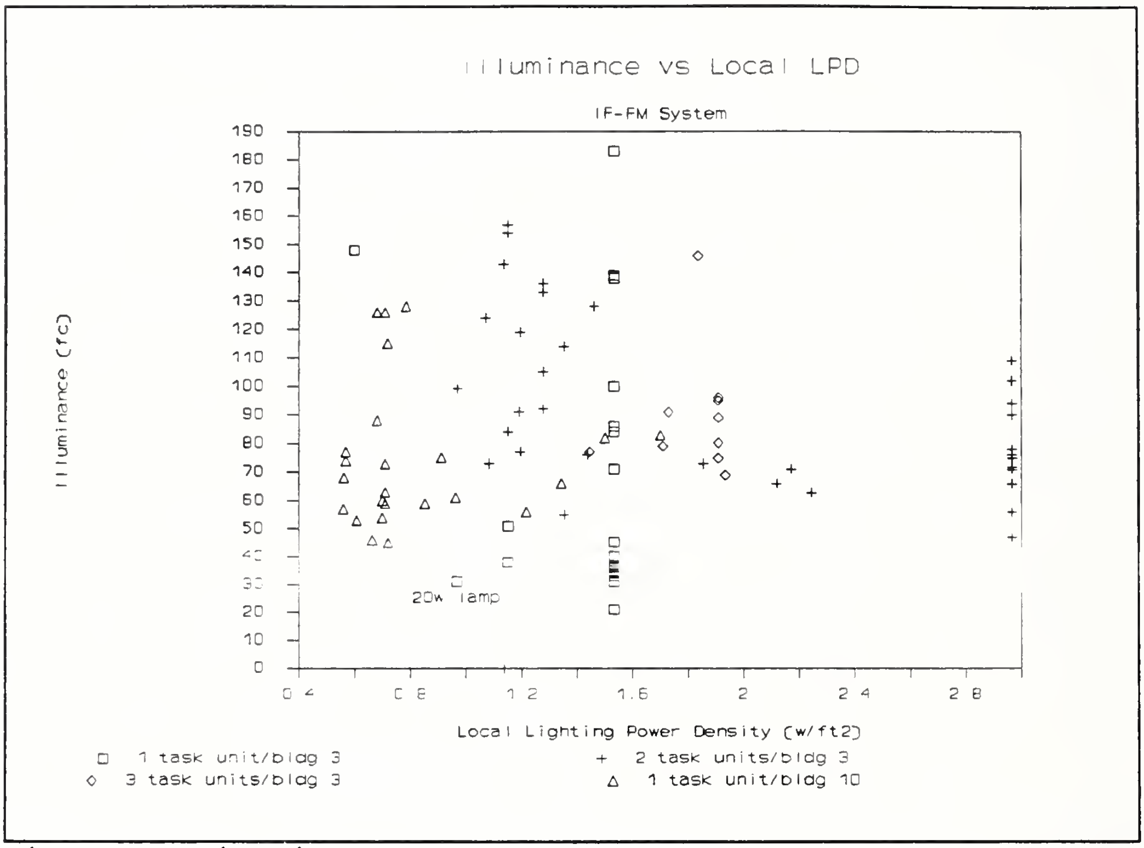
Figures 14 and 15 make yet another point. In figure 14, illuminance at the primary task location is plotted against the lighting power density for the task unit alone. This figure may be compared with figure 13 in which illuminance at the primary location was plotted against the total LPD in the space. As can be seen, the LPD's were substantially lower when only the local LPD supplied by the task unit at the primary location is considered. Yet the range of illuminances for the primary task location is virtually the same in both figures. This indicates that the local task lighting provided the majority of the illuminance at the task even though the power supplied to the workspace was actually much greater. Figure 14 suggests further that the variations in illuminance for a given LPD were most likely due to variations in the location where the illuminance measurement was taken relative to the task light, or to supplementary illumination at the task surface from the ambient lighting. Figure 15 suggests that additional scatter in illuminance for a given LPD may have been due to variations in floor area for different work stations. Again, this would be a factor in densely versus sparsely occupied offices. Figure 15, which plots the work



Little daylighting; non-system task lighting excluded.

Figure 13. Distribution of illuminance as a function of lighting power density and number of task units for the IFFM system.

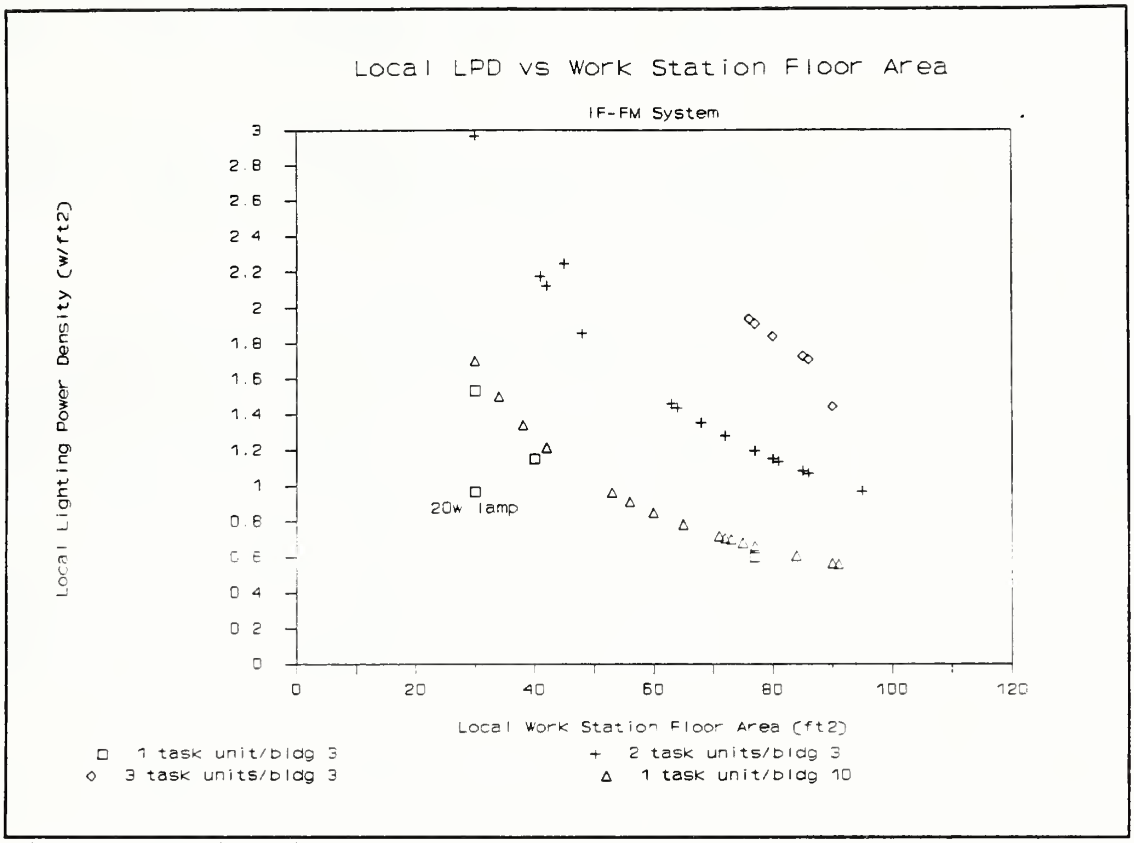
This figure demonstrates that the illuminances tended to be higher for a given LPD when more than one task unit is used. IFFM installations with two units also tended to have higher LPD's, while those with only one unit tended to have much lower illuminances (and less scatter). This figure demonstrates clearly that the LPD's for the IFFM system were concentrated between 2.5 and 4.5 w/ft^2.



Little daylighting.

Figure 14. Distribution of illuminance as a function of local lighting power density and number of task units for the IFFM system.

This figure presents illuminance as a function of LPD only for the local task lighting. It demonstrates that the LPD's associated with the task lighting were much lower, as might be expected. Furthermore, these data tend to be grouped together, and show a range of illuminances for a given LPD. This grouping can be attributed to the type and number of local task units used. Where several illuminances are shown for the same power density, the work station size, type and number of task units remained the same, but the illuminance at the primary task location varied. This variability was particularly common with the IFFM system, indicating that task illuminance was strongly determined by the location of the task relative to the task lighting.



Little daylighting.

Figure 15. Distribution of local LPDs as a function of work station area for the IFFM system.

This figure presents LPD data for local task lights as a function of work station floor area. It demonstrates the obvious: that local LPD's decreased as floor area increased, and that LPD's were systematically higher as the number of task lamps in a given area increased.

station floor area as a function of the local lighting power density, shows that LPD's decreased as work station area increased. Figure 15 also indicates discrete jumps in LPD's as task units were added.

The data showed great variability in the relationship between LPD's and illuminance, although much of this can be explained on the basis of variations in fixture position, partitions, luminaire efficiency, and task location, as well as the addition of daylight and/or task lighting.

3.2 Photometric Data for Different Lighting Systems

Tables 3 and 4 present statistical summaries of the LPD's, illuminance, and several other photometric measurements for the seven different lighting systems for two situations: the database as a whole (table 3) and work stations for which there was neither daylighting nor supplementary task lighting, except for the IFFM system (table 4). This latter condition is the "pure" case identified in table 1 and provides the best evidence of the effects of an ambient lighting system alone without either daylight or task light. Both tables 3 and 4 present the mean, maximum, minimum, and standard deviation for LPD's, illuminance at primary and secondary work station, CRF minimum, luminance ratio (both near and far), darkest luminance in field of view, brightest luminance in field of view, surround luminance and task luminance. These tables indicate that the mean illuminances at the primary task were:

Database as a Whole			No Daylight, No Task Light (except IFFM)		
System	Mean Illuminance		System	Mean Illuminance	
		Direct Systems			
DRFLV	61 fc	(652 lx)	DRFLV	48 fc	(513 lx)
DRFLN	68 fc	(736 lx)	DRFLN	39 fc	(421 lx)
DFSM	55 fc	(589 lx)	DFSM	32 fc	(340 lx)
		Indirect Systems			
IFFM	75 fc	(805 lx)	IFFM	74 fc	(793 lx)
IFP	65 fc	(702 lx)	IFP	59 fc	(635 lx)
HIDP	46 fc	(498 lx)	HIDP	35 fc	(381 lx)
		Direct/Indirect Systems			
DIFP	56 fc	(599 lx)	DIFP	58 fc	(623 lx)

This comparison indicates that the mean illuminances in the work stations with direct lighting systems were generally lower than for the indirect systems. In addition, illuminance was substantially lower for those direct systems which did not have daylight or task lighting in the work station. Illuminance in the work stations with indirect lighting showed little effect of daylight or task lights. Comparison of tables 3 and 4 shows that the maximum illuminances and standard deviations were much higher for the database as a whole than for the "pure" case, regardless of the type of lighting system.

Table 3. Photometric Statistical Summaries for the Entire Database (N = 912).

Photometric Statistic Summaries:

		LPD		Illuminance w/Body Shadow Primary		Secondary		Luminance Min	Ratios:		Darkest Luminance		Brightest Luminance		Surround Luminance		Task Luminance	
DRFLV:		W/m2	(W/ft2)	lx	(fc)	lx	(fc)	CRF	Near	Far	cd/m2	(fL)	cd/m2	(fL)	cd/m2	(fL)	cd/m2	(fL)
(N=313)	Mean	25.2	2.34	652	61	595	55	0.85	4	1189	4.6	1.3	2619	764	70	21	163	48
	Max	71.9	6.68	1689	157	1614	150	0.97	45	20000	30.8	9.0	6235	1820	322	94	500	146
	Min	4.0	0.37	151	14	43	4	0.49	1	8	0.1	0.0	10	3	3	1	41	12
	Std	8.1	0.75	291	27	285	26	0.08	5	1902	4.0	1.2	1446	422	59	17	78	23
DRFLN:																		
(N=162)	Mean	24.0	2.23	736	68	694	64	0.84	3	1255	12.5	3.7	3318	968	103	30	191	56
	Max	69.8	6.49	4315	401	1797	167	1.02	21	14600	154.2	45.0	20213	5900	617	180	901	263
	Min	13.7	1.27	204	19	65	6	0.01	1	12	0.3	0.1	452	132	3	1	55	16
	Std	8.0	0.74	466	43	362	34	0.15	4	2516	18.2	5.3	1966	574	94	28	116	34
DFSM:																		
(N=45)	Mean	31.8	2.95	589	55	565	52	0.81	3	305	21.9	6.4	4147	1210	92	27	161	47
	Max	58.3	5.41	1442	134	1259	117	0.98	11	1976	92.5	27.0	28436	8300	411	120	514	150
	Min	19.9	1.85	161	15	312	29	0.01	1	13	1.7	0.5	408	119	14	4	34	10
	Std	6.2	0.58	242	23	209	19	0.17	3	316	22.5	6.6	4480	1308	74	22	86	25
IFFM:																		
(N=166)	Mean	30.9	2.87	805	75	616	57	0.83	3	830	6.3	1.8	1429	417	68	20	192	56
	Max	59.2	5.50	2055	191	5595	520	1.03	12	17760	20.6	6.0	17130	5000	182	53	541	158
	Min	16.2	1.50	140	13	97	9	0.56	1	18	0.1	0.0	69	20	10	3	27	8
	Std	7.4	0.69	387	36	642	60	0.09	1	2695	4.9	1.4	2676	781	38	11	92	27
IFP:																		
(N=73)	Mean	30.9	2.88	702	65	738	69	0.84	2	347	8.5	2.5	1394	407	124	36	189	55
	Max	55.1	5.12	1291	120	1797	167	0.97	13	3750	85.7	25.0	4796	1400	322	94	439	128
	Min	11.0	1.02	215	20	172	16	0.46	1	9	0.7	0.2	82	24	7	2	55	16
	Std	8.8	0.81	287	27	354	33	0.11	2	619	12.2	3.6	951	278	82	24	90	26
DIFP:																		
(N=78)	Mean	23.0	2.14	599	56	676	63	0.87	5	639	4.7	1.4	1610	470	69	20	143	42
	Max	48.3	4.49	1173	109	2862	266	0.96	25	6025	22.0	6.4	5242	1530	284	83	278	81
	Min	14.2	1.32	151	14	172	16	0.67	1	35	0.3	0.1	120	35	3	1	41	12
	Std	5.7	0.53	240	22	360	33	0.06	6	627	4.1	1.2	952	278	57	17	56	16
HIDP:																		
(N=37)	Mean	24.2	2.25	498	46	222	21	0.82	6	147	12.8	3.7	2129	621	69	20	121	35
	Max	33.6	3.13	1969	183	269	25	1.04	21	343	61.7	18.0	2820	823	367	107	418	122
	Min	15.0	1.39	194	18	194	18	0.32	1	1	1.0	0.3	27	8	3	1	48	14
	Std	4.8	0.45	357	33	33	3	0.17	5	103	11.6	3.4	900	263	77	22	76	22

Table 3. Continued

Notes apply to both tables 3 and 4.

Notes:

CRF Min = Minimum contrast rendition factor at primary location.
Far Lum Ratio = Ratio of the brightest/darkest luminances in the field of view.
Near Lum Ratio = Ratio of the task/surrounding luminance.
Darkest Lum = Darkest luminance in the field of view.
Brightest lum = Brightest luminance in field of view.
Surround Lum = Luminance of local surround about task (normally desk top).
Task Lum = Luminance of white bond paper at primary location.

Table 4. Photometric Statistical Summaries for Ambient Systems Only With No Task Lighting and No Daylighting (N = 256).

Photometric Statistic Summaries: No Task Units (except IFFM) and Little Daylight

		LPD		Illuminance w/Body Shadow Primary		Secondary		Luminance Min	Ratios		Darkest Luminance		Brightest Luminance		Surround Luminance		Task Luminance	
		W/m2	(W/ft2)	lx	(fc)	lx	(fc)	CRF	Near	Far	cd/m2	(fL)	cd/m2	(fL)	cd/m2	(fL)	cd/m2	(fL)
DRFLV:																		
(N=91)	Mean	18.7	1.74	513	48	506	47	0.87	4	1106	3.7	1.1	2563	748	54	16	116	34
	Max	27.8	2.58	1044	97	979	91	0.97	35	6950	16.2	4.7	5824	1700	127	37	230	67
	Min	4.0	0.37	258	24	151	14	0.57	1	51	0.2	0.1	387	113	3	1	55	16
	Std	3.9	0.36	188	17	172	16	0.07	5	1020	3.2	0.9	1411	412	32	9	42	12
DRFLN:																		
(N=24)	Mean	20.4	1.89	421	39	387	36	0.87	5	563	8.0	2.3	2599	759	55	16	105	31
	Max	35.8	3.33	689	64	753	70	1.02	21	1700	24.0	7.0	5824	1700	178	52	171	50
	Min	13.7	1.27	204	19	65	6	0.58	1	123	1.0	0.3	857	250	3	1	55	16
	Std	5.1	0.47	130	12	161	15	0.12	5	443	6.7	2.0	1140	333	50	15	33	10
DFSM:																		
(N=5)	Mean	36.9	3.43	340	32	538	50	0.69	3	347	6.9	2.0	1718	502	45	13	86	25
	Max	58.3	5.41	452	42	678	63	0.97	7	708	13.7	4.0	2912	850	106	31	103	30
	Min	31.3	2.91	194	18	463	43	0.01	1	47	3.1	0.9	644	188	14	4	58	17
	Std	10.7	0.99	105	10	75	7	0.35	2	220	4.3	1.3	925	270	32	9	17	5
IFFM:																		
(N=93)	Mean	32.6	3.03	793	74	603	56	0.85	3	359	6.1	1.8	806	235	68	20	193	56
	Max	57.0	5.29	1969	183	1668	155	1.03	6	7367	20.6	6.0	17130	5000	182	53	411	120
	Min	19.9	1.85	204	19	129	12	0.61	1	10	0.1	0.0	69	20	10	3	41	12
	Std	6.9	0.64	344	32	430	40	0.08	1	1064	5.0	1.5	2128	621	36	10	87	25
IFP:																		
(N=4)	Mean	25.2	2.34	635	59	312	29	0.89	2	330	5.0	1.5	41	12	111	33	139	41
	Max	29.9	2.78	882	82	441	41	0.93	3	567	8.2	2.4	82	24	192	56	195	57
	Min	16.9	1.58	398	37	194	18	0.86	1	94	1.9	0.5	0	0	31	9	82	24
	Std	5.0	0.46	237	22	118	11	0.03	1	236	3.2	0.9	41	12	81	24	57	17
DIFP:																		
(N=28)	Mean	19.4	1.81	623	58	581	54	0.84	3	852	3.0	0.9	1477	431	80	23	143	42
	Max	23.0	2.14	915	85	915	85	0.95	17	6025	6.9	2.0	3303	964	219	64	195	57
	Min	18.4	1.71	280	26	291	27	0.69	1	119	0.5	0.2	473	138	7	2	69	20
	Std	1.0	0.09	119	11	140	13	0.05	4	1165	1.7	0.5	601	175	46	13	29	8
HIDP:																		
(N=10)	Mean	22.7	2.11	381	35	194	18	0.90	5	171	9.0	2.6	703	205	46	13	90	26
	Max	27.8	2.59	667	62	204	19	0.96	10	532	20.9	6.1	1045	305	89	26	154	45
	Min	15.0	1.39	226	21	194	18	0.80	1	34	1.0	0.3	510	149	7	2	51	15
	Std	4.3	0.40	146	14	0	0	0.05	4	155	6.6	1.9	151	44	34	10	34	10

The differences between the direct and indirect systems may have been due more to the lighting design targets of the owners and lighting designers for the specific buildings than to inherent differences in the lighting systems and equipment, except for the IFFM system. The IFFM system, with its ever present task lighting should provide higher task illuminances than other lighting systems which have a mix of work stations and task lighting. As a result, there is little difference in the mean illuminance for the IFFM system between the two columns. For the direct lighting systems, both daylighting and task lighting appeared to make a meaningful contribution to illuminance at the task. The greater contribution of daylighting with the direct systems may have been due to the use of partitions with the indirect systems which blocked a substantial amount of potential daylight.

Tables 3 and 4 indicate further that of the seven types of lighting systems, the IFFM system had the <u>highest</u> mean illuminance as well as the <u>greatest variation</u> in illuminance at both the primary and secondary work surface whether the unit of analysis was the entire database or the "pure" case without daylight. The maximum illuminance for the IFFM system, 183 fc (1969 lux), was over twice the maximum illuminance found for any of the other lighting systems when there was <u>no</u> daylight or task lights. This difference was most likely due to the proximity of the task light to the surface where illuminance was measured, particularly since such differences were much less pronounced for the secondary task area.

In general, the luminance contrasts and the near surround luminance ratios (task luminance to near surround luminance) shown in tables 3 (database as a whole) and 4 (the "pure" case) were within the desired range for good design practice. Across all lighting systems, the lowest CRF was 0.57, with means for each of the systems ranging from 0.69 to 0.90. The near surround luminance ratios had a greater spread, with a minimum of 1:1 and a maximum of 35:1, but the means were between 2:1 and 5:1, quite close to the desired 3:1 ratio recommended by the IESNA. The primary difference between lighting systems occurred for the IFFM system where the difference in illuminance between primary and secondary work surfaces was greater (by a 2:1 margin) than for any other system. In addition, the luminance of the surround and the brightest area of the ceiling tended to be lower for the IFFM system.

Although the mean illuminance was highest for the IFFM system, the surround and brightest ceiling luminances were among the lowest of the seven systems.

4. Lighting Satisfaction Data

Up to this point, the analysis has focused on describing the physical characteristics of the different types of lighting systems and summarizing the LPD and photometric data. A third important question is the response of the occupants to the different types of lighting systems and work stations.

4.1 Lighting Satisfaction

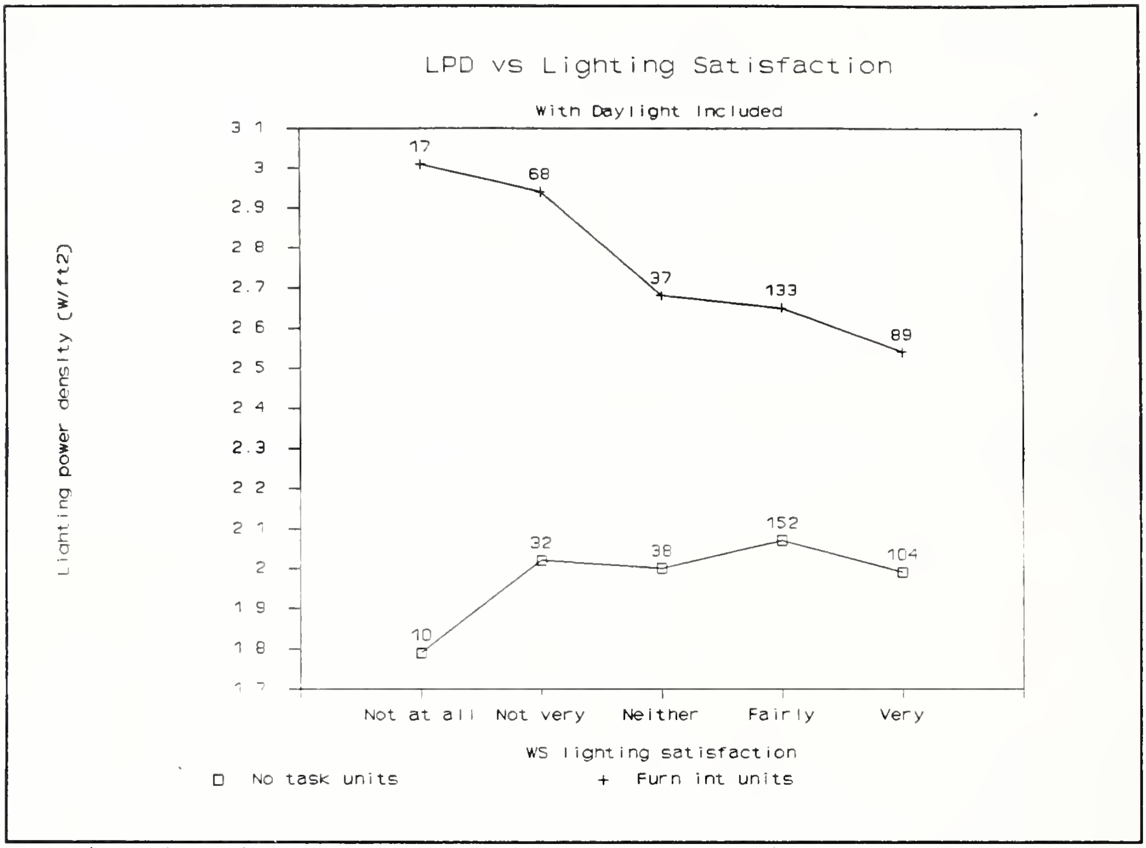
One of the most critical questions, from an illuminating engineering and lighting design point of view, is the occupant's overall satisfaction with the lighting system and the effects of different design and illumination parameters. A direct way to answer this question is to examine lighting satisfaction or the occupant's response to the question "Overall, how satisfied are you with the lighting at your office or work space?" using a five point rating scale ranging from "not at all satisfied" to "very satisfied". The next few sections will deal with the answer to this question. Satisfaction, however, is only one element of the occupant response. Other components will be explored in later sections.

4.1.1 Lighting Satisfaction, Lighting Power Density, and Illuminance

Although one of the original objectives of the POE project was to determine if the effects of LPD's on occupant satisfaction with lighting could be directly assessed, the data obtained in this project indicate that there is great difficulty in making a direct connection between the two variables. Because the relationship between LPD's and illuminance is not simple, the further connection between power and occupant response is even more complex. In addition, it is reasonable to hypothesize that occupants responded to lighting variables, which they could see, rather than power variables which they did not see. A detailed examination of the data shown in figure 16 confirms that there was no simple relationship between occupant satisfaction with lighting and LPD's. As a result, because earlier sections of the present report make it clear that a given LPD can produce a wide range of illuminances on the working surface, it appears more fruitful to relate occupant response directly to lighting variables, such as illuminance.

Figure 17 plots the relationship between illuminance and mean lighting satisfaction for the database as a whole for work stations without task lighting and for work stations with furniture integrated task lighting, while figure 18 plots similar data for work stations with daylight and then without daylight. In these figures, illuminance was separated into four categories of 0-39 fc, 40-79 fc, 80-119 fc, and 120+ fc. The mean rating of lighting satisfaction (where 1=dissatisfied and 5=very satisfied) was then calculated for each illuminance category.

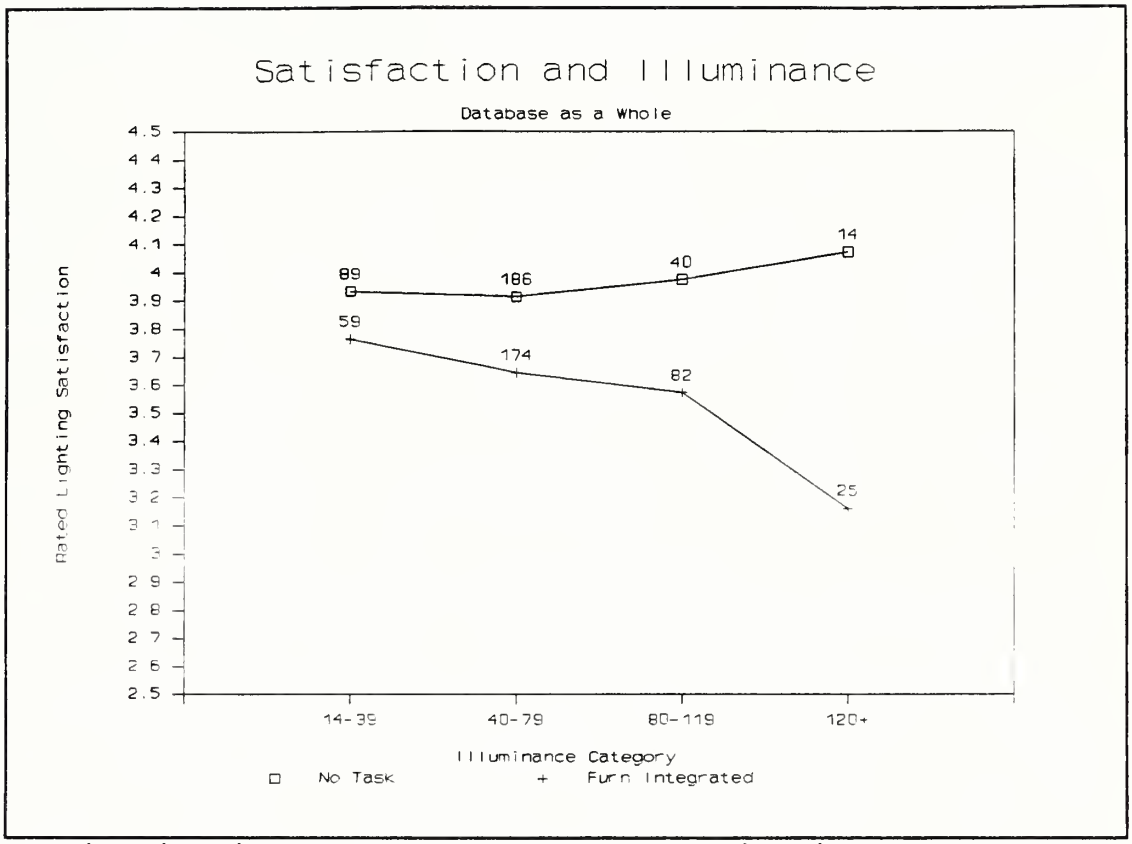
Inspection of figure 17 indicates that lighting satisfaction ratings were consistently lower for work stations with furniture integrated task lighting. Furthermore, satisfaction tended to decrease with illuminance for these work stations. Conversely, satisfaction was always higher for work stations without task lighting, and also showed a slight tendency to increase with illuminance. A χ^2 test, in which the distribution of ratings



Daylighting included; non-system task units excluded.

Figure 16. Mean LPD as a function of each rating of work station lighting satisfaction for <u>All</u> work stations.

In this figure, the data represent the mean power density at each individual satisfaction rating. The lower curve shows no relation between LPD and lighting satisfaction for workstations that did not have task lighting. The upper curve, however, indicates that the LPD's were consistently higher for work stations with furniture integrated lighting. In addition, it demonstrates that the mean LPD's were highest for those work stations with furniture integrated lighting which received the lowest ratings of lighting satisfaction.



Daylighting included; non-system task lighting excluded.

Figure 17. Mean satisfaction rating as a function of illuminance category for all work stations in the database.

In this figure, the upper curve, shown with squares, represents those work stations with no task lighting, while the lower curve, shown with pluses, represents work stations with furniture integrated task lighting. As can be seen satisfaction was consistently higher for work stations with no task lighting. Furthermore, satisfaction tended to stay constant or increase only slightly with illuminance for these work stations, but decrease for those with task lighting.

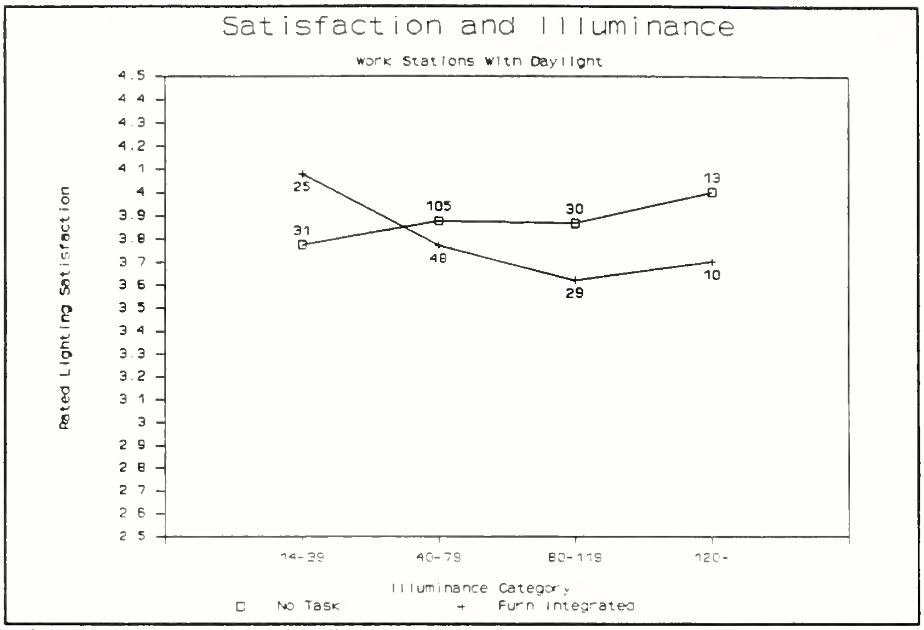


Figure 18a. Daylight only.

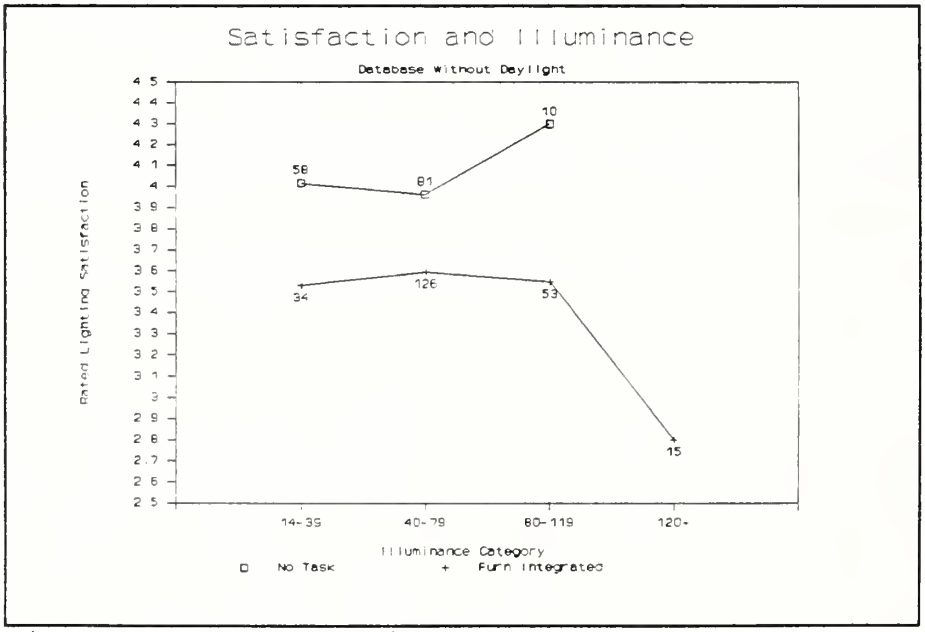


Figure 18b. No daylight.

Figure 18. Mean rated satisfaction as a function of illuminance category for work stations with and without daylight.

This figure indicates that satisfaction is lowest for work stations with furniture integrated task lighting with no daylight present, and that it tends to decrease with increasing illuminance. The effect of daylight is greatest for work stations with task lighting.

for work stations with task lighting was compared to those without task lighting, was significant ($p<.0001$), indicating that ratings of lighting satisfaction were lower for task lighting. Thus, not only were the mean ratings of lighting satisfaction higher for those without task lighting, the frequency of people giving higher ratings (4's and 5's) was also greater.

Figure 18a presents the mean satisfaction ratings for the four illuminance categories for occupants with and without furniture integrated task lighting for work stations with some daylight. Figure 18b presents similar data for work stations without daylight. Both figures confirm the data of figure 17; namely that those without task lighting had generally higher satisfaction, and that this tended to stay constant or increase only slightly with illuminance. The decline in rated satisfaction with illuminance was greatest for work stations without daylight, as shown in figure 18b.

Lighting satisfaction was significantly higher, and tended to increase as illuminance increased for those people at work stations without furniture integrated task lighting.

4.1.2 Lighting Satisfaction and Lighting System Type

A fruitful way of looking at the occupant response data is to examine the overall lighting satisfaction for all lighting systems combined, and for individual lighting systems with and without daylighting and task lighting. In section 5, several occupant response variables will be combined to create an index of lighting quality. The effect of different work station lighting designs on these combined variables will also be examined.

4.1.2.1 General Response to the Lighting Systems

Table 5 presents a distribution of the satisfaction ratings for all work stations combined, followed by the ratings for work stations with and without daylight, and then for those with and without task lighting.

The upper portion of table 5 indicates that about 69% of all respondents were either "fairly" or "very" satisfied with their lighting, 12% were neutral, and 20% were either "not very" or "not at all" satisfied with their lighting. For convenience, the "fairly" and "very" satisfied ratings are often combined to form a "satisfied" category, while the "not very" and "not at all" ratings are combined to form a "dissatisfied" category. An important issue to explore is the reasons for the dissatisfaction with the lighting - to determine if there are lighting design factors which could be related systematically to lower levels of lighting satisfaction. As a result, the various subgroups identified earlier were examined in relation to occupant satisfaction.

Table 5. Work Station Lighting Satisfaction for All Respondents, for Those With and Without Daylight, and for Those With and Without Task Lighting.

Lighting Satisfaction:	Work stations w/All Respondents		
Not at all	32	4%	
Not Very	130	16%	} 20% Dissatisfied
Neither	94	12%	
Fairly	345	43%	
Very	210	26%	} 69% Satisfied
Totals	811	100%	

Lighting Satisfaction:	Work stations w/ Daylight		w/o Daylight		w/ Task Lighting		w/o Task Lighting	
Not at all	14	4%	18	4%	21	5%	10	3%
Not Very	52	15%	78	17%	94	21%	32	10%
Neither	39	11%	55	12%	52	11%	38	11%
Fairly	155	43%	190	42%	186	41%	152	45%
Very	98	27%	112	25%	102	22%	104	31%
Totals	358	100%	453	100%	455	100%	336	100%

Daylight: $\chi^2 = 22.41$, df=4, $p < 0.001$

Task Lighting: $\chi^2 = 145.03$, df=4, $p < 0.0001$

Work Stations / Lighting Satisfaction:	w/Daylighting: w/ Task Lighting		w/o Task Lighting		w/Task Lighting: w/ Daylight		w/o Daylight	
Not at all	6	4%	8	4%	6	4%	15	5%
Not Very	31	19%	19	10%	31	19%	63	22%
Neither	19	11%	19	10%	19	11%	33	11%
Fairly	72	43%	80	44%	72	43%	113	39%
Very	39	23%	56	31%	39	23%	63	22%
Totals	167	100%	182	100%	167	100%	287	100%

w/Daylighting: $\chi^2 = 14.04$, df=4, $p < 0.01$

w/Task Lighting: $\chi^2 = 51.61$, df=4, $p < 0.0001$

The first subdivision explored is the impact of daylight or adjacency to a window on occupant satisfaction. An examination of the frequency of ratings for this subdivision in table 5 indicates that those with daylight were slightly more satisfied (70% vs 67%) than those without. A χ^2 analysis of the difference was statistically significant ($p < 0.001$).

The second subdivision considered is the effect of task lighting on occupant satisfaction, given in table 5. This comparison indicates that there was a significant difference in the frequency distribution of the ratings according to a χ^2 analysis ($p < 0.0001$). Thus, 26% of those with task lighting at their work station were "not at all" or "not very" satisfied with their lighting, as compared with only 13% of those who did not have task lighting. Conversely, only 63% of those with task lighting were satisfied, as compared with 76% of those who did not have task lighting.

The lower portion of table 5 subdivides the data further, with the first portion presenting the frequency distributions of satisfaction ratings for locations with and without task lighting for work stations with daylight. This comparison again indicates that there was a higher frequency of dissatisfied ratings (23%) for work stations with task lighting as compared to work stations without task lighting (14%). A χ^2 analysis was also significant ($p < 0.01$). The presence or absence of daylight in work stations with task lighting also had an impact. Thus, those without daylight expressed more dissatisfaction (27%) as compared to those with daylight (23%). A χ^2 analysis was significant ($p < 0.0001$).

These comparisons suggest strongly that, although some 70% of the occupants were satisfied with their lighting, the presence of task lighting as implemented in the work stations studied was one of the major contributors to dissatisfaction with the lighting.

4.1.2.2 Impact of the Seven Lighting Systems

In table 6, the effect of each of the seven ambient lighting systems (including both task lighting and daylighting) on lighting satisfaction ratings was examined. As had been shown in table 5a, the majority of those responding (69%) were satisfied with their lighting system, with only about 20% being dissatisfied.

Table 6 indicates, however, that the type of ambient lighting system had a major influence on rated satisfaction with the lighting system. As can be seen from this table, the percentage of people expressing dissatisfaction with their lighting was greatest for the IFFM system (about 37%). This is the system that combines task lighting with indirect furniture integrated ambient lighting. At least two thirds of those with each other system expressed satisfaction with it, except for the IFFM system where only about half (56%) were satisfied. Table 6 also indicates that people tended either to like or dislike the IFFM system, with relatively few (7%) being neutral about it. The following sections will concentrate on defining some of the reasons for the problems with the IFFM system - particularly since it had higher LPD's and task illuminances than the other six systems.

Table 6. Ratings of Work Station Lighting Satisfaction for the Seven Systems.

Type	Dissatisfied	Neutral	Satisfied	Total
DRFLV	13%	13%	73%	278
DRFLN	22%	12%	66%	143
DFSM	16%	10%	74%	38
IFFM	37%	7%	56%	148
IFP	17%	13%	70%	71
DIFP	16%	13%	71%	69
HIDP	0%	12%	88%	32
Total N	153 (20%)	90 (11%)	536 (69%)	779

The data suggest that the combination of task lighting with an indirect ambient lighting system had an important influence on reducing lighting satisfaction.

4.1.2.3 Impact of the Ambient Lighting System Alone

The next step is to evaluate the occupants' satisfaction with their lighting as a function of the seven ambient lighting systems alone without the influence of either daylight or task lighting. Table 7 presents the rating data for each system without either task units or daylight (n=255). Figure 19 plots the satisfaction ratings for five of the seven systems given in table 7. Here the disparity between the furniture integrated and the other lighting systems is accentuated. This figure indicates that nearly half (46%) of the occupants with the IFFM system were dissatisfied as compared with only 5% of those with the direct system with louvers (DRFLV) and 10% for those with the direct system with lenses (DRFLN).

Table 7 indicates that for the same ambient lighting system, over two-thirds (68%) of the occupants with the IFFM system gave low ratings of the amount of light available for work, even though the illuminances directly at the primary work station were the highest of the seven systems. One third (34%) of the occupants with this system felt the lighting for reading and writing was either poor or not very good. Figure 20 indicates that the presence of daylight (adjacency to a window) in the work station improved the overall satisfaction with the IFFM lighting system, however. Thus, lighting satisfaction levels were substantially higher for people who worked under the same system but who had <u>some</u> daylighting. Lighting satisfaction ratings for the IFFM system were somewhat lower for those who had VDT's at their work station (46% expressed dissatisfaction as compared with 35% of those without VDTs) as shown in table 8.

Although many occupants gave negative ratings for the lighting in the IFFM system, none of the classical field measures shown in Tables 3 and 4 (CRF, illuminances, near surround, far surround, task luminance ratios, or indivdual luminances) for the seven systems fully explained these responses. The average task illuminances of 793 lux (74 fc) and minimum task contrasts of 0.85 were within acceptable ranges. The average near surround luminance ratio of 3:1 (maximum of 6:1) was also within recommended practice.

To explain some of the negative reaction to the IFFM system in particular, the differences in illuminances between the primary and secondary work stations were evaluated. It was thought that this would provide some information about the presence of bright and dark spots in the work station. As mentioned in section 3.1.2, examination of the photometric data indicated that some of the highest <u>and</u> lowest illuminances occurred with the IFFM system. These large differences between the illuminance at the primary and secondary work station may have influenced some of the unfavorable occupant responses. To illustrate this point, the <u>difference</u> between the illuminance at the primary and the secondary work surface was plotted in figure 21 for occupants who expressed dissatisfaction and satisfaction with their lighting systems for both the IFFM system and the DRFLV system. Table 9 presents photometric data for these work stations.

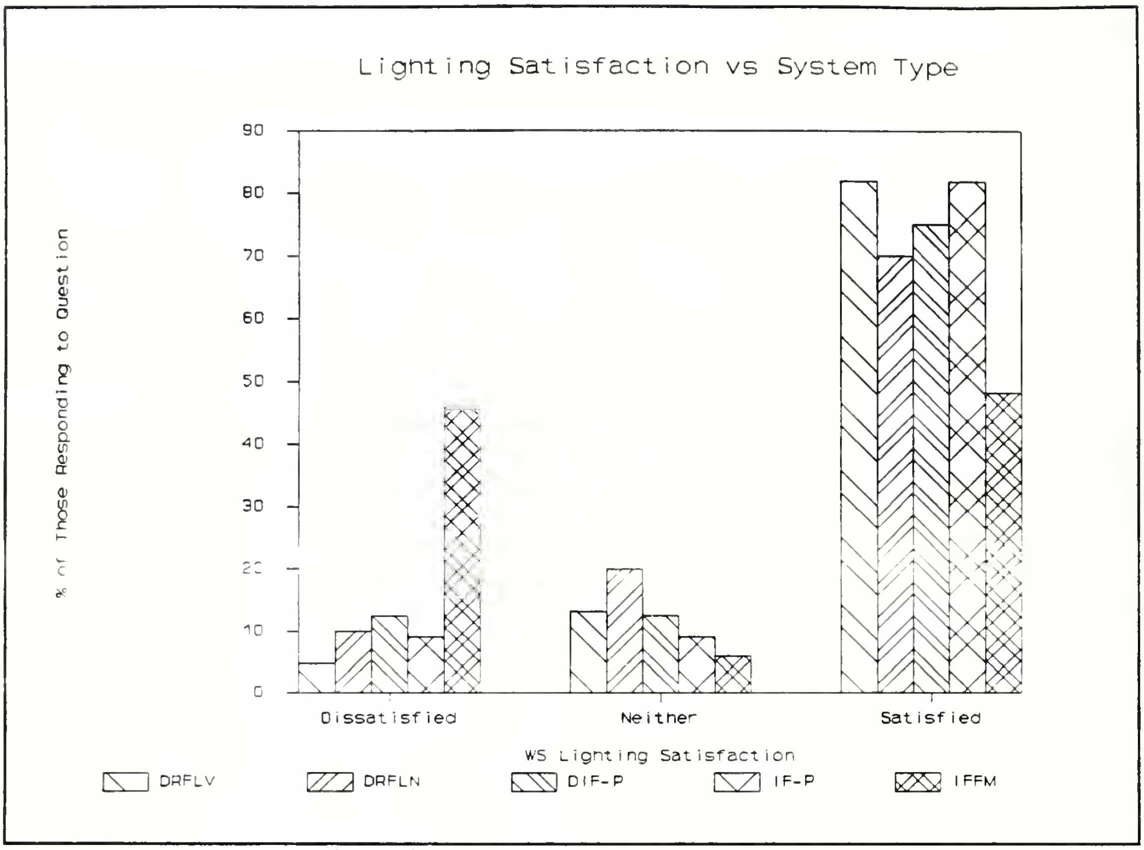
Table 7. Occupant response measures for ambient systems without task lighting and without daylighting.

Occupant Response Measures: No Task Units (except IFFM) and Little Daylight

	DRFLV	(%)	DRFLN	(%)	DFSM	(%)	IFFM	(%)	IFP	(%)	DIFP	(%)	HIDP	(%)
WS LIGHTING SATISFACTION:														
Not at all	1	1	0	0	0	0	10	12	1	25	0	0	0	0
Not very	3	4	2	10	1	25	28	34	1	25	3	13	0	0
Neither	11	13	4	20	0	0	5	6	0	0	3	13	1	10
Fairly	36	43	11	55	3	75	29	35	1	25	12	50	5	50
Very	32	39	3	15	0	0	11	13	1	25	6	25	4	40
(other)	8		4		1		10		0		4		0	
AMOUNT OF LIGHT FOR WORK:														
Poor	4	5	1	5	0	0	26	31	0	0	2	8	0	0
Fair	9	11	9	45	1	25	31	37	2	50	5	20	1	11
Good	45	54	8	40	3	75	19	23	1	25	16	64	5	56
Excellent	25	30	2	10	0	0	8	10	1	25	2	8	3	33
(other)	8		4		1		9		0		3		1	
LIGHT FOR READING:														
Poor	1	1	0	0	0	0	12	15	1	25	2	8	0	0
Not very good	5	6	3	15	1	25	15	19	1	25	2	8	0	0
Neutral	6	7	3	15	0	0	18	23	0	0	3	13	1	10
Good	43	53	10	50	2	50	27	34	1	25	12	50	4	40
Excellent	26	32	4	20	1	25	8	10	1	25	5	21	5	50
(other)	10		4		1		13		0		4		0	
GLARE FROM WORK SURFACE:														
Not at all	31	39	5	26	0	0	29	37	1	33	6	25	7	70
Not very	33	41	7	37	3	75	23	29	0	0	13	54	3	30
Fairly bothered	9	11	5	26	1	25	15	19	1	33	5	21	0	0
Very Bothered	7	9	2	11	0	0	12	15	1	33	0	0	0	0
(other)	11		5		1		14		1		4		0	
GLARE FROM TASK LIGHTS:														
Not at all	43	61	10	63	2	50	34	46	3	100	12	57	6	60
Not very	20	28	3	19	2	50	18	24	0	0	8	38	3	30
Fairly bothered	4	6	2	13	0	0	14	19	0	0	1	5	1	10
Very Bothered	4	6	1	6	0	0	8	11	0	0	0	0	0	0
(other)	20		8		1		19		1		7		0	
GLARE FROM CEILING LIGHTS:														
Not at all	32	40	7	35	1	25	46	59	1	25	8	33	4	40
Not very	33	41	5	25	2	50	20	26	0	0	13	54	4	40
Fairly bothered	8	10	6	30	1	25	8	10	2	50	2	8	2	20
Very Bothered	8	10	2	10	0	0	4	5	1	25	1	4	0	0
(other)	10		4		1		15		0		4		0	
BRIGHT LIGHTS:														
Not at all	43	54	8	40	2	50	48	63	2	50	9	41	7	78
Not very	22	28	5	25	1	25	18	24	1	25	12	55	1	11
Fairly bothered	8	10	5	25	1	25	8	11	1	25	0	0	1	11
Very Bothered	6	8	2	10	0	0	2	3	0	0	1	5	0	0
(other)	12		4		1		17		0		6		1	
GLARE ON CRT SCREEN:														
Not at all	13	28	2	18	0	0	12	38	1	50	6	40	3	50
Not very	19	41	3	27	0	0	6	19	0	0	4	27	0	0
Fairly bothered	7	15	4	36	3	100	11	34	0	0	3	20	2	33
Very Bothered	7	15	2	18	0	0	3	9	1	50	2	13	1	17
(other)	45		13		2		61		2		13		4	

Table 8. Work Station Lighting Satisfaction for Areas With and Without VDT's for the IFFM System.

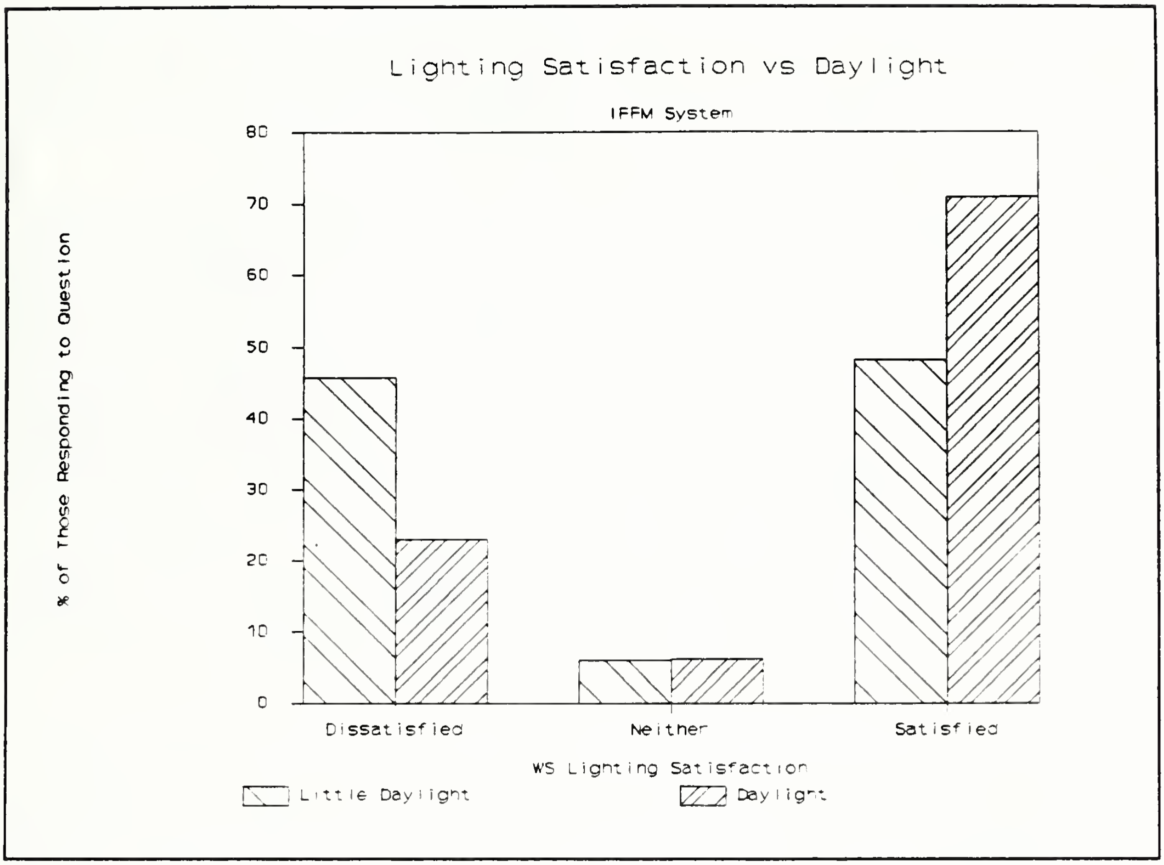
	No Daylight		With Daylight		All	
	No VDT	VDT	No VDT	VDT	No VDT	VDT
Satisfaction						
Not At All	10%	19%	8%	11%	9%	16%
Not Very	34%	33%	13%	22%	26%	30%
Neither	6%	5%	8%	0%	7%	3%
Fairly	35%	33%	49%	44%	41%	37%
Very	15%	10%	23%	22%	18%	13%
Total N	62	21	39	9	102	30



Non-system task lighting excluded.

Figure 19. Percentage of respondents rating satisfaction with their lighting systems for five different lighting systems.

In this figure the percentage of people rating their lighting as "fairly" or "very" satisfactory were combined into one "satisfied" category, while those people rating their lighting satisfaction as "not at all" or "not very" were combined into a "dissatisfied" category. The figure indicates that a much greater percentage (45%) of people with the IFFM system expressed dissatisfaction with their lighting as compared with those with any other system. Conversely, between 70 and 80% of those with four other systems expressed satisfaction with their lighting as compared to only 48% with the IFFM system. In addition, fewer people who had the IFFM system were neutral - they tended to be either dissatisfied or satisfied, but not neutral.



Furniture integrated task lighting only.

Figure 20. Percentage of respondents rating satisfaction with their lighting systems for the IFFM system.

This figure indicates that almost twice as many people with the IFFM system without daylight expressed dissatisfaction as compared with those who had daylight in their work stations. Similarly, a greater percentage (75%) of those with daylight expressed satisfaction.

Figure 21 indicates that people who were dissatisfied with their lighting system tended to have greater differences between their primary and secondary task illuminance. It also indicates that the illuminance difference was smaller for the DRFLV system than for the IFFM system, and smallest for those expressing satisfaction with the DRFLV system.

Thus far, the discussion suggests that the use of task lighting, particularly furniture integrated lighting, resulted in less satisfaction with the lighting at the work station. Because task lighting was employed with at least two general types of ambient lighting - direct and indirect, the effects of the directionality of the ambient lighting must also be explored. This analysis is made easier by the fact that these two ambient lighting systems were used at a substantial number of work stations with identical systems furniture and task lights.[6] One set of work stations had a direct recessed fluorescent system with louvers (DRFLV), while the other had an indirect furniture mounted system (IFFM). Figure 22, which compares the responses to the two lighting systems, reveals that 68% of those with the direct ambient system were satisfied with their lighting, while only 48% of those with the indirect ambient system were satisfied. While 46% of those with the indirect ambient system were dissatisfied, only 17% of those with the direct system with the same task lighting were dissatisfied.

The data indicate that for identical furniture systems with integrated task lighting (IFFM and DRFLV with task lighting), occupant satisfaction was higher where the ambient lighting consisted of recessed ceiling luminaires with louvers, than where the ambient lighting was provided by indirect furniture integrated luminaires.

Another dimension of the occupant response to the lighting is contained in the response to the question "Please describe your space" by using a seven point scale going from "bright" to "dim". Responses to this question reflect the occupants' perception of the brightness of their spaces. Table 10 contains responses to this question for those work stations with identical systems furniture but different ambient lighting (the DRFLV and IFFM systems that were discussed above). Although both the mean primary and secondary task illuminances were higher for the IFFM system, nearly half (43%) of the occupants in these spaces rated their work station as being dim as compared to 21% of those with the direct system. Ratings of harshness were virtually the same for both lighting systems, however.

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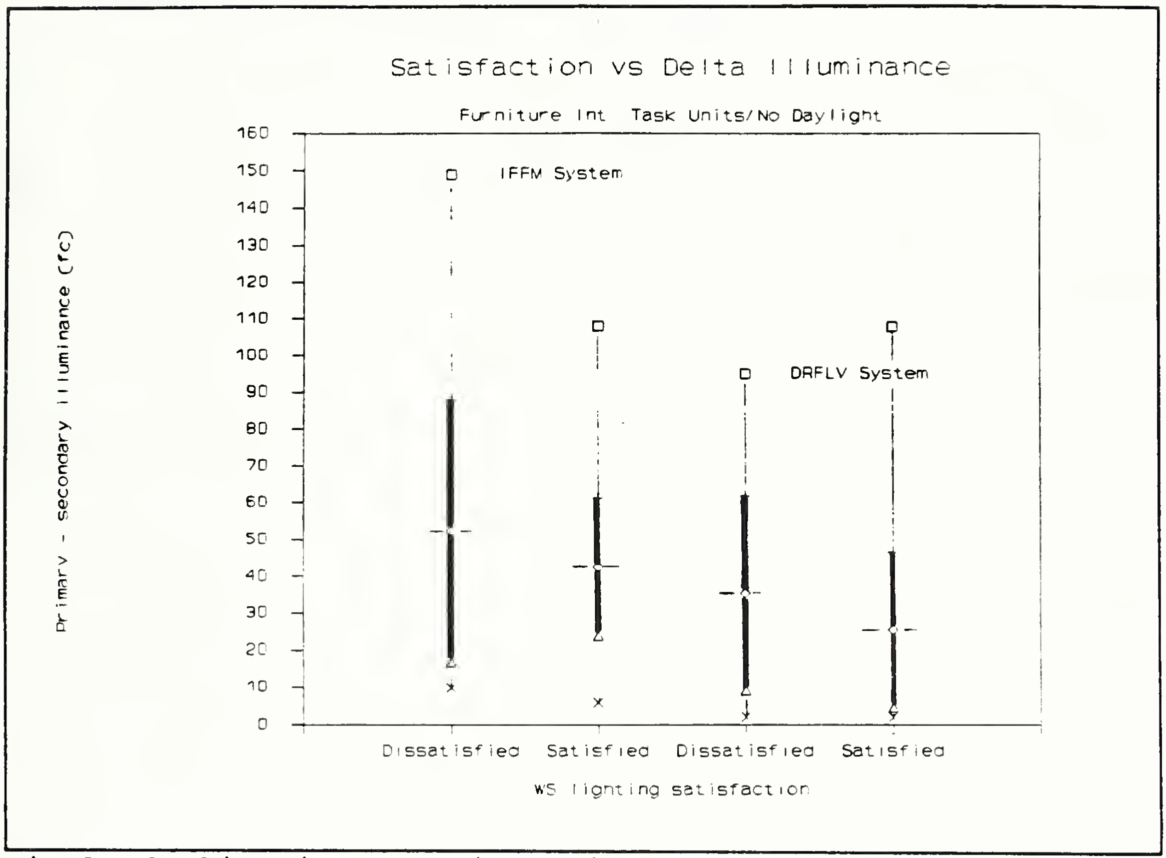
[6] These workstations contained little daylight



Little daylighting; furniture integrated task lighting only.

Figure 21. Occupant ratings of lighting satisfaction as a function of difference in illuminance between primary and secondary task location for DRFLV and IFFM systems.

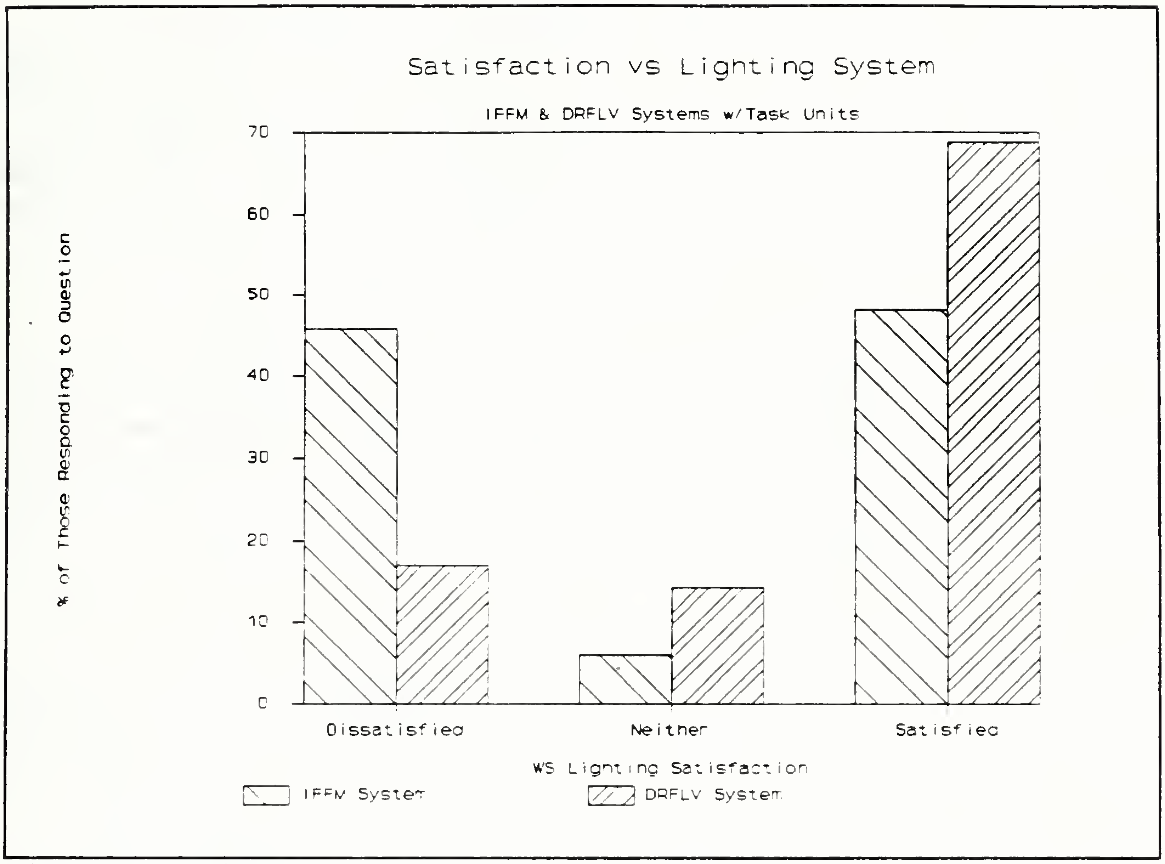
This figure indicates that the difference between the primary and secondary task locations was greater by about 10 fc for those who were dissatisfied with their lighting system than for those who were satisfied. The differences between the two locations were greatest for the IFFM system.

Table 9. Summary Photometric Data for Dissatisfied and Satisfied Occupants for the DRFLV and IFFM Systems.

		LPD		Illuminance w/Body Shadow Primary		Secondary		Difference		Min
		W/m2	(W/ft2)	lx	(fc)	lx	(fc)	lx	(fc)	CRF
DISSATISFIED										
IFFM System:										
(N=38)	Mean	34.9	3.24	75	806	61	652	53	575	0.87
	Max	47.2	4.39	183	1969	155	1668	149	1603	1.03
	Min	25.7	2.39	19	204	14	151	10	108	0.71
	Std	7.0	0.65	36	383	40	435	36	389	0.07
DRFLV System:										
(N=19)	Mean	31.8	2.96	78	835	58	628	36	382	0.83
	Max	44.6	4.15	133	1431	124	1334	95	1022	0.92
	Min	22.4	2.08	28	301	22	237	2	22	0.68
	Std	6.9	0.64	34	361	25	271	26	283	0.08
SATISFIED										
IFFM System:										
(N=40)	Mean	30.9	2.87	73	781	51	553	43	464	0.83
	Max	57.0	5.29	141	1517	154	1657	108	1162	0.95
	Min	22.4	2.08	20	215	12	129	6	65	0.61
	Std	6.1	0.56	27	293	39	420	26	278	0.09
DRFLV System:										
(N=77)	Mean	28.2	2.62	64	687	53	573	25	267	0.84
	Max	71.9	6.68	146	1571	150	1614	108	1162	0.96
	Min	15.8	1.47	18	194	4	43	0	0	0.49
	Std	7.7	0.71	26	283	25	268	21	227	0.09

(Continued)

		Luminance Ratios:		Darkest Luminance		Brightest Luminance		Surround Luminance		Task Luminance		Ceiling Luminance	
		Near	Far	cd/m2	(fL)	cd/m2	(fL)	cd/m2	(fL)	cd/m2	(fL)	cd/m2	(fL)
DISSATISFIED													
IFFM System:													
(N=38)	Mean	3	545	5.8	1.7	848	248	71	21	196	57	367	107
	Max	6	5167	20.6	6.0	3227	942	154	45	411	120	719	210
	Min	1	18	0.3	0.1	147	43	10	3	48	14	75	22
	Std	1	1303	5.6	1.6	751	219	37	11	98	29	179	52
DRFLV System:													
(N=19)	Mean	4	814	5.1	1.5	3151	920	105	31	207	60	1026	300
	Max	18	3233	9.3	2.7	5105	1490	298	87	377	110	4625	1350
	Min	1	260	1.0	0.3	1182	345	7	2	82	24	178	52
	Std	4	687	2.4	0.7	1188	347	83	24	94	27	1424	416
SATISFIED													
IFFM System:													
(N=40)	Mean	3	290	6.1	1.8	1601	467	63	18	187	55	317	93
	Max	5	1300	20 6	6.0	11306	3300	178	52	370	108	757	221
	Min	2	20	0.1	0.0	69	20	10	3	41	12	48	14
	Std	1	407	4.3	1.2	2788	813	32	9	69	20	166	48
DRFLV System:													
(N=77)	Mean	4	1145	5.0	1.5	2432	710	82	24	180	53	1503	439
	Max	31	8650	24.0	7.0	5790	1690	288	84	456	133	5208	1520
	Min	1	8	0.1	0.0	10	3	3	1	41	12	17	5
	Std	4	1505	4.4	1.3	1484	433	67	20	77	22	1452	424



Little daylighting; furniture integrated task lighting only.

Figure 22. Percentage of respondents expressing satisfaction with their lighting system for the IFFM and DRFLV (with task lighting) systems.

This figure demonstrates that a much greater percentage of those with the IFFM system were dissatisfied with their lighting when compared with those with the DRFLV system - even with a comparable furniture integrated task lighting system. (Neither set of work stations was considered to have daylight.) The figure reinforces the contention that the combination of task lighting with an indirect ambient lighting system was less satisfactory to these respondents.

Table 10. Rating of Lighting Harshness, Atmosphere, and Brightness for Two Lighting System Types

Table 10a. Ratings of Lighting Harshness and Softness for Different Ambient Lighting System Types

Rating	DRFLV		IFFM		Total	
Harsh Lighting	10	9%	9	12%	19	10%
	10	9%	5	6%	15	8%
	33	30%	20	26%	53	28%
	18	16%	15	19%	33	18%
	29	26%	19	25%	48	26%
Soft Lighting	10	9%	9	12%	19	10%
Totals	110	100%	77	100%	187	100%

Table D10b. Lighting System by Rating of Work Station Atmosphere

Rating	DRFLV		IFFM		Total	
Tense	2	2%	3	4%	5	3%
	13	12%	3	4%	16	8%
	9	8%	9	11%	18	9%
Neutral	18	16%	22	27%	40	21%
	19	17%	5	6%	24	13%
	33	30%	21	26%	54	28%
Relaxed	16	15%	19	23%	35	18%
Totals	110	100%	82	100%	192	100%

Table 10c. Lighting System Type by Rating of Work Station Brightness

Rating	DRFLV		IFFM		Total	
Dim	10	9%	19	24%	29	15%
	13	12%	15	19%	28	15%
	21	19%	12	15%	33	17%
	20	18%	11	14%	31	16%
	34	31%	17	21%	51	27%
Bright	13	12%	6	8%	19	10%
Totals	111	100%	80	100%	191	100%

Nearly half (46%) of the occupants with the IFFM system were dissatisfied as compared with only 5% of those with the direct system with louvers (DRFLV) and 10% for those with the direct system with lenses (DRFLN). Satisfaction was also higher for those people with identical furniture systems with integrated task lighting (IFFM and DRFLV with task lighting), when the ambient lighting consisted of recessed ceiling luminaires with louvers, than when the lighting was provided by indirect furniture integrated luminaires.

4.2 Analysis of the Response to Luminance

The analysis thus far indicates that occupants responded less favorably to the combination of furniture integrated task and indirect ambient lighting (IFFM system), and rated it as dimmer than systems using direct lighting. As noted earlier, work stations with this configuration had higher task illuminances and luminances than most other work stations. In addition, the negative ratings for the IFFM system shown in table 4 did not appear to relate to the classical field measures (CRF, illuminances, near surround, far surround, and task luminance ratios, and brightest, darkest, and task luminances).

Occupants with task lighting, particularly with the IFFM system, frequently rated their lighting as neither satisfactory nor bright. This finding suggests that the distribution of luminances and the placement of the light sources were somehow unacceptable, particularly when combined with indirect ambient lighting systems.

4.2.1 Average Luminance

Because no single illuminance or luminance measure could be related to lighting satisfaction ratings in any meaningful way, a summary measure of all the luminance data for each work space was created. Termed "average luminance", this measure was used to explore the relationships between luminance in the space and ratings of satisfaction, brightness and glare, as well as various photometric variables. These relationships were explored by averaging the ten measures of luminance to create "average luminance" and then organizing (sorting) selected photometric and occupant response measures by it.

Average luminance as discussed here is a preliminary formulation with many simplifying assumptions applied to the analysis. For example, in the present analysis, all the luminances in the space were weighted equally, even though certain luminances may well have been more important in determining the occupants' response to the lit environment. In future analyses the effect of different weighting factors for different areas of the work station should be explored.

Yet, average luminance appeared to be a reasonable way of summarizing the 10 luminance values for a space, and providing a better summary estimate of what the occupant sees than one luminance measure alone. Early analysis of the data revealed that neither illuminance nor luminance level predicted occupant satisfaction ratings very well. Rather, there were anomalies, particularly for the IFFM system, in which increasing illuminance appeared to lead to lower ratings of lighting satisfaction. In some of these cases, although the task illuminance was reasonably high, occupants reported that their spaces were not bright enough. These patterns of results suggested that there was some photometric quality other than task illuminance to which occupants were responding. Luminance of the task alone did not appear to be the answer since that closely followed task illuminance. Yet, because the occupants were so definite about their responses, and since there was no reason to suppose that they were responding more irrationally to their lighting systems than to other environmental variables such as temperature, it seemed appropriate to evaluate some of the other luminance measures more closely. Luminance directly ahead was examined first since that appeared to be what occupants might be looking at, followed by that to the left and to the right, but no clear-cut pattern emerged. Similarly, the effects of averaging three ceiling luminance measures (brightest area, luminaire, and ceiling between luminaires) were evaluated, only to find that no clear patterns emerged for this measure either. When all the luminances were averaged, however, the patterns of response to the other occupant and photometric variables began to make sense.

The rationale for averaging all the luminances is thus based on the hypothesis that the occupants' response to the brightness of their spaces is a response to the whole space - to its total lighting gestalt - as opposed to a single luminance value. There are limitations to this approach - in that there are likely to be better ways of summarizing the data than averaging them - but exploring these avenues would require a luminance meter capable of measuring all the luminances in a scene and then developing weighting factors for the occupant response. Such a meter is currently under development by Kambich and Rea (1987).

As used in the present report, average luminance is a composite photometric variable developed by averaging ten luminance readings taken for each work station, namely:

- luminance of the ceiling between luminaires;
- brightest light source in the field of view;
- brightest ceiling area in field of view;
- darkest area in the field of view;
- task luminance (white bond paper);
- surround luminance (work area immediately next to paper);
- wall luminance at eye level straight ahead;
- luminance 90° to the right;
- luminance 90° to the left; and
- sky luminance at the window.

To begin the analysis, the data for several occupant rating and photometric variables in the database were sorted by average luminance categories: 0-49, 50-99, 100-199, 200-299, 300-399, 400-499 and 500+ fL (0-167, 168-339, 340-682, 683-1024, 1025-1367, 1368-1709, and 1710+ cd/m^2). Each category contains only the average luminance data that fell between the upper and lower bounds of the category. Table 11 presents the summary data for the rating and photometric variables for each categories. Grouping a large set of the data in this way allows one to compare both occupant ratings and photometric variables for a given average luminance category.

4.2.2 Relationship Between Average Luminance and Occupant Response

To examine the relationship between average luminance and other occupant and photometric variables, the data in table 11 were sorted and categorized by average luminance, first for the database as a whole, and then for the seven individual lighting systems. The first five columns in the table are the occupant rating data; the remaining columns are photometric data. Each entry in a column is the mean for the data as categorized by each average luminance category - i.e., those between 0 - 49 fL, between 50 - 99 fL, etc.

The occupant rating data presented in table 11 include the means for work station lighting satisfaction, work station brightness, glare from work surface, glare from task light, and glare from the ceiling light. The photometric data include the means for the individual luminances, the primary and secondary illuminances, and the LPD's. Examination of the data for the full sample indicates that 94% of the work stations fell into the first five categories of average luminance (0 - 399 fL). Twenty two percent of the data were categorized as being between 0 - 49 fL; 17% between 50 - 99 fL; 29% between 100 - 199 fL; 17% between 200 - 299 fL; 9% between 300 - 399 fL; and the remaining 7% above 400 fL.

Examination of table 11 reveals that the ratings for both mean lighting satisfaction and mean work station brightness increased with increasing average luminance category, at least up to the 300-399 fL category. This category, which contained only 9% of the data, represents a reversal in satisfaction ratings. At the same time the three ratings for problems with glare show a marked increase for this category (meaning that it is more bothersome), and were higher than for any other average luminance category. This suggests that the ratings of lighting satisfaction may have declined because of increasing problems with glare at the task for this average luminance.

Of particular interest in the present analysis is the way in which the photometric values increased with increasing average luminance category. This relationship also held true for ceiling brightness, brightness between luminaires, brightness of the luminaire, luminances to the left and right, and window luminance. The only major break in the trend to increase regularly with average luminance category occurred for luminances straight ahead where there was some deviation for the fourth and fifth categories (200-299 fL, and 300-399 fL). Even the two illuminance categories follow the pattern set by the average luminance categories.

The pattern observed for the database as a whole generally held true for the seven individual lighting systems, although there was more variation depending on lighting system. The most revealing comparisons are those between the DRFLV, DRFLN, and IFFM systems, which comprised 70% of the work stations.

Table 11. Data Sorted by Average Luminance for Full Database and for Individual Lighting Systems.

All Data Sorted by Average Luminance:

LUMave	n	(%)	WSLITSAT	WSBRT	GLRWKSF	GLRTSKLT	GLRCLNLT	LUMBRCLN	LUMBRLIT	LUMCBWL	LUMDRKST	LUMSUR	LUMTASK	LUMWLFT	LUMWRGT	LUMWSRT	LUMWIN	ILLUMPBS	ILLUMSBS	LPD
0-49	197	22%	3.5	4.6	2.0	1.7	1.7	103	151	13	1.7	18	46	10	10	10	88	60	49	2.8
50-99	152	17%	3.6	4.7	1.9	1.7	1.8	135	356	15	1.6	22	46	24	21	18	261	59	52	2.4
100-199	259	29%	3.8	5.0	2.0	1.7	1.8	228	721	15	2.1	23	48	37	43	33	476	62	59	2.4
200-299	155	17%	4.0	5.4	1.8	1.7	1.8	642	886	17	2.3	23	50	117	71	61	652	62	59	2.3
300-399	83	9%	3.4	4.9	2.2	1.8	2.3	1139	1194	18	3.4	29	56	160	85	27	745	68	67	2.2
400-499	23	3%	3.8	5.5	2.0	1.4	1.9	1274	1208	39	6.6	35	68	192	320	36	1176	82	103	2.4
500+	32	4%	4.0	5.3	2.0	1.6	1.8	1134	2020	31	7.9	49	78	296	706	217	2805	90	87	2.7
	===	=====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====
	901	100%	3.7	4.9	2.0	1.7	1.8	378	755	16	2.4	24	50	59	57	33	657	63	59	2.5

DRFLV System:

LUMave	n	(%)	WSLITSAT	WSBRT	GLRWKSF	GLRTSKLT	GLRCLNLT	LUMBRCLN	LUMBRLIT	LUMCBWL	LUMDRKST	LUMSUR	LUMTASK	LUMWLFT	LUMWRGT	LUMWSRT	LUMWIN	ILLUMPBS	ILLUMSBS	LPD
0-49	31	10%	3.9	4.9	1.9	1.6	1.7	51	155	10	1.2	24	50	9	7	14	132	61	46	2.7
50-99	62	20%	4.0	4.8	1.9	1.7	1.9	175	346	11	1.2	23	44	14	21	16	295	58	52	2.4
100-199	129	41%	3.9	5.1	1.9	1.8	1.8	252	803	11	1.3	21	45	19	29	40	332	58	59	2.4
200-299	67	21%	4.1	5.6	1.8	1.8	1.8	756	1060	12	1.5	17	48	53	56	40	512	60	50	2.2
300-399	20	6%	3.3	4.5	2.1	2.1	2.1	1087	1268	15	1.6	18	67	246	13	24	817	80	68	2.2
400-499	3	1%	4.0	5.7	2.0	1.7	2.0	202	561	42	2.5	27	60	454	624	32	2250	83	104	1.7
500+	1	0%	4.0	4.0	1.0	1.0	1.0		640		0.9	13	29				313	37	39	2.9
	===	=====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====
	313	100%	3.9	5.1	1.9	1.8	1.8	424	764	12	1.3	21	48	49	36	31	463	61	55	2.3

DRFLN System:

LUMave	n	(%)	WSLITSAT	WSBRT	GLRWKSF	GLRTSKLT	GLRCLNLT	LUMBRCLN	LUMBRLIT	LUMCBWL	LUMDRKST	LUMSUR	LUMTASK	LUMWLFT	LUMWRGT	LUMWSRT	LUMWIN	ILLUMPBS	ILLUMSBS	LPD
0-49	3	2%	3.0	6.7	1.0	1.0	2.7	9	265	8	2.0	27	41	4	7	9		39	29	1.6
50-99	20	13%	3.7	5.0	1.9	1.3	1.7	18	509	12	1.9	17	46	10	10	22	373	57	39	2.3
100-199	41	26%	3.5	5.1	1.9	1.6	2.2	257	719	12	3.7	24	52	37	22	19	393	65	52	2.4
200-299	34	22%	3.8	5.7	1.6	1.4	1.8	943	841	19	2.8	26	49	62	46	14	529	62	65	2.2
300-399	42	27%	3.3	5.2	2.0	1.4	2.3	1303	1251	19	4.0	35	56	68	63	33	617	69	76	2.0
400-499	9	6%	3.9	5.5	1.9	1.1	2.0	1515	1467	38	7.3	37	81	136	77	28	961	95	126	2.3
500+	9	6%	3.8	5.6	1.8	1.4	1.9	1332	1941	29	6.0	75	100	88	117	58	3229	119	110	2.3
	===	=====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====
	158	100%	3.6	5.3	1.8	1.4	2.1	779	968	17	3.7	30	56	54	44	25	753	69	65	2.2

Table 11. Continued

DFSM System:

LUMave	n	(%)	WSLITSAT	WSBRT	GLRWKSF	GLRTSKLT	GLRCLNLT	LUMBRCLN	LUMBRLIT	LUMCBWL	LUMDRKST	LUMSUR	LUMTASK	LUMWLFT	LUMWRGT	LUMWSRT	LUMWIN	ILLUMPBS	ILLUMSBS	LPD
0-49	1	2%	4.0	1.0	2.0	2.0	2.0	-	119	4	0.5	9	14	7	7	2	-	19	90	2.7
50-99	1	2%	4.0	6.0	2.0	2.0	2.0	-	188	-	4.0	4	29	-	-	-	-	42	43	2.9
100-199	5	11%	3.4	3.2	2.2	1.8	2.0	-	500	-	4.8	10	28	-	-	-	394	33	53	3.0
200-299	9	20%	3.9	5.3	2.4	1.4	2.0	-	596	-	3.8	27	36	-	-	-	738	43	47	3.2
300-399	10	22%	3.6	4.9	3.3	2.3	3.2	-	828	-	5.9	25	41	-	-	-	789	53	41	2.9
400-499	8	18%	3.9	5.4	2.1	1.7	1.8	-	1104	-	5.1	30	54	-	-	-	1058	68	64	2.7
500+	11	24%	4.0	5.4	2.4	1.6	1.8	-	2654	-	11.5	38	70	-	-	-	2152	71	54	3.0
	===	=====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====
	45	100%	3.8	4.9	2.4	1.8	2.1	-	1210	4	6.4	27	47	7	7	2	1201	55	52	3.0

IFFM System:

LUMave	n	(%)	WSLITSAT	WSBRT	GLRWKSF	GLRTSKLT	GLRCLNLT	LUMBRCLN	LUMBRLIT	LUMCBWL	LUMDRKST	LUMSUR	LUMTASK	LUMWLFT	LUMWRGT	LUMWSRT	LUMWIN	ILLUMPBS	ILLUMSBS	LPD
0-49	111	67%	3.3	4.4	2.0	1.8	1.5	92	140	14	1.7	19	52	8	11	9	76	70	50	2.9
50-99	22	13%	2.7	3.4	2.2	2.3	1.6	123	272	14	2.4	19	58	33	39	19	243	74	54	3.1
100-199	20	12%	3.2	4.5	2.6	2.3	1.5	67	841	17	1.2	21	63	163	155	51	639	89	66	2.6
200-299	9	5%	3.4	5.2	1.9	2.0	1.8	95	667	23	3.1	28	83	421	113	194	974	109	120	2.7
300-399	2	1%	4.0	3.0	1.5	1.5	1.5	80	3300	14	2.6	31	50	21	638	12	1270	62	24	2.5
400-499	0	0%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
500+	1	1%	3.0	1.0	2.0	2.0	2.0	89	5000	11	1.0	22	74	8	13	15		81	45	3.6
	===	=====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====
	165	100%	3.3	4.3	2.1	1.9	1.6	93	410	15	1.8	20	56	53	45	26	378	75	57	2.9

IFP System:

LUMave	n	(%)	WSLITSAT	WSBRT	GLRWKSF	GLRTSKLT	GLRCLNLT	LUMBRCLN	LUMBRLIT	LUMCBWL	LUMDRKST	LUMSUR	LUMTASK	LUMWLFT	LUMWRGT	LUMWSRT	LUMWIN	ILLUMPBS	ILLUMSBS	LPD
0-49	16	24%	4.2	4.9	2.1	1.7	2.1	132	111	14	1.2	12	30	29	11	11	86	40	48	2.3
50-99	12	18%	3.6	5.3	2.1	1.8	2.1	214	177	15	2.9	34	48	44	35	14	201	61	60	2.8
100-199	19	28%	3.4	4.5	1.9	1.7	1.8	563	353	11	2.6	49	69	76	33	27	286	80	82	3.4
200-299	14	21%	4.2	5.4	1.9	1.6	1.9	377	590	24	2.1	37	60	265	267	78	621	73	68	2.9
300-399	4	6%	3.8	5.3	2.0	2.0	1.8	162	803	14	1.7	40	57	1240	8	16	913	61	91	2.9
400-499	1	1%	4.0	7.0	2.0	1.0	2.0		970		1.0	46	66	-	-	-	970	46	75	2.9
500+	2	3%	4.5	5.0	2.5	2.0	2.5	8400	1400		13.5	92	110	-	-	-	1400	107	136	2.8
	===	=====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====
	68	100%	3.8	5.0	2.0	1.7	2.0	545	407	16	2.5	36	55	120	65	27	419	65	69	2.9

Table 11. Continued

DIFP System:

LUMave	n	(%)	WSLITSAT	WSBRT	GLRWKSF	GLRTSKLT	GLRCLNLT	LUMBRCLN	LUMBRLIT	LUMCBWL	LUMDRKST	LUMSUR	LUMTASK	LUMWLFT	LUMWRGT	LUMWSRT	LUMWIN	ILLUMPBS	ILLUMSBS	LPD
0-49	5	6%	3.4	3.8	1.6	1.8	1.0	80	125	12	1.0	13	43	9	12	16	113	58	52	3.1
50-99	28	36%	3.7	4.7	1.9	1.4	1.7	140	361	22	1.1	22	40	30	12	22	205	51	56	2.0
100-199	23	30%	4.2	5.2	1.8	1.8	1.6	127	624	25	1.1	21	40	36	80	25	578	55	61	2.2
200-299	13	17%	4.1	5.2	1.9	1.7	1.7	120	530	22	1.8	15	38	297	103	149	1078	52	62	2.0
300-399	2	3%	4.0	3.0	3.5	2.5	3.5	161	229	31	1.1	28	51	807	769	15	1555	62	67	1.8
400-499	1	1%	2.0	4.0	1.0	1.0	1.0	117	1530	41	6.4	23	63	20	1470	48	1470	79	88	2.2
500+	5	6%	4.3	6.3	1.7	1.3	1.3	154	429	36	2.3	20	58	474	2205	639	3110	82	103	2.4
	===	=====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====
	77	100%	3.9	4.9	1.9	1.6	1.7	131	470	24	1.4	20	42	124	229	84	884	56	63	2.1

HIDP System:

LUMave	n	(%)	WSLITSAT	WSBRT	GLRWKSF	GLRTSKLT	GLRCLNLT	LUMBRCLN	LUMBRLIT	LUMCBWL	LUMDRKST	LUMSUR	LUMTASK	LUMWLFT	LUMWRGT	LUMWSRT	LUMWIN	ILLUMPBS	ILLUMSBS	LPD
0-49	14	38%	3.9	4.9	1.8	1.7	2.0	222		14	2.4	12	24	6	8	9		29		2.3
50-99	1	3%	4.0	3.0	2.0	2.0	2.0	305		46	1.8	3	29	11	2	4		38	19	2.2
100-199	19	51%	4.6	5.5	1.5	1.1	1.2	188	588	28	4.8	24	41	14	28	16	993	56	22	2.2
200-299	2	5%	5.0	5.0	2.0	2.0	1.5	303	820	74	4.0	59	59	177	5	32	1105	69		2.3
300-399	1	3%	4.0	6.0	1.0	1.0	2.0	204		46	3.6	6	45	16	29	5	2380	62		2.6
400-499	0	0%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
500+	0	0%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	===	=====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====
	37	100%	4.3	5.1	1.6	1.4	1.6	211	621	26	3.7	20	35	20	19	14	1070	46	21	2.2

WSLITSAT = work station lighting satisfaction.
WSBRT = work station brightness.
GLRWKSF = glare from work surface.
GLRTSKLT = glare from task lighting.
GLRCLNLT = glare from ceiling lighting.
LUMave = average of measured luminances.
LUMBRCLN = luminance of brightest ceiling area.
LUMBRLIT = luminance of brightest light source.
LUMCBWL = luminance of ceiling between luminaires.
LUMDRKST = luminance of darkest area.
LUMSUR = luminance of area surrounding task.
LUMTASK = luminance of white bond paper at task location.
LUMWLFT = luminance of area to left while seated.
LUMWRGT = luminance of area to right while seated.
LUMWSRT = luminance of area straight ahead while seated.
LUMWIN = highest luminance of window visible while seated.
ILLUMPBS = illuminance at primary location w/body shadow.
ILLUMSBS = illuminance at secondary location w/body shadow.
LPD = lighting power density.

The first and most important point is that 10% and 2% of the data for the two direct systems (DRFLV and DRFLN, respectively) were categorized as falling between 0 - 49 fL (the first average luminance category), while fully 67% of the data for the IFFM system fell into this category. In fact, 80% of the data for the IFFM system fell into the average luminance category of 0 - 99 fL. This indicates that the majority of the work stations with this lighting system had quite low average luminances when compared with all other lighting system types. Satisfaction and brightness ratings tended to be lower while the ratings of glare from the work surface and from task lights tended to be higher for the IFFM system. Ratings for ceiling glare, however, were lower which is consistent with the lower luminances recorded for the ceiling and brightest source in the field of view. By contrast, 51% of those with the HIDP system (the most favorably rated system) fell into the 100-199 fL average luminance category with a mean satisfaction rating of 4.6. Although only 37 people had this system, their average luminance data provide an interesting contrast to those with the IFFM system.

Thus, 67% of those with the IFFM system had average luminances between 0 and 49 fL, as compared with 10% of those with the DRFLV system.

4.2.3 Average Luminance and Task Lighting

These comparisons led to the development of table 12 which presents a more detailed examination of the effects of ambient lighting system and presence of task lighting. This table is a different way of looking at the data for the DRFLV and IFFM systems discussed above. Because nearly half the work stations in the DRFLV system had the same type of systems furniture with integrated task lighting as the IFFM system, a subset of 417 work stations was analyzed to compare the effects of overhead versus indirect ambient lighting, and furniture integrated task lighting. The first entries (Set 1) in table 12 refer to those work stations which had a direct ambient lighting system (DRFLV) with no task lights (and no systems furniture). The second set (Set 2) refers to work stations that had the same direct ambient lighting system but also had task lighting in a furniture integrated design. The third set of data (Set 3) refers to work stations with the same furniture integrated task lighting as Set 2, but this time with an indirect ambient lighting system (IFFM). This means that Sets 1 and 2 had similar ambient lighting but different task lighting and furniture systems, while Sets 2 and 3 had similar task lighting and furniture systems but different ambient lighting. (Daylighting effects were included in this table.) Table 12 thus allows one to disentangle the effects of general lighting and furniture integegrated lighting.

Again it is apparent from table 12 that the majority of work stations (68%) with the indirect system with task lighting (Set 3) were located in the lowest average luminance category (0-49 fL), as compared with 2% and 14% of Sets 1 and 2, respectively. In fact, comparisons can reasonably be made only for the first three to four average luminance categories because of the paucity of data in the higher categories for Set 3.

Comparison of the mean ratings for work station lighting satisfaction reveals that the ratings for Set 2 were always below those for Set 1, while

Table 12. Comparison of Data Sorted by Average Luminance for Three Configurations of Furniture Systems, Task Lighting, and Ambient Lighting System.

Direct System w/o Task Units:

LUMave	n	(%)	WSLITSAT	WSBRT	GLRWKSF	GLRTSKLT	GLRCLNLT	LUMBRCLN	LUMBRLIT	LUMCBWL	LUMDRKST	LUMSUR	LUMTASK	LUMWLFT	LUMWRGT	LUMWSRT	LUMWIN	ILLUMPBS	ILLUMSBS	LPD
0-49	2	2%	5.0	7.0	1.5	1.0	1.0			8	1.0	26	35	14	14	18		53	52	2.1
50-99	25	23%	4.3	5.4	1.8	1.5	1.8	153	361	12	0.8	20	33	19	23	17	233	46	47	1.7
100-199	45	42%	4.1	5.5	1.8	1.6	1.8	169	818	11	1.1	14	34	14	47	54	304	48	45	1.7
200-299	26	24%	4.3	5.8	2.0	1.6	2.0	691	1051	13	1.3	10	32	74	12	37	543	44	41	1.7
300-399	6	6%	3.2	3.8	2.0	1.3	2.2	76	978	26	1.1	18	41	593	20	53	1447	57	59	1.6
400-499	3	3%	4.0	5.7	2.0	1.7	2.0	202	561	42	2.5	27	60	454	624	32	2250	83	104	1.7
500+	1	1%	4.0	6.0	2.0	2.0	2.0	165	989	14	3.8	33	67	1940	17	6	1940	97	85	2.1
	===	=====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====
	108	100%	4.2	5.5	1.9	1.5	1.9	298	775	13	1.1	16	35	92	47	40	591	49	47	1.7

Direct System w/ Task Units:

LUMave	n	(%)	WSLITSAT	WSBRT	GLRWKSF	GLRTSKLT	GLRCLNLT	LUMBRCLN	LUMBRLIT	LUMCBWL	LUMDRKST	LUMSUR	LUMTASK	LUMWLFT	LUMWRGT	LUMWSRT	LUMWIN	ILLUMPBS	ILLUMSBS	LPD
0-49	23	14%	3.8	4.7	2.0	1.6	1.9	50	107	11	1.2	23	55	8	6	16	132	65	40	2.6
50-99	28	17%	3.9	4.4	2.0	1.9	2.0	210	355	10	1.5	20	48	10	22	16	383	59	51	2.7
100-199	63	39%	3.8	5.0	2.0	1.9	1.9	330	804	11	1.4	25	51	24	21	24	341	65	64	2.6
200-299	35	21%	4.0	5.3	1.8	2.0	1.8	784	1090	12	1.5	21	59	44	72	48	467	70	53	2.5
300-399	14	9%	3.3	4.8	2.1	2.4	2.1	1376	1393	10	1.9	17	78	97	10	12	344	90	71	2.4
400-499	0	0%	0.0	0.0	0.0	0.0	0.0	0	0	0	0.0	0	0	0	0	0	0	0	0	0.0
500+	0	0%	0.0	0.0	0.0	0.0	0.0	0	0	0	0.0	0	0	0	0	0	0	0	0	0.0
	===	=====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====
	163	100%	3.8	4.9	2.0	1.9	1.9	538	801	11	1.5	22	55	30	29	26	365	67	57	2.6

Indirect System w/ Task Units:

LUMave	n	(%)	WSLITSAT	WSBRT	GLRWKSF	GLRTSKLT	GLRCLNLT	LUMBRCLN	LUMBRLIT	LUMCBWL	LUMDRKST	LUMSUR	LUMTASK	LUMWLFT	LUMWRGT	LUMWSRT	LUMWIN	ILLUMPBS	ILLUMSBS	LPD
0-49	99	68%	3.3	4.4	2.0	1.7	1.5	90	144	14	1.7	20	55	9	11	9	83	74	47	2.8
50-99	19	13%	2.6	3.4	2.3	2.4	1.6	124	247	14	2.2	20	60	36	30	20	232	76	46	3.0
100-199	16	11%	3.3	4.8	2.5	2.3	1.5	70	981	19	1.2	23	67	202	164	63	625	95	68	2.5
200-299	9	6%	3.4	5.2	1.9	2.0	1.8	95	667	23	3.1	28	83	421	113	194	974	109	120	2.7
300-399	2	1%	4.0	3.0	1.5	1.5	1.5	80	3300	14	2.6	31	50	21	638	12	1270	62	24	2.5
400-499	0	0%	0.0	0.0	0.0	0.0	0.0	0	0	0	0.0	0	0	0	0	0	0	0	0	0.0
500+	1	1%	3.0	1.0	2.0	2.0	2.0	89	5000	11	1.0	22	74	8	13	15		81	45	3.6
	===	=====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====	====
	146	100%	3.3	4.3	2.1	1.9	1.6	92	436	15	1.8	21	59	59	45	28	386	78	55	2.8

those for Set 3 were always lower than those for Set 2 (and hence 1). Workstation lighting satisfaction was always higher for Set 1 than Sets 2 or 3, regardless of average luminance category. A similar consistency between the three sets was found for the brightness ratings. This trend reversed for the glare ratings, however. As might be expected, Sets 2 and 3 had higher ratings for glare from the work surface and task light than Set 1. Set 3, however, had the lowest ratings of the three systems for glare from the ceiling lights (which is to be expected since this system had very little direct light on the ceiling).

Set 3 had an overall mean average luminance that was less than half of that for each of the other systems, while the overall means for the luminance of the ceiling and brightest area in the field of view were also substantially below those for Sets 1 and 2. Yet, task luminance as well as primary and secondary illuminances were consistently higher across categories for Set 3.

This suggests that this lighting system (the IFFM) was characterized by extremes, with some very dark areas (particularly in the ceiling) and some very bright areas (largely in the vicinity of the task).

The ratings for work station lighting system and brightness tended to confirm this pattern. Overall satisfaction and brightness ratings were consistently lower for Set 3 than for the other two systems. While rated glare from the work surface tended to run higher for this system, rated glare from the ceiling lighting was lower.

As noted earlier, there are limitations to averaging all the luminance data because each luminance is weighted equally. It is unlikely that people actually respond equally, yet it is clear from the earlier analysis that one single luminance (or illuminance) measure did not explain their lighting satisfaction and brightness responses. The consistencies found in the average luminance analysis suggest the need to explore the reponse to luminance patterns in much greater detail, using more precise photometric and occupant response measures.

The average luminance analysis suggests that the IFFM system was characterized by extremes, with some very dark areas (particularly in the ceiling) and some very bright areas (largely in the vicinity of the task). The analysis of the occupant response and photometric data suggests that the distribution of luminances in a space was an important factor in influencing occupant satisfaction and brightness perceptions. Such considerations appeared to be even more important than amount of light on the task for the participants in the present study.

5. Lighting Quality

The previous discussion has centered on occupant satisfaction with the lighting system primarily in terms of the questions, "Overall, how satisfied are you with the lighting at your office or work space?" as well as ratings of the brightness of the space. Satisfaction with lighting, however, does not provide as much information as might be desired about the overall quality of the lighting system. Lighting quality is justifiably viewed as encompassing factors such as brightness, color, design, luminance ratios, visual comfort, visibility, and emotional reaction to a space. Design factors such as daylighting, type of task, type of work station, and overall illuminance are also important contributors to the quality of a lighting installation.

Figure 23 presents a model of some of the influences on lighting quality. This model suggests that lighting quality is directly affected by the perception of the brightness of a space as well as by five major factors that influence both brightness and lighting quality together. In other words, although brightness is a prime component of lighting quality, other factors present in the lighting system, including the daylight condition, the work station view, lighting system, luminance, and illuminance also influence lighting quality. The occupant's perception of the brightness and quality of the light also depends on the task performed.

In addition to the question on direct ratings of satisfaction with the lighting system, the questionnaire contained three other questions which can also be considered indicators of lighting quality. Workers were asked to: 1) rate the amount of light for work; 2) rate the amount of light for reading; and 3) indicate whether lighting hindered them from performing their jobs. Figure 24 indicates that responses to the four questions were strongly correlated with one another. This correlation held regardless of the type of lighting system, the presence or absence of daylighting, the availability of local task lighting, or the degree of office enclosure. Thus, workers who were satisfied with their lighting were also likely to rate the amount of light for work and the amount for reading highly, and feel that lighting did not hinder their job performance. Conversely, workers who were dissatisfied with their lighting also rated the amount of light as being poor, and felt that the lighting interfered with their ability to work.

A lighting quality index, using a scale of 4 to 20, was developed in which the ratings for the four questions were summed. The higher the "lighting quality" (LQ) score, the more favorably a person viewed the lighting system at his/her work space. Figure 24 presents the correlations between the four questions and provides the basis for the Lighting Quality Index. The reliability of the index for the full sample and for different groups of workers and work stations is shown in table 13. Data are also presented in this table for several other indices to be discussed in subsequent sections.

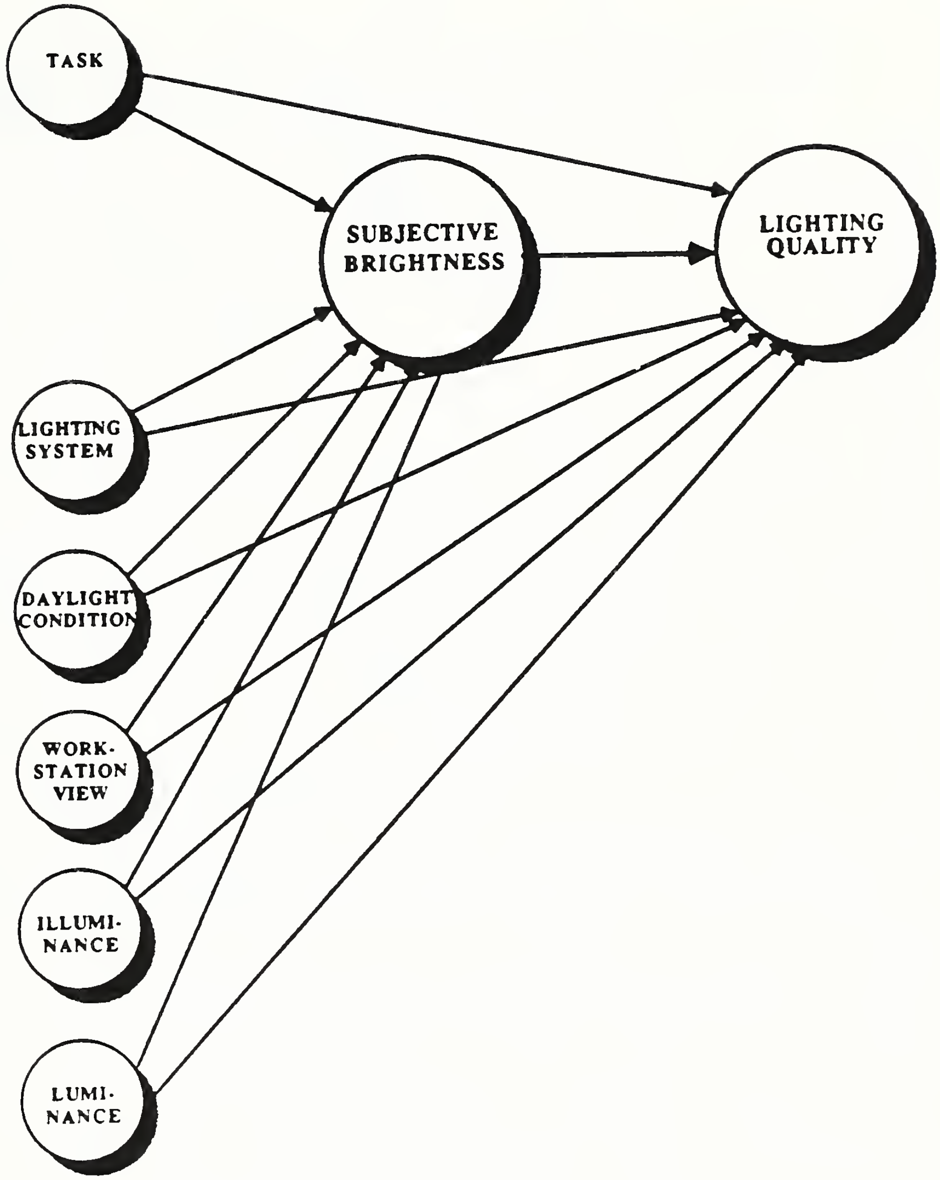
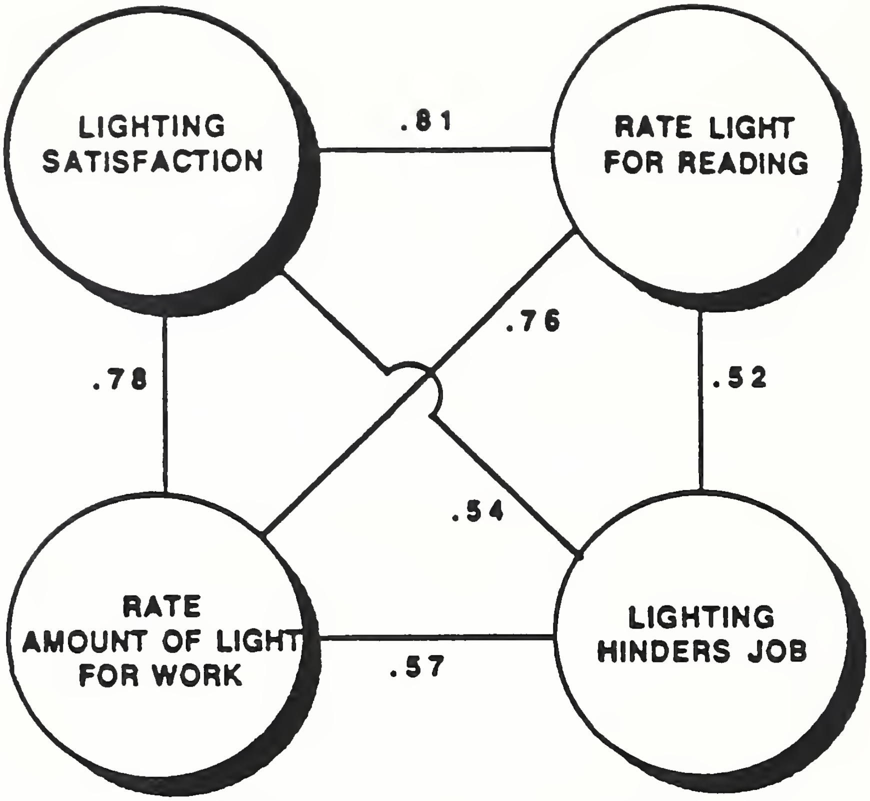


Figure 23. Model of some environmental influences on lighting quality.

This figure presents a model of lighting quality in which brightness is seen as a very important intermediate influence on lighting quality. Brightness is determined by task characteristics, as well as by lighting system, daylight, work station view, and, of course, illuminance - all of which interact to creat: a condition known as lighting quality.



LIGHTING QUALITY INDEX

- "Overall, how satisfied are you with the lighting at your office or work space?" 5 Very satisfied, 4 Fairly satisfied, 3 Neither satisfied nor dissatisfied, 2 Not very satisfied, 1 Not at all satisfied.
- "Rate the lighting available to you for reading." 5 Excellent, 4 Pretty good, 3 Neutral, 2 Not very good, 1 Poor.
- "Rate your workstation on the amount of light for the work you do." 4 Excellent, 3 Good, 2 Fair, 1 Poor.
- "Lighting at my desk hinders me from doing my job well." 4 Not at all true, 3 Not very true, 2 Somewhat true, 1 Very true.

Figure 24. Factors considered in the development of the lighting quality index.

This figure indicates that the responses to four questions concerning lighting satisfaction, rated amount of light for reading, rated amount of light for working, and extent to which lighting hinders the ability to do the job, were highly correlated. The correlation holds regardless of the type of lighting system, the presence/absence of daylighting, the availability of task lighting, and the extent of office enclosure. Thus people who were satisfied with their lighting also tended to rate the amount of light for both reading and working favorably, and to indicate that the lighting did not hinder them from performing their jobs.

Table 13. Reliability coefficients for indices of lighting quality, visual quality, and visual health for different environmental conditions.

Reliability Coefficients for Indexes - Full Sample and Special Environmental Conditions

	Coefficients of Reliability			
	Lighting Quality	Visual Quality	Visual Health	Lighting Control Assessment
Total Sample	.89	.87	.77	.83
Major Lighting Systems				
DRFLo	.86	.86	.75	.78
DRFLe	.88	.88	.75	.84
IF-FM	.89	.88	.78	.82
Daylight				
With Daylight	.89	.90	--	--
Little Daylight	.88	.85	--	--
Task Lighting				
With Task Lights	.87	.86	.78	.82
Without Task Lights	.89	.90	.78	.84
Degree of Enclosure				
Totally Enclosed 1	.91	.88	.75	.80
Totally Enclosed 2	.87	.87	.79	.82
Partially Enclosed	.89	.84	.78	.82
Partially Open	.85	.82	.80	.86
Totally Open	.89	.86	.71	.92
Enclosed Office	.90	.91	.75	.81
Predominant Job				
Read/Write	.88	.88	.76	.83
Read	.92	.89	.82	.76
Write	.89	.85	.77	.90
Type	.85	.89	.81	.82
CRT User	.87	.83	.76	.85
Job Status				
Manager	.82	.89	--	--
Professional/Technician	.89	.88	--	--
Secretary/Clerk	.88	.82	--	--
Age of Respondents				
Under 35	--	--	.75	-
35-54	--	--	.77	--
55 and Over	--	--	.70	--
Glasses/Bifocals				
No Glasses	--	--	.80	--
Glasses without Bifocals	--	--	.75	--
Glasses with Bifocals	--	--	.69	--

5.1 Lighting Quality Assessments

Figure 25 presents assessments of lighting quality among people performing different tasks for two different lighting systems (DRFLV and IFFM). This figure indicates that assessments of lighting quality for the IFFM systems were lower than those for the DRFLV systems, regardless of the primary task performed by the worker (except for drafting tasks). The difference in quality scores between the two lighting systems could not be attributed to differences in illuminances. That is, there was no significant relationship between illuminance and lighting quality assessments for either the IFFM systems (r=.07) or the DRFLV systems (r=.19). (The "r" is the coefficient or measure of the correlation between two sets of data. It goes from -1, a perfect negative correlation, to +1, a perfect positive correlation. Scores near zero have little correlation.) As noted earlier, lighting satisfaction was not directly related to illuminance at the task, so it is reasonable that lighting quality was not either.

The next issue to be examined is the relationship between the lighting quality assessments and the brightness of a work station. Table 14 summarizes the relationships between lighting quality and two subjective measures of brightness obtained for 512 work stations[7]. One measure covered the perception of brightness at the work station, and was determined by a question asking respondents to describe their offices using a seven-point scale ranging from "dim" to "bright" (as discussed in 4.1.2.2). The second measure dealt with the assessment of brightness, and was determined by asking respondents to rate the <u>amount</u> of light available to them using a five-point scale ranging from "too bright" to "too dim". The first question evaluates the perception of the amount of light for the space, while the second question assesses the amount of light for doing work. Table 14 combines the ratings of the amount of light for work along the upper axis, with the ratings of the perception of brightness of the overall office along the left axis. Entries in the table refer to the average lighting quality (LQ) score for each of these combinations.

Table 14 indicates that subjective brightness was an important contributor to lighting quality: no space that was perceived as "dim" was considered to have the <u>right</u> amount of light for work. Furthermore, spaces rated as "too dim" received lower scores on the lighting quality index. At the same time, spaces rated as "too bright" received higher scores on the lighting quality index, with spaces seen as "bright" with the right amount of light for work receiving the highest scores of lighting quality. About 49% (251) of those responding felt that their space was "bright", with only 11% (55) of these feeling that it was "<u>too</u> bright" (and giving it a lower lighting quality score).

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[7]Sample size was only 512 for this particular evaluation because these questions were only asked in 10 buildings, rather than in the full sample of 13 buildings.

LIGHTING QUALITY, BY PREDOMINANT TASK

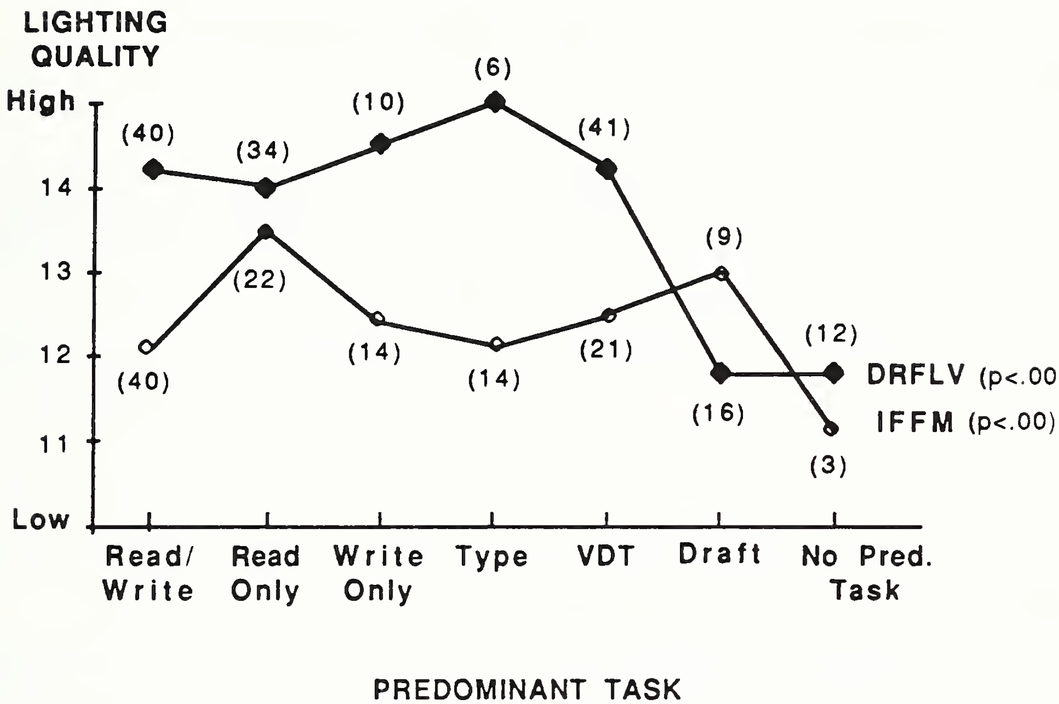

Figure 25. Assessments of lighting quality as a function of predominant task performed in the work station for the DRFLV and IFFM systems.

This figure indicates that assessments of lighting quality tended to be lower under the IFFM system than under the DRFLV system, regardless of the primary task performed by the worker. The differences in lighting quality cannot be attributed to differences in illuminance since the correlation between lighting quality and illuminance was 0.07 for the IFFM system and 0.19 for the DRFLV system.

Table 14. Relationships Between Lighting Quality and Assessments/perceptions of Brightness.

RELATIONSHIPS BETWEEN LIGHTING QUALITY AND ASSESSMENTS/PERCEPTIONS OF BRIGHTNESS

(eta. = .70, $p < .00$)

Overall Office (Perception)	Amount of Light for Work (Assessment): Too Bright	About Right	Too Dim
Bright	LQ = 12.5 (n=55)	LQ = 15.4 (n=196)	
Neither Bright Nor Dim (So-So)	LQ = 12.0 (n=24)	LQ = 14.1 (n=128)	LQ = 11.0 (n=82)
Dim			LQ = 10.0 (n=27)

Lighting quality is highest among workers who say the amount of light available is "just about right" and describe their workspace as "bright." Those who say the amount of light available is "too dim" and describe their workspace as "dim" have the lowest lighting quality ratings.

Figure 26 presents the relationship between the combined measure of subjective brightness and lighting quality for the same set of work stations. This figure indicates clearly that those spaces that were judged to be "too dim" for working and which had "average" or "low" brightness had the lowest lighting quality. The assessments of lighting quality were highest for those spaces which were judged to be "about right" in brightness availability and perceived as "bright" or "average".

Of interest is the fact that the lighting quality was higher for those spaces that were judged to be too "bright" than for those seen as too "dim".

The upper line in Figure 27 plots the relationship between illuminance and lighting quality for spaces considered to be "about right for work" and "bright", while the lower line plots the same relationship for spaces considered to be "too dim" for work and "average". It is very clear that the lighting quality was consistently higher for the first group than for the second, regardless of illuminance. Furthermore, about 69% of the people in these two categories (the data shown in the upper curve) rated their lighting as being of "high quality", "about right", and "bright". Figure 28 indicates that the presence of a VDT made little difference in the relationship between lighting quality and perceived brightness, except for those rating the space as "too bright" and "bright".

Further inspection of the upper curve of Figure 27 raises the question of the broad range of task illuminances (and, hence, luminances) that are considered to be of high quality by the occupants of work spaces. Research reported by others (Boyce, 1981; Guth, 1951) reveals that people vary widely in the luminance conditions they will accept as being comfortable.

Figures 29 and 30 present the effects of daylight presence and view out on lighting quality scores for three lighting systems - IFFM, DRFLV, and DRFLN. Figure 29 indicates that the only lighting system for which daylight improved lighting quality was the IFFM system. There was little change in the score for the two direct systems with daylight but substantial improvement for the IFFM system. Figure 30 suggests that the effect shown in figure 29 may really be a daylighting effect rather than a view out effect since the extent of view out appears to have had little influence on the lighting quality score. Although the score was lowest for those with no view out at work stations with the IFFM system, this difference was not significant.

Thus, subjective brightness was an important contributor to lighting quality: no space that was perceived as dim was considered to have the right amount of light for work or have high ratings of lighting quality. Of interest is the fact that the lighting quality was higher for those spaces that were judged to be too bright than for those seen as too dim.

LIGHTING QUALITY, BY ASSESSMENTS/PERCEPTION OF BRIGHTNESS

(p<.001)

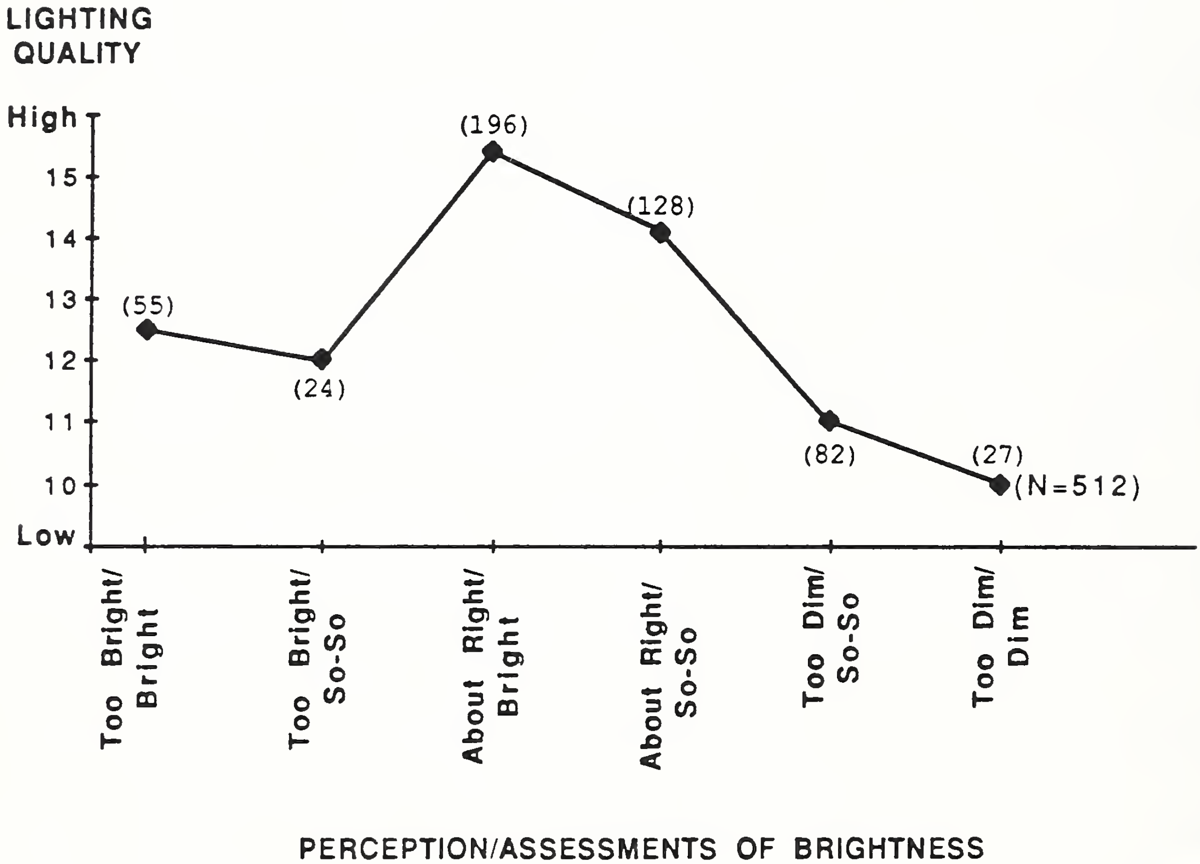

Figure 26. Lighting quality as a function of assessments and perceptions of brightness for the whole sample.

This figure indicates that lighting quality was highest among those people who said that the amount of light was "just about right" and who also described their work space as "bright". Those who said the amount of light was "too dim" and who also described their work space as "dim" gave the lowest lighting quality ratings.

LIGHTING QUALITY, BY ILLUMINANCE FOR TWO GROUPS OF WORKERS RESPONDING TO BRIGHTNESS

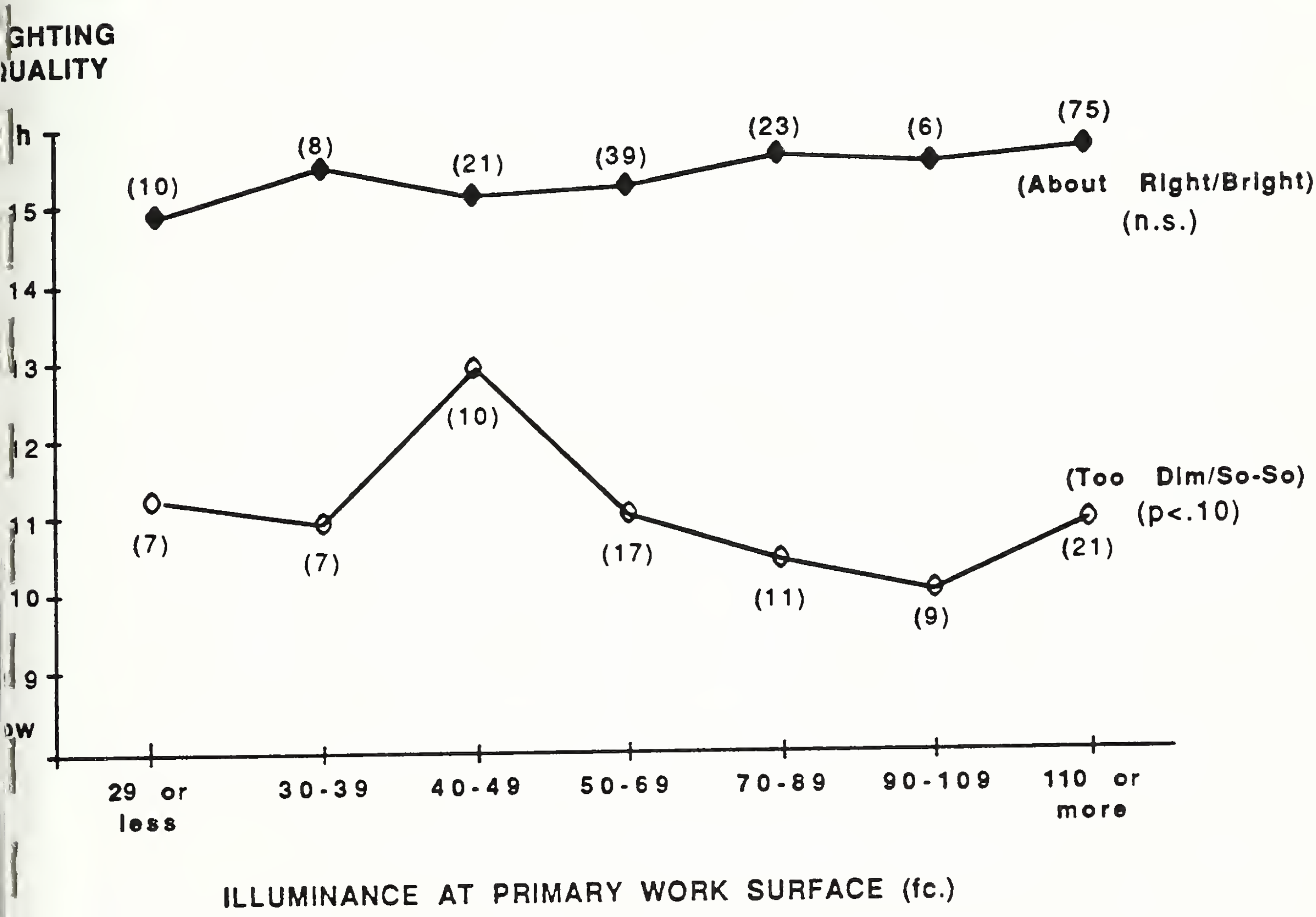

Figure 27. Lighting quality as a function of illuminance for two sets of respondents.

This figure indicates that lighting quality was high for those people who said the amount of lighting was "about right" and considered their space to be "bright", regardless of the illuminance at their primary task location. Similarly, lighting quality was low for those who said their space was "too dim", and considered their space to be "neither bright nor dim", again regardless of the illuminance.

LIGHTING QUALITY, BY ASSESSMENTS/PERCEPTIONS OF BRIGHTNESS AMONG VDT AND NON-VDT WORKERS

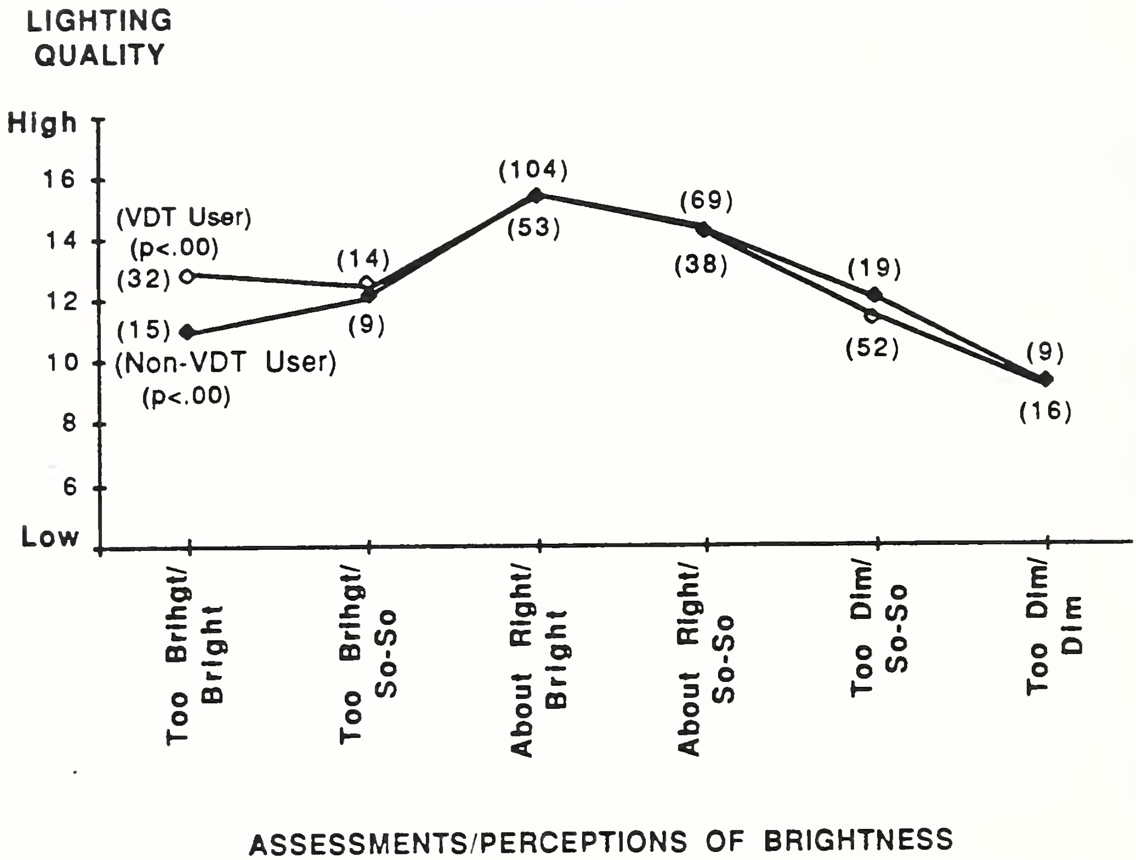

Figure 28. Lighting quality as a function of assessments and perceptions of brightness for both VDT and non-VDT workers.

This figure indicates that there was very little difference in assessments of lighting quality for people who worked with VDT's and those who did not. Again, both groups rated the lighting quality as highest if they also consided the amount of lighting to be "about right" and the space to be "bright".

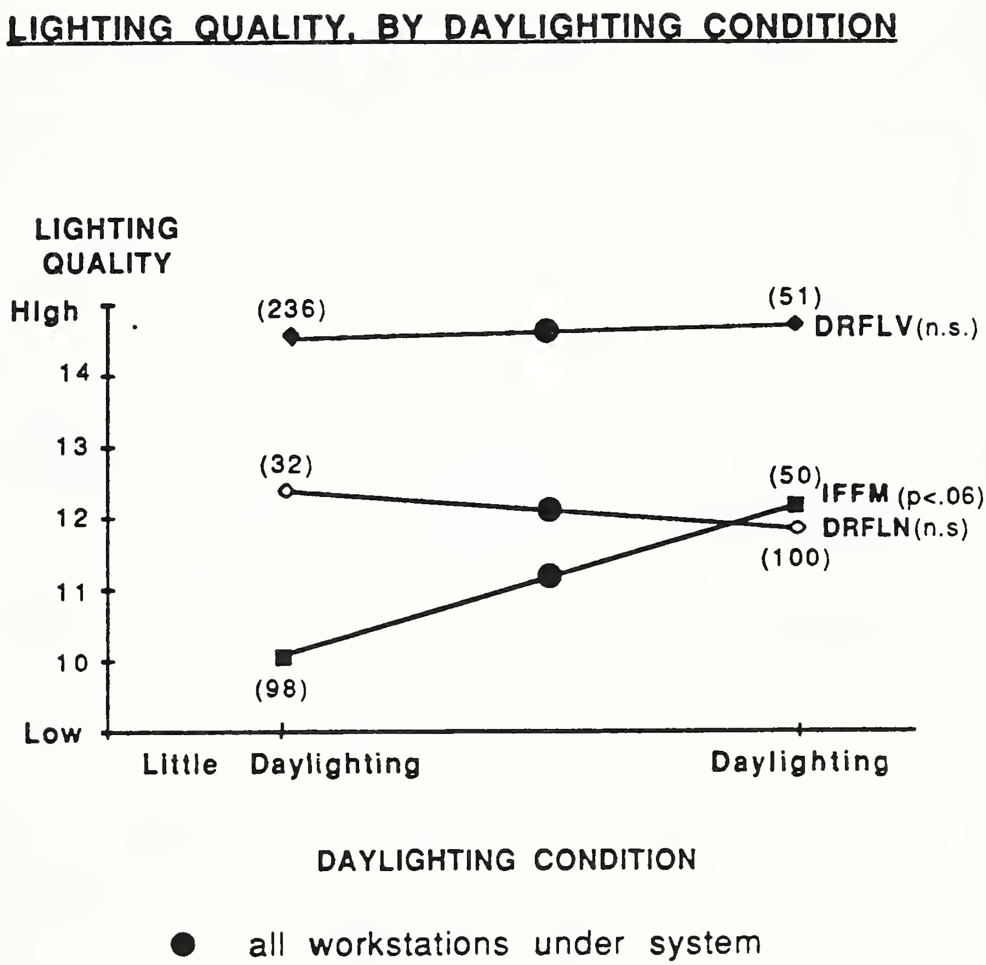

Figure 29. Lighting quality as a function of daylighting condition for DRFLV, IFFM, and DRFLN systems.

This figure indicates that people who were at work stations with the IFFM system and with daylighting tended to rate their lighting quality as higher than those who had little daylighting. There was little difference in the judgements of lighting quality for the DRFLV and DRFLN systems as a function of daylighting.

LIGHTING QUALITY, BY WORKSTATION VIEW

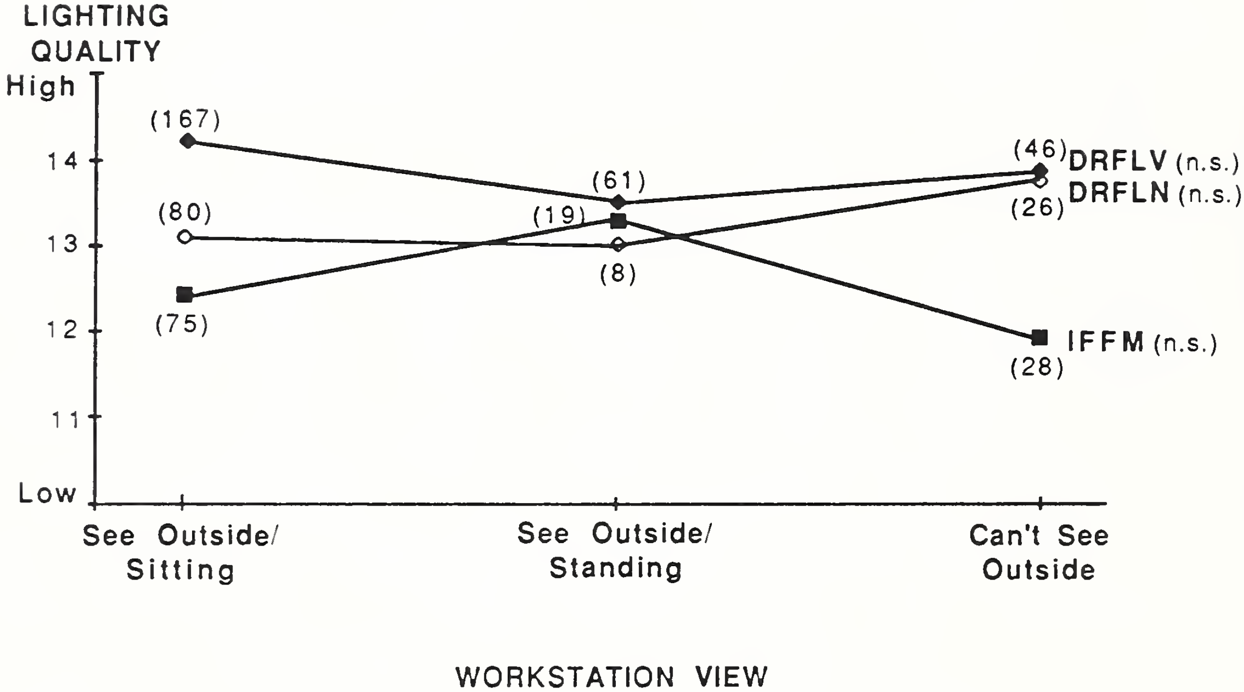

Figure 30. Lighting quality as a function of work station view for DRFLV, IFFM, and DRFLN systems.

This figure indicates that the ability to see outside from either a sitting or a standing position had little effect on the assessments of lighting quality, regardless of the lighting system type (although the assessments were lowest for those people with the IFFM system who could not see outside).

5.1.1 Visual Health

In addition to the summary measure termed lighting quality, another index, termed visual health, was developed to consider some of the health impacts of lighting in the work station. Answers to two questions were seen as important determinants of visual health; namely, eye irritation and trouble focusing eyes. Figure 31 indicates that there was a moderately high correlation ($r = 0.63$) between the responses to the two questions. As a result, ratings on these two questions were combined to create a visual health index similar to the lighting quality index.

Figure 32 indicates that lower scores on the visual health index were associated with lower lighting quality scores for both the IFFM and DRFLV systems, although the latter were consistently lower for the IFFM system. Figure 33 indicates that people who did not use VDTs consistently rated their visual health as higher than those who did use VDTs. In addition, the visual health of both groups was highest for those offices where the brightness was also rated as "about right"/"bright" or "about right"/"so so". Figure 33 suggests further that visual health was judged to be poorer in those offices that were seen as either "too bright" or "too dim". The availability of daylighting or task lighting did not appear to have any bearing on the relationship between visual health and lighting quality, although figure 34 indicates that the ratings of visual health were lowest for those who could not see outside, particularly under the IFFM system. The effect was not particularly strong, however. Finally, figure 35 indicates that task illuminance had no effect on the ratings of visual health, regardless of the lighting system.

Ratings of visual health were more strongly related to lighting quality assessments for workers whose primary task was writing than for workers who were primarily involved in VDT use as shown in figure 36.

5.1.2 Visual Quality and Visual Health

Lighting quality is not the only measure of a person's response to the quality of his/her environment. Visual quality is another important response to the space as a whole. An index for visual quality was developed by combining the responses for questions about attractiveness, pleasantness, interestingness, spaciousness, and comfort of the work station (Marans, 1987). While this index relates to the overall visual perception of a space, beyond the overall lighting quality, the associations shown in table 15 indicate that visual quality was strongly related to lighting quality, regardless of the type of lighting system, the presence of daylighting, or the presence of task lights. In addition, as the assessments of visual quality by different types of workers increased, so did their assessment of lighting quality. Table 15 indicates that visual quality was significantly related to lighting quality for all workers except typists.

Visual quality is strongly related to lighting quality, regardless of the type of lighting system, the presence of daylighting, or the presence of task lights.

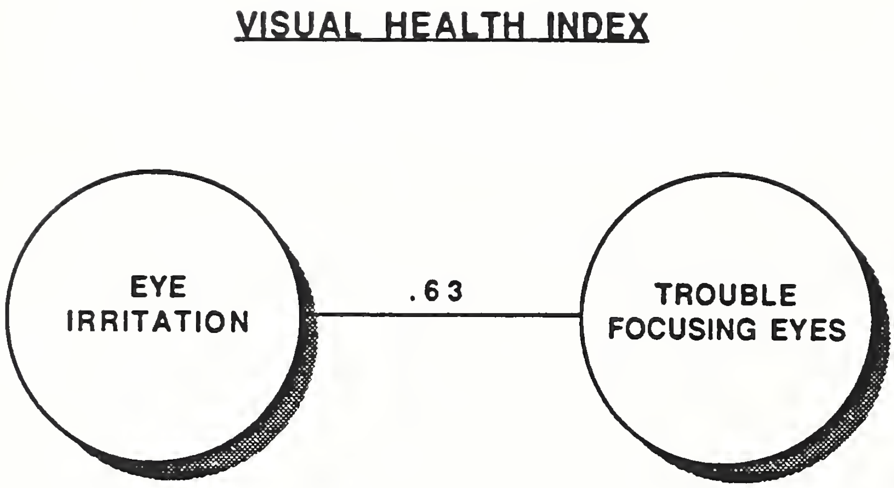

Figure 31. Factors used in the development of the visual health index.

This figure indicates that the responses to questions about eye irritation and trouble focusing one's eyes were moderately highly correlated (r = .63), and so were used in developing a visual health index.

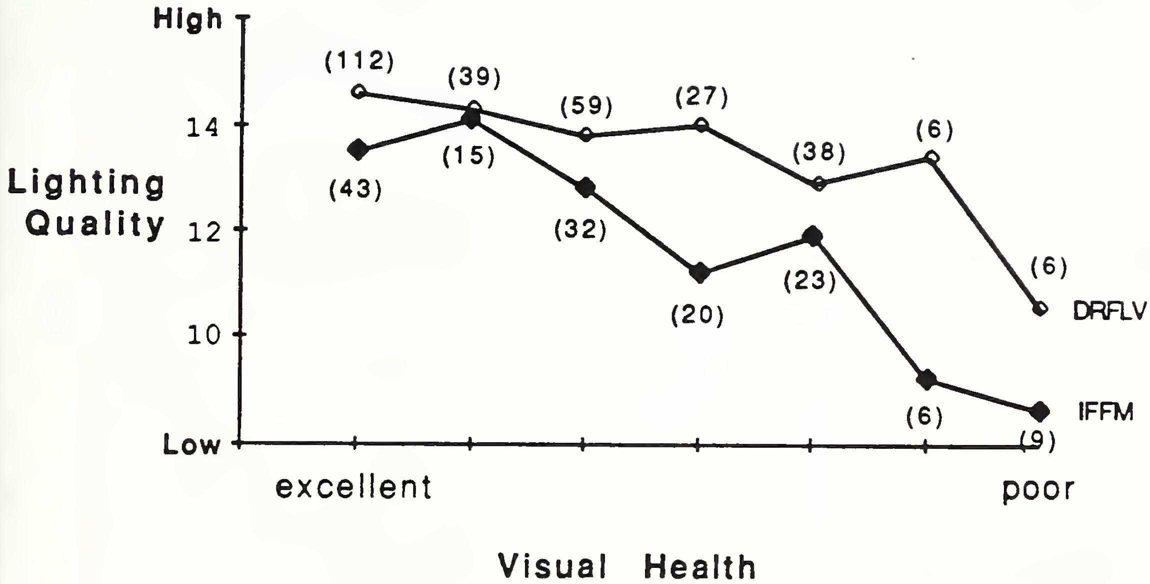

Figure 32. Lighting quality as a function of visual health for DRFLV and IFFM systems.

This figure indicates that lighting quality scores decreased as the scores on the visual health index decreased. Furthermore, assessments of lighting quality and visual health were consistently lower for those with the IFFM system.

VISUAL HEALTH, BY ASSESSMENTS/PERCEPTIONS OF BRIGHTNESS AMONG VDT AND NON-VDT WORKERS

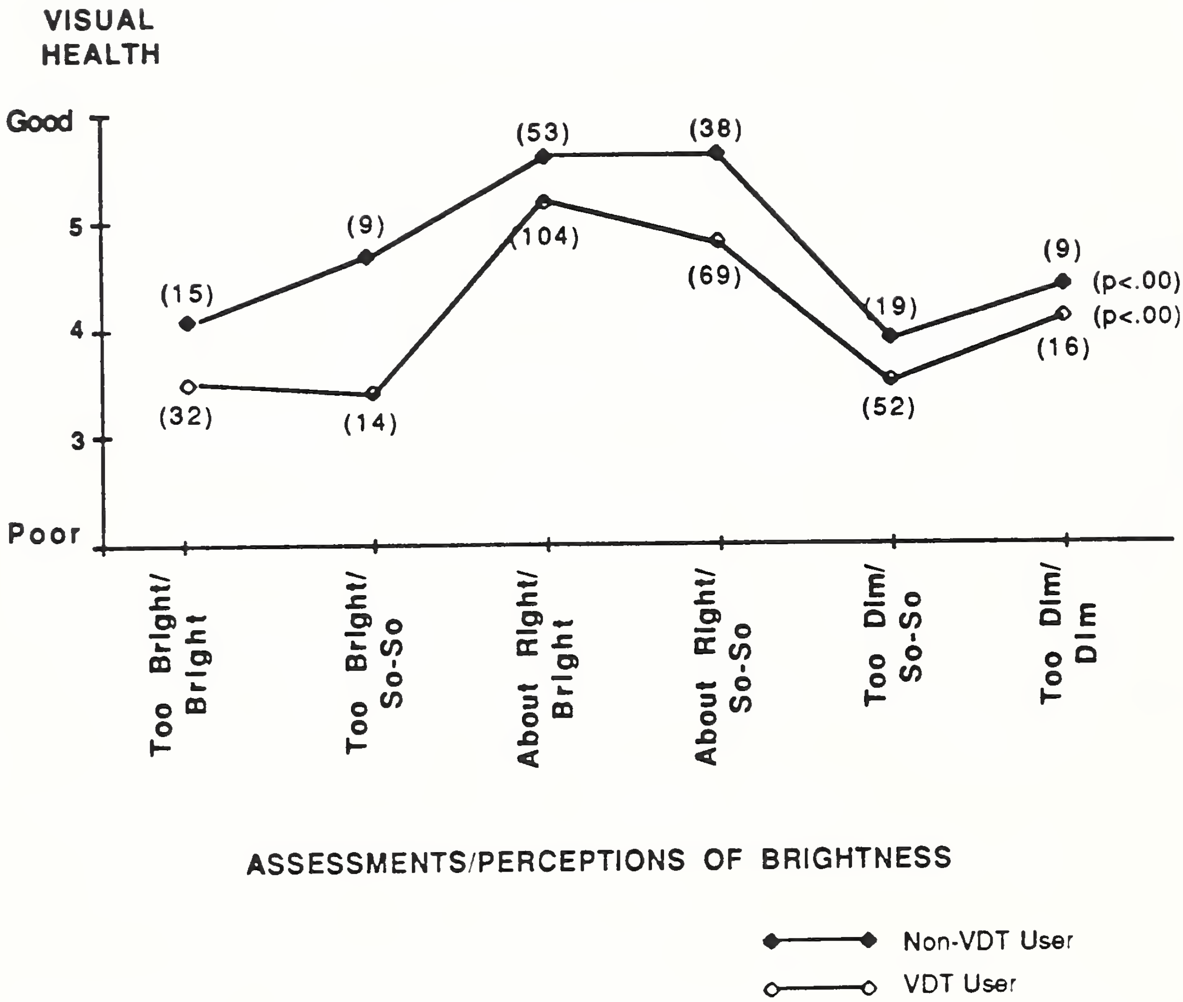

Figure 33. Visual health as a function of assessments and perceptions of brightness for both VDT and non VDT workers.

This figure indicates that assessments of visual health as a function of assessments of the amount of light and perceptions of the brightness were higher for those who do not use VDT's. The judgements of visual health were highest for those who assessed brightness as about right, and who also perceived their space as being bright, for both VDT and non-VDT users.

VISUAL HEALTH, BY WORKSTATION VIEW

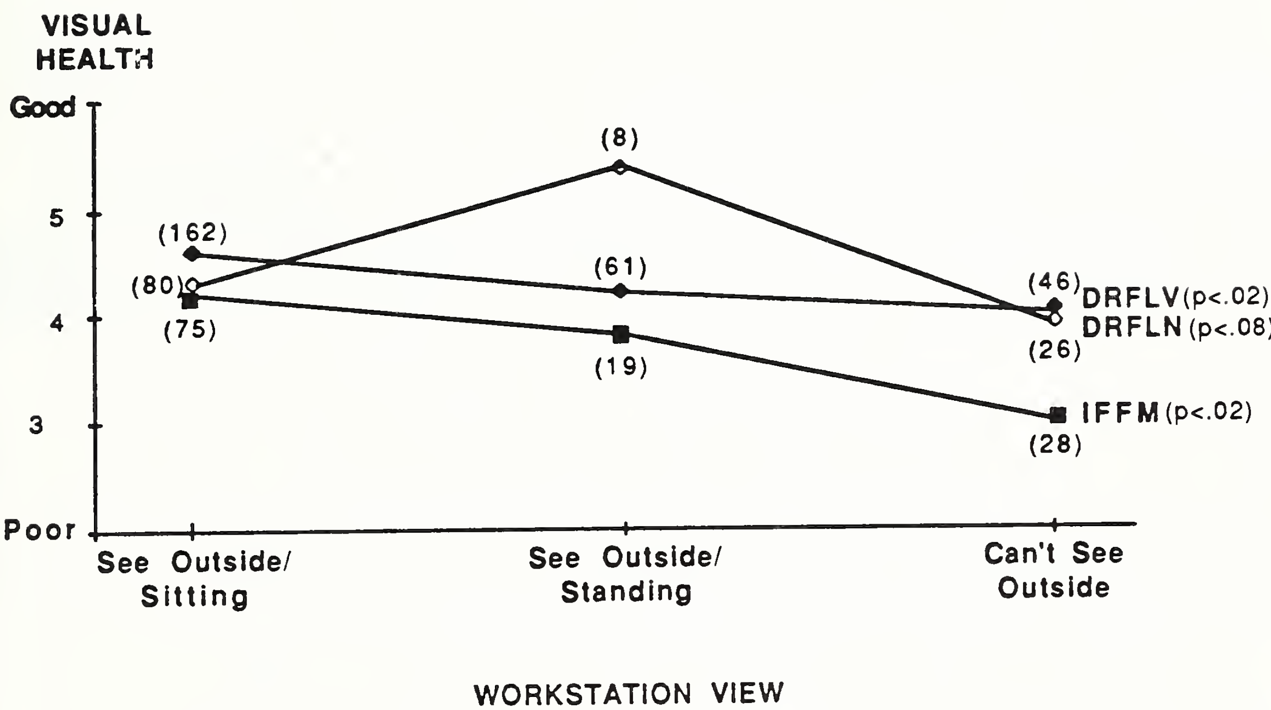

Figure 34. Visual health as a function of type of work station view for DRFLV, DRFLN, and IFFM systems.

This figure indicates that the assessments of visual health were lowest for those with the IFFM system, particularly for those who could not see outside, and highest for those few people with the DRFLN system who could see outside while standing. The assessments of visual health were higher for those who could see outside from a sitting position, and about the same for the three lighting systems examined.

VISUAL HEALTH, BY ILLUMINANCE

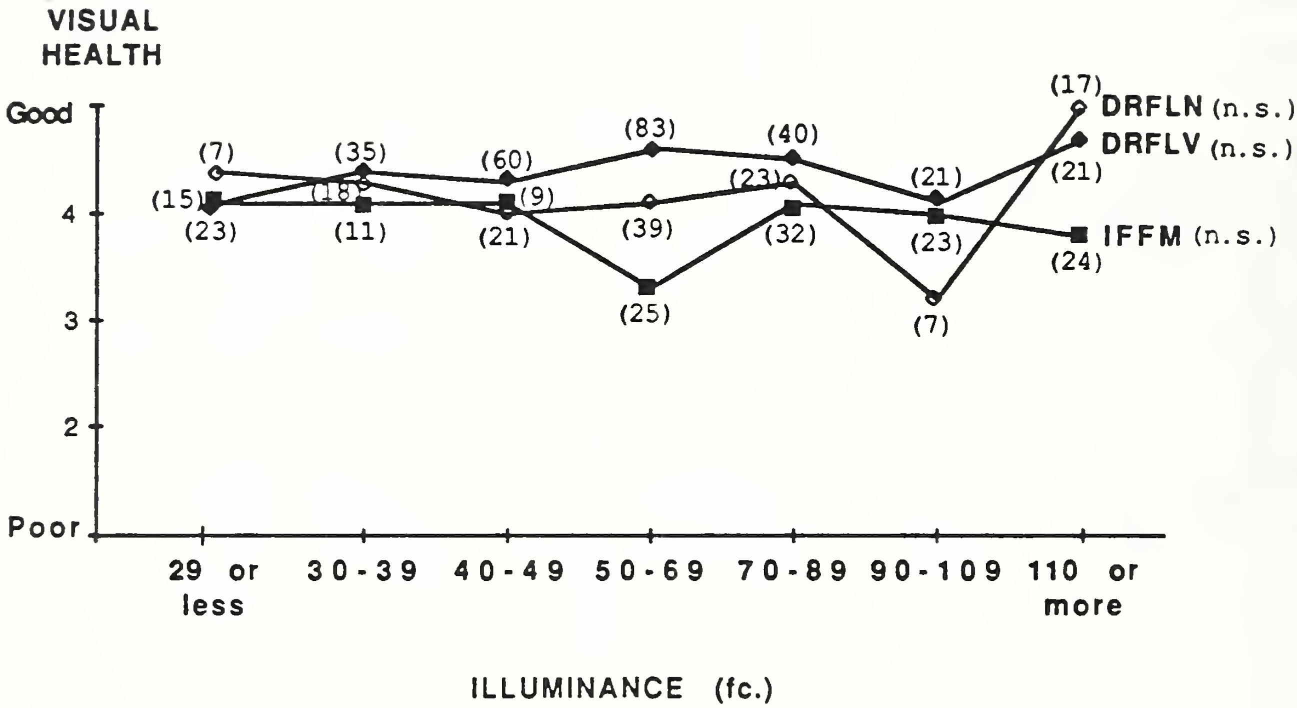

Figure 35. Visual health as a function of illuminance at the primary task for DRFLV, DRFLN, and IFFM systems.

This figure indicates that there was very little difference in ratings of visual health as a function of illuminance and lighting system type.

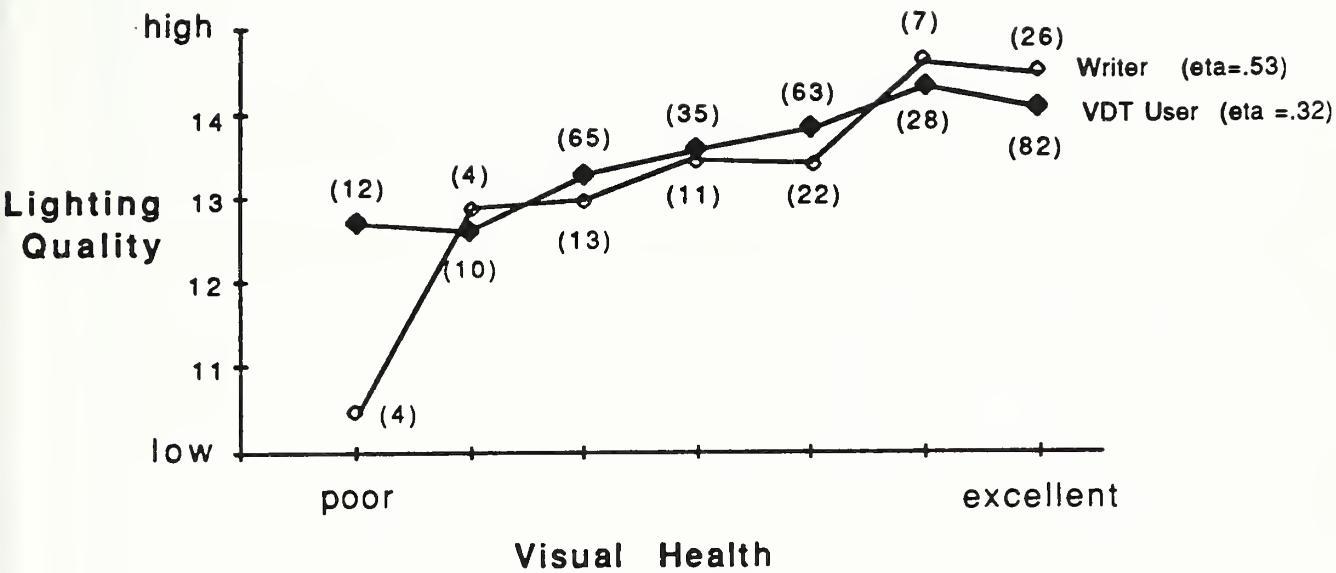

Figure 36. Lighting quality as a function of visual health for both writers and VDT users.

This figure indicates that there was relatively little difference in assessments of lighting quality as a function of visual health between writers and VDT users. It also indicates that lighting quality increased as ratings of visual health increased for both types of people.

Table 15. Measures of Association Between Lighting Quality, Visual Quality, Bright Lights, Visual Health, and Lighting Control.

Measures of Association Between Lighting Quality and Selected Variables
(eta coefficient)

	Selected Variables				
	Visual Quality	Bright Lights	Visual Health	Lighting Control Assessment	Lighting Control
Full Sample	.38 ($p<.00$)	.25 ($p<.00$)	.40 ($p<.00$)	.38 ($p<.00$)	.07 ($p<.04$)
Major Lighting Systems					
DRFLo	.28 ($p<.01$)	.18 ($p<.01$)	.26 ($p<.00$)	.34 ($p<.00$)	.08 (n.s.)
DRFLe	.45 ($p<.00$)	.33 ($p<.00$)	.45 ($p<.00$)	.37 ($p<.00$)	.00 (n.s.)
IF-FM	.45 ($p<.00$)	.25 ($p<.01$)	.43 ($p<.00$)	.51 ($p<.00$)	.00 (n.s.)
Daylight (V.4008)					
With Daylight	.45 ($p<.00$)	.36 ($p<.00$)	.42 ($p<.00$)	.44 ($p<.00$)	.00 (n.s.)
Little Daylight	.38 ($p<.00$)	.18 ($p<.00$)	.40 ($p<.00$)	.33 ($p<.00$)	.09 ($p<.04$)
Task Lights					
With Task Lights	.36 ($p<.00$)	.20 ($p<.00$)	.36 ($p<.00$)	.53 ($p<.00$)	.10 ($p<.07$)
Without Task Lights	.45 ($p<.00$)	.30 ($p<.00$)	.47 ($p<.00$)	.37 ($p<.00$)	.00 (n.s.)
Predominant Job					
Reading/Writing	.43 ($p<.00$)	.33 ($<.00$)	.44 ($p<.00$)	.40 ($p<.00$)	.07 (n.s.)
Read	.46 ($p<.00$)	.17 ($p<.03$)	.40 ($p<.00$)	.39 ($p<.00$)	.00 (n.s.)
Write	.37 ($p<.07$)	.00 (n.s.)	.53 ($p<.00$)	.25 ($p<.08$)	.16 (n.s.)
Type	.00 (n.s.)	.43 ($p<.00$)	.58 ($p<.00$)	.31 ($p<.04$)	.00 (n.s.)
CRT User	.39 ($p<.00$)	.25 ($p<.00$)	.32 ($p<.00$)	.33 ($p<.00$)	.05 (n.s.)

5.2 Glare

Another important component of work station lighting quality and hence, lighting satisfaction is the reaction to glare from lights, tasks, and surfaces. Ideally, a high quality lighting environment will be free from annoying glare.

Table 16 tabulates responses to three questions about glare; namely, glare from ceiling lights, work surfaces and task lights, both as a function of lighting system type and then as a function of lighting satisfaction. Table 16a, indicates that 10-35% of the respondents considered glare from ceiling lights to be "fairly" or "very" bothersome[8], with the DRFLN, DFSM and INDFP systems considered bothersome by 28-35%, and the IFFM and DIFP systems being bothersome to only 10-12% of those responding. Table 16b indicates that only 8% of the respondents were both bothered by ceiling lighting and dissatisfied with their lighting in general, while 60% were neither bothered nor dissatisfied.

Table 16c demonstrates that 16 to 42% of the respondents were bothered by glare from work surfaces, with those with the DFSM, IFFM and INDFP being most bothered (33-42%). Table 16d indicates that 10% of the respondents were bothered by glare from the work surface and dissatisfied with their lighting, while 56% were satisfied and not bothered by glare.

Finally, table 16e indicates that the percentage of those bothered by glare from task lighting ranged from 10-26%, with those with the IFFM system being most bothered. Comparison of table 16f and 16g indicates that more people with furniture integrated lighting (11% vs 6%) were both dissatisfied with their lighting and bothered by glare from their task lighting.

Table 16 indicates that ratings of work station lighting satisfaction were higher (left hand portions of the table) for work stations rated as having less glare from the task lights, ceiling lights and work surfaces. In addition, glare from the work surface bothered a higher percentage of people in each lighting system type (except DRFLN) than the other types of glare. Glare from task lighting was particularly bothersome, however, to those people with furniture integrated task lighting.

Table 16h tabulates data for the bothersomeness of glare from task lights for work stations with and without furniture integrated task units.[9] This table indicates that occupants in work stations with task lights were slightly more likely to be bothered by glare from task lights ($p < 0.02$).

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[8]The "fairly" and "very" bothersome responses were combined in subsequent discussion as a "bothersome" category.

[9] These work stations had little daylight.

Table 16. Reaction to Glare in the Work Station

Table 16a. Bothersomeness of Glare from Ceiling Lights - All Respondents

Lighting System	Bothersomeness Not at all		Not Very		Fairly		Very		Total	
DRFLV	116	43%	105	39%	27	10%	23	8%	271	100%
DRFLN	58	42%	33	24%	32	23%	16	12%	139	100%
DFSM	12	32%	13	35%	9	24%	3	8%	37	100%
IFFM	86	61%	37	26%	11	8%	6	4%	140	100%
INDFP	24	35%	25	37%	15	22%	4	6%	68	100%
DIFP	34	49%	28	41%	4	6%	3	4%	69	100%
HIDP	16	53%	10	33%	3	10%	1	3%	30	100%
Total	346	46%	251	33%	101	13%	56	7%	754	100%

Table 16b. Bothersomeness of Glare from Ceiling Lights to Occupants as a Function of Lighting Satisfaction - All Respondents

Lighting Satisfaction	Bothersomeness Not at all		Not Very		Fairly		Very		Total	
Not at all	10	1%	6	1%	2	0%	10	1%	28	4%
Not Very	37	5%	36	5%	29	4%	20	3%	122	16%
Neither	28	4%	35	5%	19	2%	5	1%	87	11%
Fairly	133	17%	138	18%	45	6%	20	3%	336	43%
Very	144	19%	47	6%	11	1%	2	0%	204	26%
Total N	346	45%	262	34%	106	14%	57	7%	777	100%

Table 16c. Bothersomeness of Glare from Work Surfaces for Each Lighting System - All Respondents

Lighting System	Bothersomeness Not at all		Not Very		Fairly		Very		Total	
DRFLV	106	39%	109	40%	35	13%	23	8%	273	100%
DRFLN	64	47%	41	30%	21	15%	11	8%	137	100%
DFSM	6	16%	16	42%	9	24%	7	18%	38	100%
IFFM	50	35%	47	33%	30	21%	17	12%	144	100%
INDFP	25	37%	20	29%	18	26%	5	7%	68	100%
DIFP	28	40%	28	40%	10	14%	4	6%	70	100%
HIDP	17	57%	8	27%	4	13%	1	3%	30	100%
Total	296	39%	269	35%	127	17%	68	9%	760	100%

Table 16d. Bothersomeness of Glare from Work Surfaces and Lighting Satisfaction

Lighting Satisfaction	Bothersomeness: Not at all		Not Very		Fairly		Very		Total	
Not at all	5	1%	4	1%	7	1%	12	2%	28	4%
Not Very	29	4%	40	5%	33	4%	22	3%	124	16%
Neither	24	3%	33	4%	27	3%	6	1%	90	11%
Fairly	110	14%	143	18%	54	7%	28	4%	335	43%
Very	133	17%	57	7%	13	2%	4	1%	207	26%
Total N	301	38%	277	35%	134	17%	72	9%	784	100%

Table 16e. Rating of Bothersomeness of Glare from Task Lights for Each System All Respondents

Lighting System	Bothersomeness: Not at all		Not Very		Fairly		Very		Total	
DRFLV	121	47%	93	36%	27	10%	18	7%	259	100%
DRFLN	82	71%	22	19%	8	7%	3	3%	115	100%
DFSM	16	47%	11	32%	6	18%	1	3%	34	100%
IFFM	59	43%	42	31%	23	17%	12	9%	136	100%
INDFP	34	52%	22	33%	7	11%	3	5%	66	100%
DIFP	36	55%	21	32%	5	8%	3	5%	65	100%
HIDP	21	70%	6	20%	2	7%	1	3%	30	100%
Total	384	52%	230	31%	82	11%	42	6%	738	ERR

Table 16f. Bothersomeness of Glare from Task Lights and Lighting Satisfaction For All Respondents

Lighting Satisfaction	Bothersomeness: Not at all		Not Very		Fairly		Very		Total	
Not at all	8	1%	3	0%	2	0%	9	1%	22	3%
Not Very	41	6%	33	5%	26	4%	10	1%	110	15%
Neither	40	5%	32	4%	7	1%	5	1%	84	12%
Fairly	143	20%	119	16%	39	5%	14	2%	315	43%
Very	147	20%	41	6%	7	1%	3	0%	198	27%
Total N	379	52%	228	31%	81	11%	41	6%	729	100%

Table 16g. Bothersomeness of Glare from Task Lights and Lighting Satisfaction For Occupants with Furniture Integrated Task Units

Lighting Satisfaction	Bothersomeness									
	Not at all		Not Very		Fairly		Very		Total	
Not at all	3	1%	1	0%	2	1%	7	2%	13	4%
Not Very	21	7%	18	6%	18	6%	5	2%	62	19%
Neither	9	3%	19	6%	3	1%	4	1%	35	11%
Fairly	50	16%	49	15%	18	6%	9	3%	126	39%
Very	60	19%	19	6%	4	1%	2	1%	85	26%
Total N	143	45%	106	33%	45	14%	27	8%	321	100%

Table 16h. Comparison of Ratings of Glare From Task Unit

Bothersomeness of Glare from Lights	No Task Unit		Furn. Int Unit	
Not at all	79	59%	97	46%
Not Very	40	30%	71	33%
Fairly	10	8%	33	15%
Very	5	4%	15	7%
Total N	134		216	

$\chi^2 = 9.09$ $p<.03$

Table 16i. Rating of Glare from the Work Surface

Bothersomeness of Glare from Lights	No Task Unit		Furn. Int Unit	
Not at all	50	38%	84	39%
Not Very	53	40%	71	33%
Fairly	20	15%	39	18%
Very	10	8%	19	9%
Total N	133		213	

$\chi^2 = 1.74$ $p=0.63$

Table 16i indicates that these people were not more likely to be bothered by reflected light from the work surface, however.

Analysis of the occupant reaction to the bothersomeness of glare in the work station indicates that glare had a small, but measurable impact on work station lighting satisfaction. Thus, glare from ceiling lights was bothersome to those with the DRFLN and DFSM systems, glare from the work surface was bothersome to those with the DFSM, INDFP and IFFM systems, and glare from task lights was bothersome to those with the IFFM and DFSM systems. The extent to which bright lights were bothersome influenced peoples' assessment of lighting quality for all workers except those whose primary task was writing.

Ratings of work station lighting satisfaction were higher for those work stations that were rated as having less glare from the task lights, ceiling lights and work surfaces. In addition, glare from the work surface bothered a higher percentage of people in each lighting system type than the other types of glare. Glare from task lighting was bothersome, however, to those people with furniture integrated task lighting. In addition, the more people were bothered by bright lights, the more likely they were to give lower assessments of lighting quality.

5.3 Control

Still another important component of lighting satisfaction and quality is peoples' feelings about their ability to control their lighting. Feelings about control influenced the assessments of lighting quality as shown in table 15, regardless of the type of lighting system, the presence or absence of daylighting, the availability of task lighting, and the worker's predominant task. The relationship, however, was strongest for people without task lighting as shown in figure 37. The rating of lighting quality was more strongly related to the ability to control lighting for workers with the IFFM system than workers with DRFLV systems as shown in figure 38.

5.4 Impact of VDT's in the Work Space

The lighting quality associated with a particular lighting system was determined not only by design factors but also by task characteristics as shown in Figure 39. With the advent of the personal computer with a VDT monitor, offices are no longer primarily paper operations. Lighting a work station with a VDT imposes certain constraints not found in offices with conventional paper tasks, not the least of which is the effect of ceiling lights on the screen.

Glare from ceiling lights was significantly more bothersome to those with VDTs than to those without VDTs ($p<.002$). At the same time, workers with VDTs did not find glare from task lights to be particularly bothersome. This is not surprising since task lights are often located in the furniture behind the VDT unit, while ceiling lights are located above the unit and can be in the offending zone. By way of illustration, Figure 39 indicates that lighting quality scores for occupants with the DRFLV system were lower the longer they used VDTs during the day. This figure also indicates little

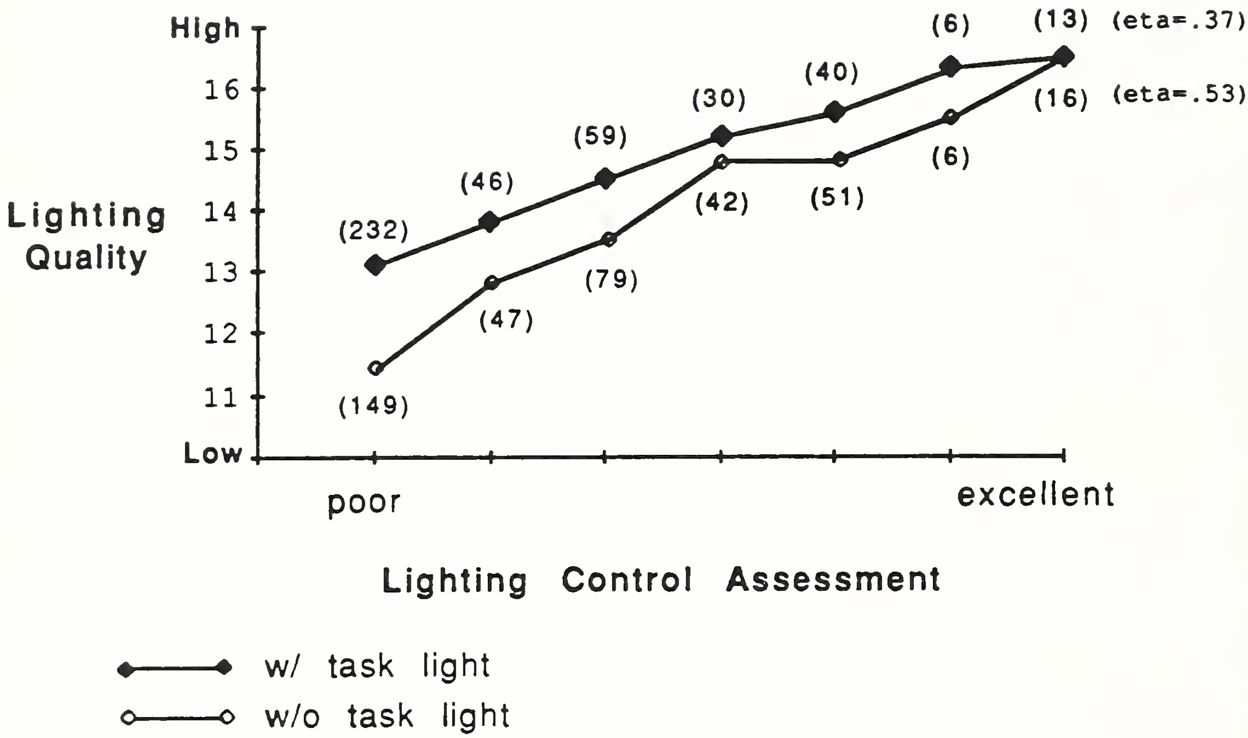


Figure 37. Lighting quality as a function of lighting control assessment for respondents with and without task lighting.

This figure indicates that ratings of lighting quality were higher when the ratings of the ability to control lighting were also higher. In addition, those who had task lighting tended to rate their lighting quality as better for all assessments of their ability to control their lighting.

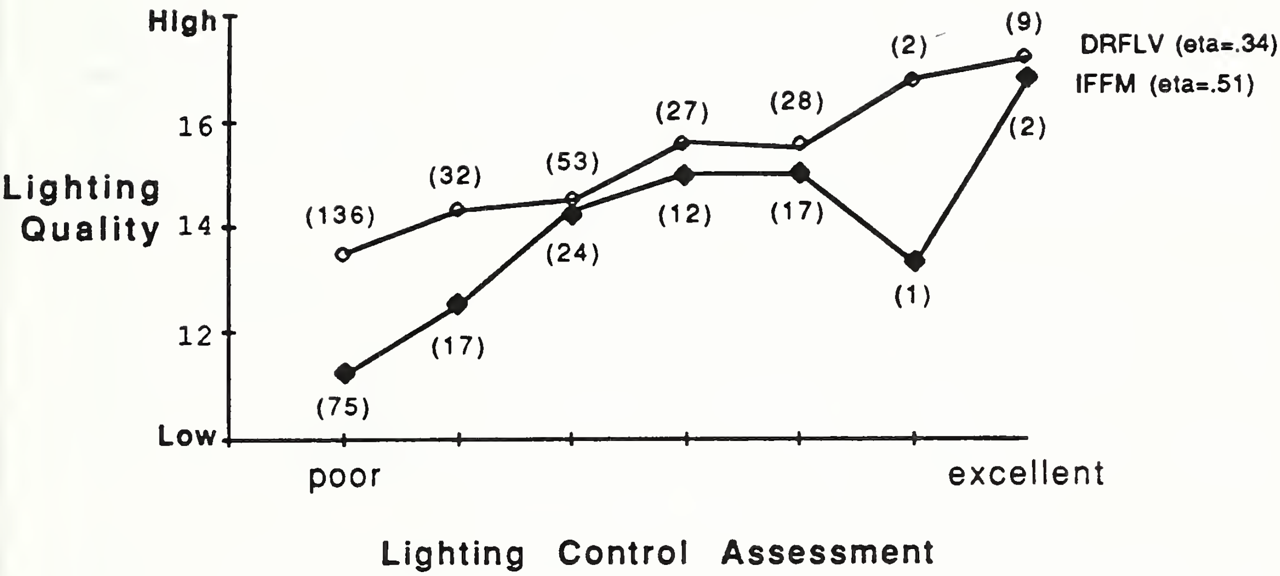


Figure 38. Lighting quality as a function of lighting control assessment for DRFLV and IFFM systems.

This figure indicates that assessments of lighting quality were consistently higher for those with the DRFLV system and increased as the assessment of the ability to control the lighting increased. Furthermore, it also indicates that the majority of those with the IFFm system (75 people) rated their lighting quality as low and also considered their ability to control the lighting to be poor.

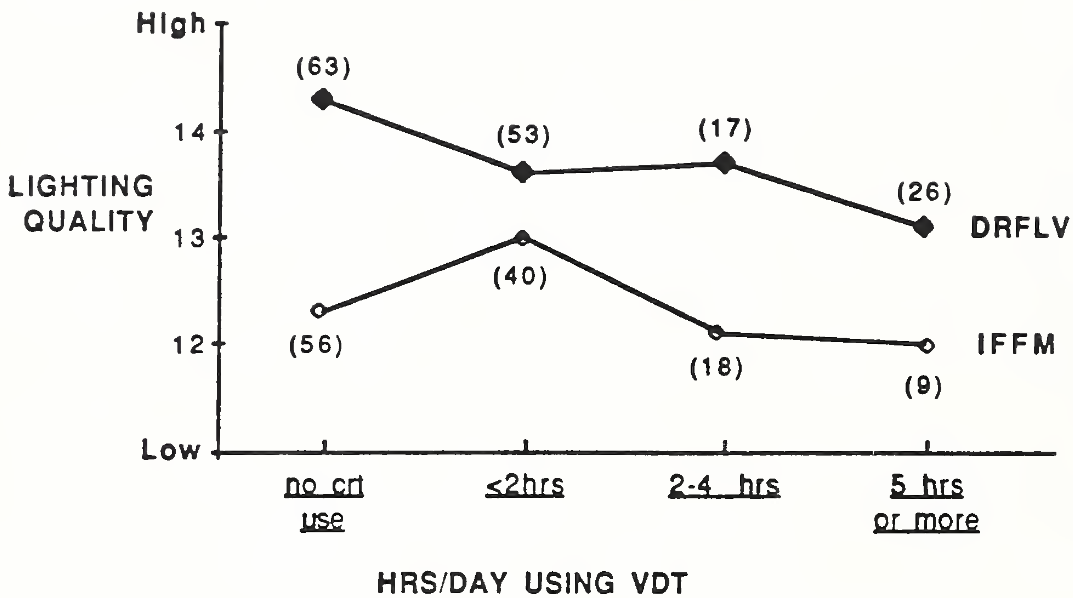


Figure 39. Lighting quality as a function of hours spent per day using a VDT for DRFLV and IFFM systems.

This figure indicates that assessments of lighting quality decreased as the number of hours per day spent using a VDT increased but that the DRFLV system was always rated as having higher lighting quality than the IFFM system regardless of the amount of time spent using a VDT.

change in lighting quality scores for those with the IFFM system regardless of the length of time they used a VDT during a day. Comparison of the two curves suggests that the DRFLV system may have created some problems, such as reflections on the VDT monitors.

Nonetheless, lighting quality scores for the DRFLV system were consistently higher than for the IFFM system, even for those who used VDTs for five or more hours a day.

5.5 Impact of Office Characteristics

5.5.1 Desired Changes to Space

Another way of looking at the impact of lighting on occupant response is to examine the data on changes that people would make to their environment if the opportunity arose. They were asked to select four improvements from a list of ten possible changes that could be made to their work station and indicate their most preferred choice. Examination of these data, given in table 17, allows one to determine the importance of changes to lighting relative to other factors in the environment.

Table 17a presents the desired improvements for the database as a whole (all) followed by the choices for each individual lighting system. This table indicates that the desire for increased privacy was the major factor in people's selections. Nearly one fourth (23%) of the respondents chose greater privacy as their preferred improvement, followed by 17% who chose a better office temperature. Improved air circulation (15%) was next followed by improved lighting (11%).

Of major interest is the high percentage of occupants - 22% - with the IFFM system who picked improved lighting as a desired improvement. Only privacy was selected by more people with this lighting system (25%). This pattern of responses may be compared with that for the DRFLV system where only 9% selected lighting as a desired improvement, but 30% selected increased privacy. This comparison suggests that although privacy was an important concern for those with the IFFM system, the desire for improved lighting were almost as great, and substantially greater than for those with the DRFLV system. For the other lighting systems, improved air circulation was a paramount concern for the DRFLN system, improved colors in the space for the DFSM system, improved temperatures for the DIFP system, greater privacy for the INDFP system, and improved view out and temperature for the HIDP system. Across lighting systems, the desire for improved daylight was substantially lower than the desire for an improved view out.

Table 17b presents the choices for different types of office layouts. Thus, people in open plan offices (with or without partitions) selected improved privacy as their most desired improvement. However, respondents in fully enclosed offices selected better air circulation (21%) as their most preferred improvement, followed by better office temperature (17%), and better space colors (13%). In addition, improvements to lighting dropped from fourth for the open office to a distant seventh in enclosed offices.

Table 17. Desired Work Station Improvements

Table 17a. Selections for Different Lighting System Types

Choice	All	DRFLV	DRFLN	DFSM	IFFM	DIFP	INDFP	HIDP
View	10%	12%	9%	3%	11%	6%	8%	20%
Temperature	17%	17%	15%	11%	11%	31%	13%	20%
Privacy	23%	30%	17%	11%	25%	20%	25%	12%
Space Color	8%	8%	6%	27%	3%	3%	12%	16%
LIGHTING	11%	9%	3%	5%	22%	17%	12%	0%
Less Noise	9%	8%	13%	8%	7%	9%	13%	12%
Air Circ	15%	9%	29%	14%	16%	9%	8%	12%
Near People	0%	0%	0%	0%	0%	0%	2%	0%
Daylight	2%	2%	1%	3%	5%	2%	2%	0%
Furniture	5%	4%	8%	19%	0%	2%	6%	8%
Total N	688	224	139	37	122	64	52	25

Table b. Improvement Selections for Different Work Station Types

Choice	Open Plan	Open Pool	Enclosed	Total
View	9%	15%	10%	68
Temperature	16%	24%	17%	114
Privacy	29%	18%	9%	159
Space Color	7%	9%	13%	58
LIGHTING	13%	3%	8%	75
Less Noise	10%	6%	9%	66
Air Circ	12%	12%	22%	101
Near People	0%	0%	1%	2
Daylight	3%	3%	1%	16
Furniture	2%	9%	11%	35
Total N	475	33	186	694

Table c. Improvement Selections for Different Task Light Types

Choice	No Task	Furniture	Desk Movable	Other
View	10%	12%	4%	6%
Temperature	18%	14%	19%	6%
Privacy	21%	27%	16%	41%
Space Color	10%	7%	7%	12%
LIGHTING	6%	13%	22%	0%
Less Noise	9%	10%	10%	6%
Air Circ	17%	12%	14%	18%
Near People	0%	0%	0%	12%
Daylight	2%	3%	3%	0%
Furniture	8%	2%	5%	0%
Total N	296	286	96	17

Finally, those occupants who rated their view out as poor listed an improved view out as their second most commonly desired change, second only to improved privacy.

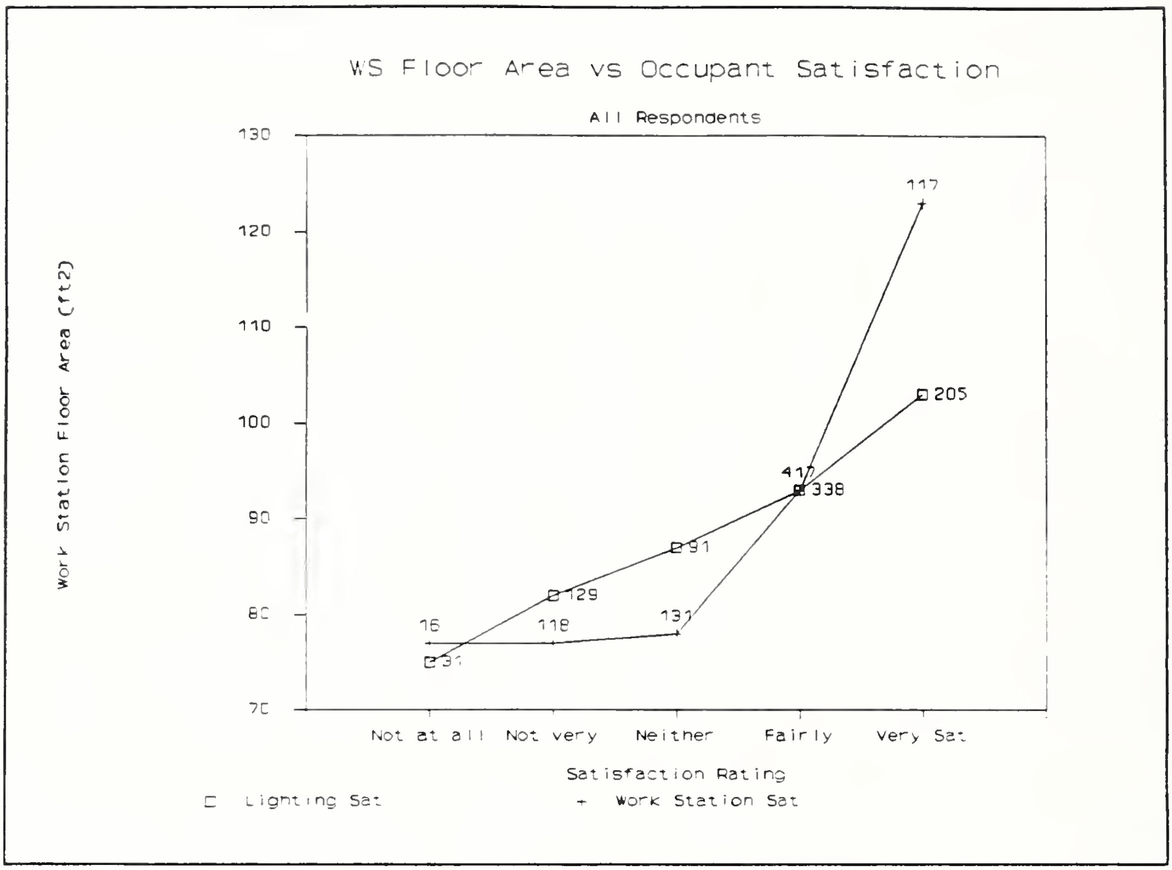
Improved lighting ranked eighth for occupants at work stations without task lighting, but third for those with furniture integrated task lighting (Table 17c). In addition, improved lighting was selected as the most desired improvement for occupants at work stations with movable desk units.

5.5.2 Impact of Space

Another factor that can influence satisfaction with offices and lighting is the amount of space in the work station. Figure 40 indicates that those who were not satisfied with their lighting (gave it ratings of 1 or 2) had the smallest work station floor area, while those who were most satisfied had larger floor areas. This figure shows a virtually linear relation between increasing work station floor area and the rating of work station lighting satisfaction. Figure 40 also presents a nonlinear relationship between work station floor area and overall work station satisfaction. In this figure, floor area was about the same for overall work station satisfaction until ratings of "fairly" and "very satisfied" are examined. Those ratings were associated with larger floor areas. Those who were "very satisfied" with their work station had much larger work areas than did those who were "very satisfied" with their lighting.

If, however, work station lighting satisfaction ratings are averaged and then plotted as a function of work station floor area, the picture is much less straightforward as shown in figure 41. Although there is still a tendency for lighting satisfaction ratings to be higher with larger floor areas if the ten work stations with average floor areas below 20 ft^2 are excluded, the increase in satisfaction was only slight, while the standard deviation was large. (Occupants in these very small offices tended to be technical staff or others such as field engineers who were in their work stations only 1 to 5 hours per day.) The differences between figures 40 and 41 underscore the difficulty of presenting and analyzing data in a POE analysis, as well as some of the problems with averaging rating data.

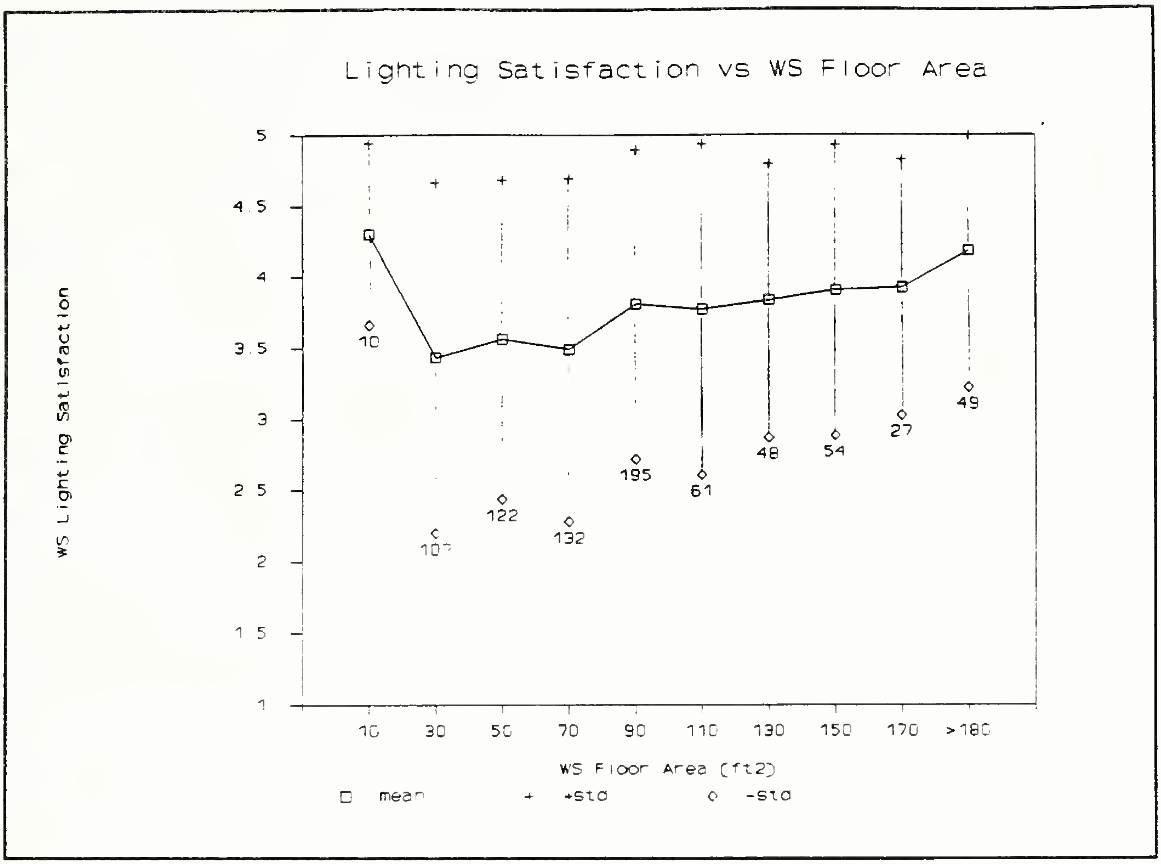
As should be expected, occupant ratings of spaciousness were strongly related to their work station floor area as shown in figure 42. Thus, those who rated their spaces as "confined" had average floor areas of 70 ft^2, while those who rated their spaces as "spacious" had average floor areas of about 110 ft^2, with a reasonably linear relationship between spaciousness rating and floor area. Less obvious, perhaps is the strong relationship between work station lighting satisfaction and ratings of spaciousness shown in table 18. When the ratings of "not at all" or "not very" satisfied with lighting are compared with ratings of spaciousness (table 18c), it can be seen that 10% of those rating their lighting as unsatisfactory also rated their work space as "confined" (1, 2 or 3), as compared with only 17% who rate it as "spacious" (5, 6, or 7). The opposite relation held for those who rated their lighting as "fairly" or "very" satisfactory. Only 5% of



Daylighting included; task lighting included.

Figure 40. Mean floor area as a function of both individual categories of lighting satisfaction ratings and work station ratings.

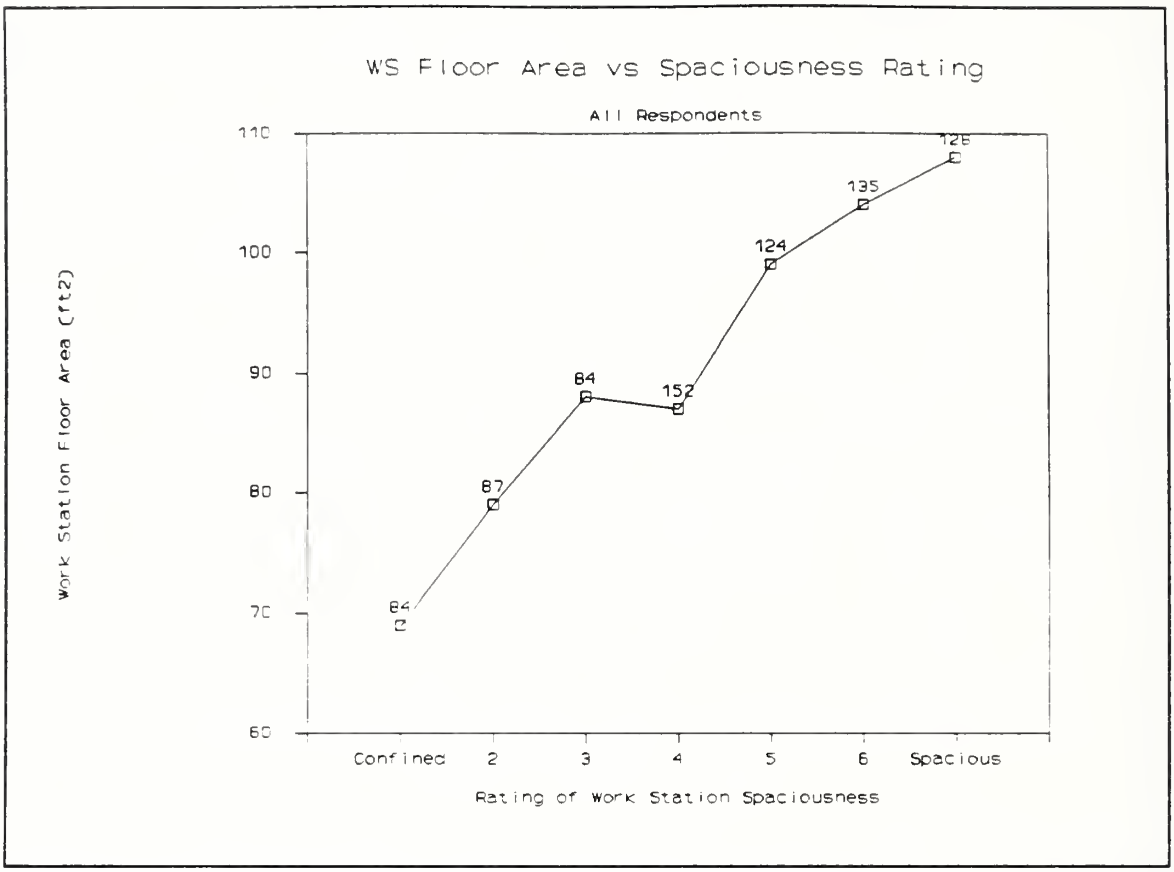
This figure indicates that floor areas increased as both rated lighting satisfaction and work station satisfaction increased. Those who considered themselves "very" satisfied with their work station had the largest mean floor areas (125 ft^2), while those who were "very" satisfied with their lighting had slightly smaller floor areas (with a mean of about 100 ft^2).



Daylighting included; task lighting included.

Figure 41. Mean lighting satisfaction rating as a function of work station floor area category.

This figure indicates that when average lighting satisfaction was plotted for work station floor area, the relationship between floor area and lighting satisfaction was virtually non-existent. In this figure, the average lighting satisfaction increased only slightly as work station floor area increased (particularly if the ten cases with very small floor areas who were also identified as spending very little time in their work stations are excluded). The great variability in ratings for each floor area category points out some of the problems with averaging rating data.



Daylighting included; task lighting included.

Figure 42. Mean work station floor area as a function of individual categories of ratings of work station spaciousness.

In this figure, mean work station floor area increased as the rated spaciousness of the work station increased. Here, the floor area for each individual rating category was averaged.

Table 18. Ratings of Lighting Satisfaction and Area

Table 18a. Ratings of Work Station Lighting Satisfaction and Spaciousness as a Function of Work Station Floor Area in Ft^2

Rated Spaciousness		Lighting Satisfaction: Not at all	Not Very	Neither	Fairly	Very Sat	Mean
Confined	1	56	63	53	78	82	69
	2	87	75	81	81	75	79
	3	137	75	85	96	79	88
	4	72	70	97	82	105	87
	5	98	100	91	99	102	99
	6	90	115	105	100	105	104
Spacious	7		112	93	102	114	108
Mean Area		76	82	88	93	103	92

Table 18b. Number of Occupants Providing Ratings of Lighting Satisfaction and Work Station Spaciousness

Rated Spaciousness		Lighting Satisfaction: Not at all	Not Very	Neither	Fairly	Very Sat	Mean
Confined	1	9	23	9	29	14	84
	2	4	25	15	32	11	87
	3	1	20	14	38	11	84
	4	11	24	19	64	34	152
	5	5	12	17	58	32	124
	6	1	16	11	64	43	135
Spacious	7	0	9	6	53	60	128
Total Responding		31	129	91	338	205	794

Table 18c. Percentage of Occupants Providing Ratings of Lighting Satisfaction and Work Station Spaciousness for Combined Categories

Rated Spaciousness	Lighting Satisfaction: Not at all/ Not Very	Neither	Fairly/ Very Sat	Mean
Confined 1,2,3	10% (82)	5% (38)	17% (135)	32% (255)
4	4% (35)	2% (19)	12% (98)	19% (152)
5,6,7 Spacious	5% (43)	4% (34)	39% (310)	49% (49%)
Total N	20% (160)	11% (91)	68% (543)	100% (794)

Table 18d. Ratings of Work Station Satisfaction as a Function of Work Station Floor Area in Ft^2

Work Station Floor Area

Rated Spaciousness		Work Station Satisfaction Not at all	Not Very	Neither	Fairly	Very Sat	Mean
Confined	1	77	67	74	70		70
	2	90	83	71	80	88	78
	3		73	80	100		88
	4	54	85	79	91	116	87
	5		65	97	94	132	99
	6	127	228	55	99	124	104
Spacious	7		51	119	97	119	108
Mean Area		77	77	79	94	121	92

Table 18e. Lighting Satisfaction and Work Station Satisfaction

Work Station Floor Area in ft^2

Work Sta. Satisfaction	Lighting Satisfaction Not at all	Not Very	Neither	Fairly	Very Sat	Mean
Not at all	65	95	57	70	105	77
Not Very	66	78	65	77	89	77
Neither	79	67	85	80	78	78
Fairly	90	93	94	93	95	93
Very Sat		97	152	126	121	123
Mean Area	75	82	87	93	103	92

Table 18f. Lighting Satisfaction and Work Station Satisfaction

Number of Respondents

Work Sta. Satisfaction	Lighting Satisfaction Not at all	Not Very	Neither	Fairly	Very Sat	Mean
WS Sat						
Not at all	7	4	2	1	2	16
Not Very	10	41	13	39	15	118
Neither	5	33	34	42	17	131
Fairly	10	48	42	220	97	417
Very Sat	0	2	2	35	78	117
Total Responding	32	128	93	337	209	799

those people rated their work space as "confined", as compared with 39% who rated it as "spacious". (These comparisons excluded those who were neutral about their work space or their lighting satisfaction.) This relationship is in line with studies of spaciousness which have indicated that lighting plays an important role in the perception of the amount of space in an area. (See Inui and Miyata, 1973; Flynn, 1977.)

5.6 Demographic Influences

Other factors which may influence work station lighting satisfaction are those related to demographics or the characteristics of the people responding to the questionnaire. Such factors include age, sex, job type, and corrective lenses.

The data shown in table 19a suggest that work station lighting satisfaction increased with age, so that older occupants were more satisfied with their lighting (p=.004). Thus, 38% of those over 54 were very satisfied with their lighting, as compared with 22% of those under 35. They also tended to be more satisfied with their overall work station (p=.00005). Table 19 also indicates that older occupants tended to be male (by a 3:1 ratio), tended to be either managers or professionals, and tended to have larger work station floor areas. In general, older occupants did not have noticeably higher task illuminances, nor did they have fewer local task lights; however, they were more likely to be in an enclosed office with daylight available.

Table 19j indicates that women were slightly less satisfied with their work station lighting in particular (p=.05) and less satisfied with their work station in general than men. They also had a substantially smaller average work station floor area (73 ft^2) than for men (108 ft^2) as shown in 19i. About half (56%) of the women were under the age of 35 and about half (54%) held either secretarial or clerical positions. Although there was an almost equal mix of males and females in the full sample, three-fourths (76%) of the occupants with the IFFM system (without daylight) who were dissatisfied with lighting were female. There were more men than women (by a 2:1 ratio) in spaces with the DRFLV system, and more women than men (by a 3:1 ratio) in those with the INDFP system. The distribution of males and females for the other systems was about equally divided. Finally, there was no statistically significant relationship between work station lighting satisfaction and glasses, contacts, or bifocals.

No significant relationship between job type and work station lighting satisfaction was found, although larger work station floor areas were associated with increased job importance. Thus, managers and administrators had about twice the floor area per work station as secretarial and clerical personnel, with professional and technical personnel having intermediate amounts as shown in figure 43. The greatest impact of floor area on work station lighting satisfaction occurred for managers and administrators as shown in figure 44. As their floor area increased, so did their lighting satisfaction. The relationship between floor area and work station lighting satisfaction was weaker for secretarial and clerical personnel, and non-existent for professionals and technical personnel.

Table 19. Demographic Characteristics of Respondents

Table 19 a. Occupant Age and Work Station Lighting Satisfaction

	Work Station Lighting Satisfaction											
	Not at all		Not Very		Neither		Fairly		Very Sat		Mean	
Under 25	1	3%	4	3%	10	11%	32	9%	18	9%	65	8%
25-34	14	44%	48	37%	36	39%	122	36%	60	29%	280	35%
35-44	12	38%	53	41%	26	28%	93	27%	56	27%	240	30%
45-54	5	16%	21	16%	13	14%	53	16%	38	18%	130	16%
55-64			2	2%	7	8%	37	11%	31	15%	77	10%
65-74			1	1%	1	1%	3	1%	2	1%	7	1%
Over 75							1	0%	1	0%	2	0%
Total	32	100%	129	100%	93	100%	341	100%	206	100%	801	100%

Table 19b. Occupant Age and Overall Work Station Satisfaction

	Overall Work Station Satisfaction											
	Not at all		Not Very		Neither		Fairly		Very Sat		Mean	
Under 25	1	6%	8	7%	13	10%	37	9%	6	6%	65	8%
25-34	4	25%	51	42%	40	31%	154	36%	33	29%	282	35%
35-44	9	56%	41	34%	46	35%	123	29%	24	21%	243	30%
45-54	2	13%	14	13%	21	16%	68	16%	24	21%	129	16%
55-64			4	3%	10	8%	35	8%	26	23%	75	9%
65-74			3	2%			4	1%			7	1%
Over 75							1	0%	1	1%	2	0%
Total	16	100%	121	100%	130	100%	422	100%	114	100%	803	100%

Table 19c. Distribution of Age and Sex of Occupants

	Female		Male		Total	
Under 25	51	13%	15	3%	66	8%
25-34	160	42%	124	29%	284	35%
35-44	116	31%	128	30%	244	30%
45-54	33	9%	98	23%	131	16%
55-64	18	5%	59	14%	77	9%
65-74	1	0%	6	1%	7	1%
Over 75	0	0%	2	0%	2	0%
Total	379	100%	432	100%	811	100%

Table 19d. Job Title of Occupants

	Managerial		Professional		Secretarial		Total	
Under 25	2	1%	14	4%	35	18%	51	7%
25-34	45	21%	120	38%	85	44%	250	35%
35-44	82	39%	85	27%	53	27%	220	30%
45-54	51	24%	58	18%	13	7%	122	17%
55-64	30	14%	33	10%	9	5%	72	10%
65-74	0	0%	5	2%	0	0%	5	1%
Over 75	1	0%	1	0%	0	0%	2	0%
Total	211	100%	316	100%	195	100%	722	100%

Table 19e. Occupant Age and Type of Work Station Enclosure

	Open Pool		w/Partitions		Enclosed		Total	
Under 25	3	9%	56	10%	7	3%	66	8%
25-34	13	37%	214	38%	57	27%	284	35%
35-44	13	37%	170	30%	60	28%	243	30%
45-54	2	6%	80	14%	49	23%	131	16%
55-64	4	11%	42	7%	31	15%	77	10%
65-74	0	0%	1	0%	6	3%	7	1%
Over 75	0	0%	0	0%	2	1%	2	0%
Total	35	100%	563	100%	212	100%	810	100%

Table 19f. Mean Floor Area (ft2) for Lighting Satisfaction and Different Age Groups

	Lighting Satisfaction					
	Not at all	Not Very	Neither	Fairly	Very Sat	Mean
Under 25	75	79	50	64	61	62
25-34	73	65	83	79	83	77
35-44	88	88	98	94	93	93
45-54	50	98	102	118	137	116
55-64		95	95	114	141	123
65-74		203	64	103	101	111
over 75				98	147	122
Total	75	82	87	92	103	92

Table 19g. Sex and Job Title of Different Occupants

	Managerial		Professional		Secretarial		Total	
Female	60	28%	97	31%	181	92%	338	47%
Male	152	72%	220	69%	15	8%	387	53%
Total	212	100%	317	100%	196	100%	725	100%

Table 19h. Daylight Availability for Occupants of Different Ages

	Daylight		Little Daylight		Total	
Under 25	24	7%	42	9%	66	8%
25-34	96	37%	188	41%	284	35%
35-44	108	30%	135	30%	243	30%
45-54	79	22%	52	11%	131	16%
55-64	41	12%	36	8%	77	10%
65-74	6	2%	1	0%	7	1%
Over 75	1	0%	1	0%	2	0%
Total	355	100%	455	100%	810	100%

Table 19i. Occupant Sex and Type of Office Enclosure

	Open		w/Partitions		Enclosed		Total	
Female	22	63%	283	50%	77	36%	382	47%
Male	13	37%	282	50%	136	64%	431	53%
Total	35	100%	565	100%	213	100%	813	100%

Table 19j. Mean Floor Area (ft^2) for Lighting Satisfaction and Sex

Lighting Satisfaction

	Not at all	Not very	Neither	Fairly	Very Sat	Totals
Female	69	68	61	74	82	73
Male	83	101	106	106	118	108
Total	75	82	87	92	103	92

Table 19k. Sex and Lighting Satisfaction

Lighting Satisfaction:	Female		Male		Total
Dissatisfied	94	25%	68	16%	162
Neither	39	10%	54	13%	93
Satisfied	245	65%	304	71%	549
Total	378	100%	426	100%	804

Table 19l. Sex and Lighting Satisfaction for Occupants With Different Lighting Systems

Lighting System Type:	Female		Male		Total
DRFLV	97	27%	180	43%	277
DRFLN	77	21%	65	16%	142
DF-SM	21	6%	17	4%	38
IFFM	78	21%	73	18%	151
INDF-P	51	14%	19	5%	70
DIF-P	27	7%	43	10%	70
HID-P	13	4%	19	5%	32
Total	364	100%	416	100%	780

IFFM System w/Task Units
(No daylight)

Lighting Satisfaction:	Female		Male		Total
Dissatisfied	29	53%	9	32%	38
Neither	5	9%	0	0%	5
Satisfied	21	38%	19	68%	40
Total	55	100%	28	100%	83

DRFLV System w/Task Units
(No daylight)

Lighting Satisfaction:	Female		Male		Total
Dissatisfied	4	10%	15	21%	19
Neither	3	8%	13	18%	16
Satisfied	32	82%	45	62%	77
Total	39	100%	73	100%	112

Table 19m. Occupant Sex and Type of Task Lighting

	No Task		Furn Int		Movable Desk		Total	
Female	175	53%	136	39%	62	54%	373	47%
Male	157	47%	211	61%	52	46%	420	53%
Total	332	100%	347	100%	114	100%	793	100%

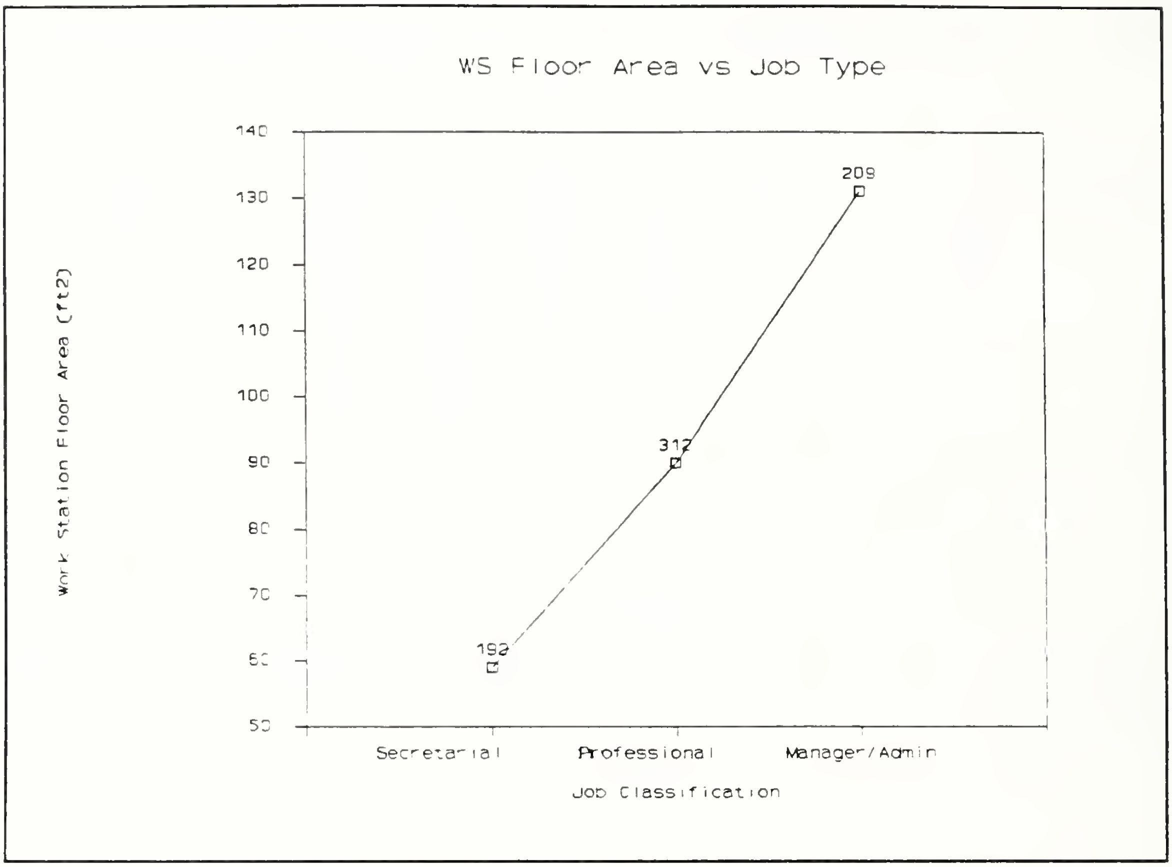
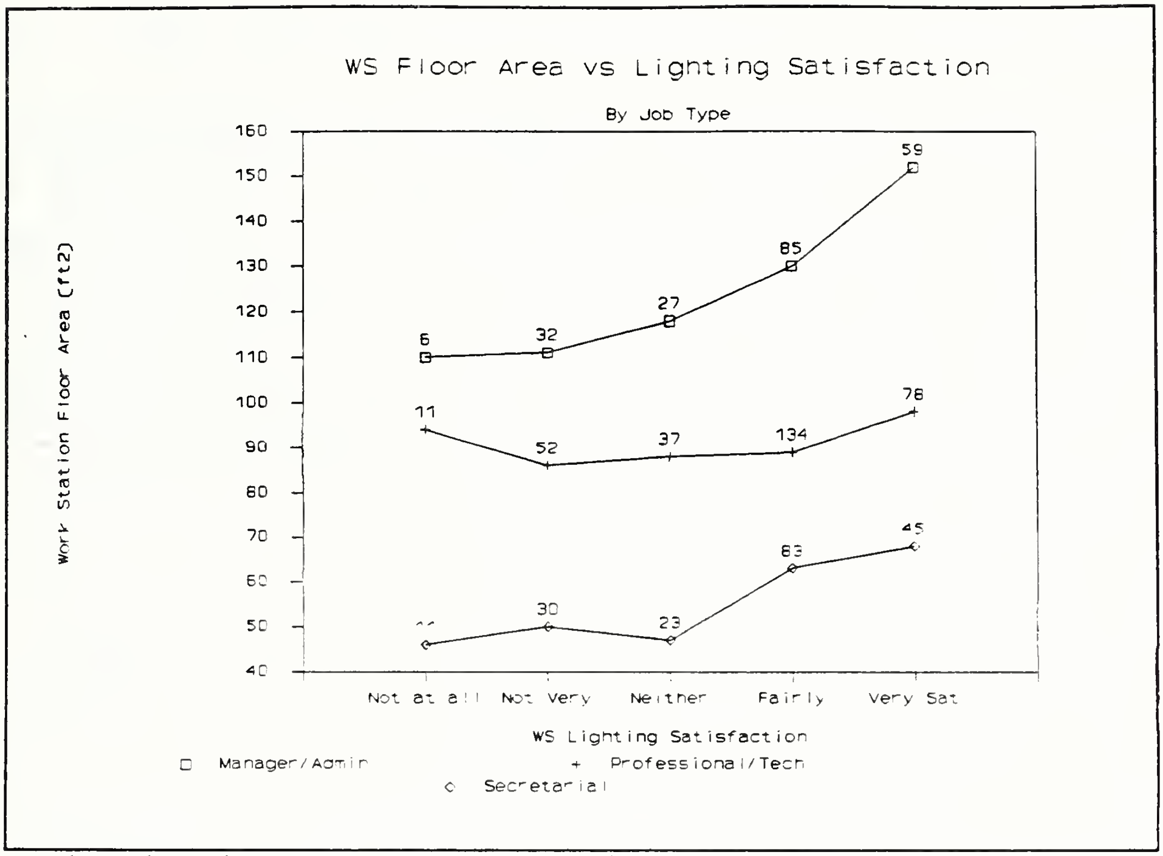


Figure 43. Mean work station floor area for different job classification categories.

This figure indicates that the mean floor area was smallest for secretarial and clerical staff, intermediate for professional and technical staff, and greatest for managerial and administrative staff.



Dylighting included; task lighting included.

Figure 44. Relationship between mean work station floor area, job classification, and lighting satisfaction.

This figure indicates that lighting satisfaction was slightly higher for larger floor areas for managerial and administrative staff, as well as for secretarial personnel, but that there was little change in lighting satisfaction with floor area for professional and technical staff.

5.7 Other Factors

A series of χ^2 statistical tests were run to determine if there were other environmental factors that might have influenced lighting satisfaction. These tests looked at the impact of eight different lighting systems (breaking DRFLV into two systems based on task lighting) on different non-lighting variables. Table 20 presents the variables, χ^2 values, significance, and degrees of freedom. The first two variables examined were perceptual ones. This analysis showed no significant differences in the perception of hot temperatures in summer among occupants with the eight lighting systems. The second analysis, work station noise, revealed some slight differences among the eight systems, with DRFLN being perceived as least quiet and the HIDP being the most quiet. The next two analyses related to the time that a person had spent in his/her current building and then in his/her current work station. Both showed that there was a significant effect related to lighting system type. Thus more people (80-85%) had spent 2 or more years in buildings with the DFSM, HIDP, and DIFP systems. More people (50%) had worked for 2 or more years in work stations with HIDP and DFSM systems than for DRFLV or DRFLN systems (40%). Only 22% of those with the IFFM, IFP and DRFLVw/T task systems had spent two or more years in their space. All, however, had spent at least one year in their space. This suggests that the response to the lighting systems was not based on the novelty of the work station; occupants had had time to become accustomed to their work stations before the survey was done.

Table 20 indicates that there was a significant difference in rated chair comfort with only 45% of those with the DRFLN and DFSM systems rating their comfort as good, as compared with 70-75% of those with the IFFM, DRFLV and DRFLVw/T systems rating their comfort as good. Differences in the amount of space in the work stations were highly significant, with work stations with the HIDP system having the smallest area and those with the DFSM system having the largest. About 80% of those with the systems furniture (IFFM and DRFLVw/T) had less than 100 ft^2 per work station, compared with only 60% of those with all other lighting systems.

The next two variables presented in table 20 relate to the perception of ceiling light position. The first, which tabulated rated ceiling light position for the eight lighting systems, showed a significant difference with the indirect systems (such as the IFFM) rated as poor to fair by 72% of those responding but the direct systems (such as the DRFLV) rated as good to excellent by 68%. Similarly the relationship between rated ceiling light position and work station lighting satisfaction was significant. These analyses indicate that as the rating of ceiling light position improved from poor to fair, work station lighting satisfaction increased from "not at all" to "very" satisfied. Thus, 81% of those who rated their satisfaction as "not at all", also rated their ceiling light position as "poor". Conversely, 42% of those who rated their lighting satisfaction as "very", also rated their ceiling light position as "excellent".

Table 20. Cross Tabulation Data for Lighting System Type vs Selected Independent Variables.

Independent Variable	χ^2 Value	Significance	DF
Hot Temperature Summer	31.4	0.07-NS	21
Work Station Noise	64.3	0.02	42
DRFLN least quiet HIDP most quiet			
Length in Current Building	51.1	0.005	28
All at least 65% 2+ years DFSM,HIDP,DIFP 80-85% 2+ years			
Length in Current Space	55.7	0.0006	21
HIDP,DFSM - 50% 2+ years DRFLV,DRFLN - 40% 2+ years IFFM,IFP, DRFLV w/Task 22-31% 2+years			
Rated Comfort of Chair	48.8	0.0005	21
DRFLN,DFSM - 45% comfort poor DIFP - 82% comfort good IFFM, DRFLV, DRFLV W/T - 72-75% comfort good			
Work Station Floor Area	127.6	1.1E-14	28
HIDP smallest, DFSM largest IFFM, DRFLV W/T 80% <100 sq ft, all other systems 60%			
Rated Ceiling Light Position	57.1	000	3
Indirect rated Poor to Fair by 72%; Direct (DRFLV) rated Good to Excellent by 68%			
Rated Ceiling Light Position vs. Work Station Lighting Satisfaction	151.5	000	12

Work station lighting satisfaction was directly related to rated ceiling light position. As ceiling light position rating improved from poor to fair, work station lighting satisfaction increased from "not at all" satisfied to "very" satisfied. Thus, of those who rated their satisfaction as "not at all", 81% also rated their ceiling light position as "poor". Conversely, of those who rated their satisfaction as "very", 42% rated their ceiling light position as "excellent".

Table 21 tabulates the χ^2 values for the relationship between work station lighting satisfaction and a series of independent variables in order of their χ^2 values. For this table, the relationship was considered to be statistically significant, if the significance were less than 0.05, but non-significant if p were greater than 0.10. By this criterion, entries in the upper half of the table are significant; those in the lower portion are not.

Inspection of this table indicates that work station brightness was most closely related to work station lighting satisfaction - thus, spaces seen as brighter were also more satisfying. Lighting in conference rooms, hallways, and lobbies were also significantly related to work station lighting satisfaction. Finally, spaciousness, work station quiet, chair comfort, perceived temperature (hot in summer and hot in winter), work station type (open vs. enclosed), and work station floor area were also significantly related to lighting satisfaction. Variables which were not significantly related to lighting satisfaction (by the χ^2 test) included:

Hours per day at a VDT
Days per weeks at building
Work station type (open pool/plan/enclosed)
Work station partition height
Cold room temperature in summer; winter
Hours per day in building; reading; drafting; in work station
Length of time in current work station
Previous work station type.

Further inspection of the data presented in table 21 reveals that the variables with the highest χ^2 values (the strongest amount of association) were those which relate directly to lighting or to work station area, with rated brightness being the greatest determinant. Length of time in the work station and previous work station type were not significantly related to lighting satisfaction. This analysis suggests further that a number of non-lighting variables had no noticeable impact on lighting satisfaction, and strengthens the case that the different lighting systems did affect lighting satisfaction and perceived lighting quality.

Thus, rated brightness was most strongly related to lighting satisfaction, followed by lighting of conference rooms and hallways, and then perceived spaciousness of the work space.

Table 21. Cross Tabulation of Selected Independent Variables against Work Station Lighting Satisfaction as the Dependent Variable.

Independent Variable	χ^2 Value	Significance Level (p=)	DF
Work Station Brightness (dim-bright)	400.3	0.00000	20
Lighting of Conference Rooms	122.4	0.00000	8
Lighting of Hallways	112.3	0.00000	8
Spaciousness Rating (confined-spacious)	107.3	1.67×10^{12}	24
Work Station Noise Rating (quiet-noisy)	63.5	9.38×10^{11}	8
Lighting of Lobby	45.4	3.13×10^{7}	8
Comfort of Chair	31.1	0.00190	12
Work Station Floor Area	36.0	0.00294	16
Hot Room Temperature in Summer Rating	21.3	0.00633	8
Hot Room Temperature in Winter Rating	18.6	0.0171	8
Work Station Type (open/enclosed)	10.9	0.028	4
Hours/Day at VDT	18.6	0.097	12
Days/Week at building	18.2	0.108	12
Work Station Type (open pool/plan/enclosed)	12.7	0.123	8
Work Station Panel Height	15.8	0.201	12
Cold Room Temperature in Summer Rating	8.9	0.347	8
Hours/Day at Building	8.8	0.359	8
Hours/Day Reading	12.4	0.415	12
Hours/Day Drafting	7.6	0.476	8
Hours/Day at Work Station	6.6	0.583	8
Cold Room Temperature in Winter Rating	5.8	0.670	8
Length of Time with Current Work Station	9.2	0.685	12
Previous Work Station Type	6.0	0.914	12

6. Discussion

6.1 General Conclusions

Data from a post-occupancy evaluation of 912 work stations with lighting power density, photometric, and occupant response measures were analyzed in detail. The design of the work stations was similar to current office design practices, with about 25% of the offices being enclosed and the rest being open plan. About 40% of the work stations had no task lighting, while the remainder had movable or furniture integrated lighting. In addition, about 40% of the work stations were considered to have some daylighting. Seven major types of lighting systems were identified with different combinations of direct and indirect ambient lighting as well as task lighting.

Analysis of the data indicated that the majority of the occupants (69%) were satisfied with their lighting. Second, the mean illuminances at the primary task location were within the IES target values for office tasks with a range of mean illuminances from 32 to 75 fc, depending on the lighting system. Third, the median LPD was about 2.36 W/ft^2, with about one-third the work stations having LPD's at or below 2.0 W/ft^2.

The analysis of the LPD's for each lighting system indicated that the IFFM system had a significantly higher mean LPD (2.87 W/ft^2) than the DRFLV system (2.34 W/ft^2). In addition to the difference between these two systems, there was also a great deal of variability for all the systems attributable to luminaire efficiency, room design, partitions, lamp positioning, and task lighting. Similar variability was observed when the relationship between LPD and illuminance at the primary task was examined. The mean illuminances for the primary task tended to be higher for the indirect systems than for the direct systems, with the IFFM system having the highest mean illuminance (75 fc). The differences between the primary and secondary task illuminance also tended to be greater for the IFFM system than for any other system.

Because about 20% of the occupants expressed dissatisfaction with their lighting, an attempt was made to determine whether this dissatisfaction could be related to lighting system variables. Although there was no relationship between LPD and satisfaction for work stations without task lighting, rated satisfaction declined as LPD increased for work stations with task lighting. Analysis of the data for people in work stations with daylight indicated that they were slightly more satisfied with their lighting than those who did not have daylight. Secondly, fewer of those (63%) with task lighting were satisfied with their lighting than those (76%) without such lighting. Thus the presence of task lighting was identified as an important contributor to dissatisfaction with lighting. In addition, the presence of daylighting contributed substantially to increased lighting satisfaction with the IFFM system, but seemed to have a less pronouced effect with other systems.

An analysis of the effect of the different lighting systems on occupant satisfaction indicated that the highest percentage of those expressing dissatisfaction (37%) with their lighting systems had the IFFM system. The highest percentage expressing satisfaction were those with the HIDP system (88%) followed by those with the DFSM and DRFLV system (74% and 73%, respectively). The negative reaction of so many of those with the IFFM system suggests that the combination of furniture integrated task lighting with an indirect ambient system had an important influence on lighting satisfaction, even though task illuminances tended to be higher with this system. When work stations with daylight were excluded from the analysis, the dislike of the IFFM system became even greater, with 45% of the respondents expressing dissatisfaction with their lighting, as compared with 10% of those with the other systems. People with the IFFM system also rated the amount of light for work as poor.

Comparison of the responses to two sets of the same furniture integrated lighting systems, one with direct ambient lighting (DRFLV) and the other with indirect ambient lighting (IFFM) revealed that 17% of those with the direct system were dissatisfied with their lighting as compared with 46% of those with the indirect system. Similarly, 43% of those with the indirect system rated their work spaces as dim as compared with 21% with the direct system. An analysis of the average luminances in the work stations revealed that a much higher percentage (67%) of those with the IFFM system had very low average luminances (0-49 fL) in their spaces as compared with the DRFLV system (10%). Yet, mean task illuminances were higher (70 fc) for the IFFM system than for the DRFLV system (61 fc). This indicates that the IFFM system was characterized by extremes - with dark ceiling areas and bright task areas. At the same time, ratings of overall lighting satisfaction and brightness were consistently lower for the IFFM system. This suggests that the pattern of luminances in a space was a more important factor in influencing the occupants' satisfaction with their lighting and perceptions of brightness in their spaces than the amount of light on the task.[10]

A summary index of lighting quality was developed from the responses to questions about lighting satisfaction, amount of light for work, amount of light for reading, and extent to which lighting hindered job performance. An analysis of the assessments of lighting quality indicated that they were lower under the IFFM system than under the DRFLV system. Finally, although lighting quality scores were lower for those who used VDT's five or more hours per day, they were always higher for those with the DRFLV system than those with the IFFM system.

Judgements of lighting quality were also closely related to judgements of subjective brightness. Thus, spaces seen as too dim received the lowest scores on the lighting quality index, while spaces judged to be both bright and have the right amount of light for work received the highest scores of lighting quality. The response to glare was another important component of lighting quality. Analysis of several questions about the bothersomeness of glare indicated that glare from ceiling lights was bothersome to 28-35% of those with the DRFLN, DFSM, and INDFP systems. Glare from work surfaces was

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10 It should be remembered that task illuminances were at or above the IES recommendations.

bothersome to 33 to 42% of those with the DFSM, IFFM, and INDFP systems, while glare from task lights was bothersome to 26% of those with the IFFM system. Ratings of work station lighting satisfaction were higher for those work stations that were rated as having less glare from task lights, ceiling lights, and work surfaces.

A visual health index was developed to summarize responses to questions about eye irritation and problems focusing eyes. Lower scores on the visual health index were associated with lower lighting quality scores. In addition, visual health was judged to be poorer in those offices that were seen as either too bright or too dim.

Analysis of the demographic data indicated that older occupants tended to be more satisfied with their lighting. They also tended to be male, to be managers or professionals, and to have larger floor areas. The women tended to be slightly less satisfied with their lighting systems, particularly the IFFM system where 53% of the females were dissatisfied as compared with 32% of the males.

When respondents were given a chance to select changes that they would make to their office, increased privacy was selected as the most desired change by 23% of the entire database. Yet when responses from the individual lighting systems were considered, 22% of those with the IFFM system selected better lighting as their most desired change, as compared to only 9% of those with the DRFLV system.

An analysis of the other environmental factors that might have influenced occupant responses indicated that all occupants had spent at least one year in their work station before the survey was done. Although there were significant differences in noise, chair comfort, and work station size, these were not associated with any one lighting system, suggesting that the dislike of lighting provided by the IFFM system was related primarily to lighting variables rather than other environmental factors. The variable that was most closely related to work station lighting satisfaction was work station brightness, which was perceived to be lowest for the IFFM system.

Thus, the data analysis indicated that many of the negative responses to the lighting systems were associated with the IFFM system and could be related to the combination of a fixed task lighting system with an indirect ambient system. Unlike many task lighting systems, this one was not adjustable. It was located at the back of the desk, and concealed under an upper shelf, so that light was directed toward the task and could easily fall into the offending zone[11]. Occupants had no control over the position or direction of the light. The ambient lighting was located in the top of the furniture system and directed up to the ceiling often resulting in a non-uniform pattern of ceiling luminance. The result appears to have been an

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11 The offending zone is that area of the visual task which is subject to specular reflections because of the positions of the eye, task, and light source. Such reflections reduce task contrast and visibility.

unsatisfactory lighting system for many occupants. By contrast, the DRFLV system was rated much more favorably, even with the same type of systems furniture and task lighting. The results suggest that the occupants surveyed were responding to the pattern of luminances in the space, rather than to the illuminance on the task as an important component of lighting quality and satisfaction.

6.2 Relationship to Other Research

To relate the findings from the present study to other studies, research from several areas was examined, including other POE surveys and subjective evaluations, both from laboratory and field studies. Several areas of overlap will be discussed in the following sections.

6.2.1 Other POE Surveys

A major survey of attitudes toward the office environment was conducted by Louis Harris and Associates for Steelcase (1987). Using a telephone survey approach, they questioned 1000 U.S. workers, 250 Canadian workers, 150 CEO's, 150 designers, and 150 facility managers to determine the importance of various features of the office environment. While many questions were directed toward issues such as productivity and job satisfaction, a number of questions dealt with design features. Of interest, is the importance that CEO's, designers, and facility managers placed on comfort as the key to increasing productivity. Toward this end, each group placed a great deal of emphasis on office layout, furniture, and chairs. Workers also placed considerable importance on privacy, improved temperatures, and reduced distractions or noise.

Although lighting was not a major focus of the study, 91% of the designers considered lighting for tasks to be a very important characteristic of an office for helping an employee to get a job done well. In fact, this was the most frequently selected characteristic, ahead of chair comfort and proper HVAC functioning. Providing good ambient lighting was important to 81% of the designers, as well. Facility managers reported that 19% of the complaints they received dealt with glare on VDT screens, while 13% indicated that room lighting was too bright for good VDT use. Among office workers, 33% considered that inadequate or improper lighting was a very or somewhat serious office comfort problem. The CEO's were not questioned about lighting. Unfortunately, no information was obtained about the actual physical conditions in the offices, so that there is no way to determine what type of lighting systems caused problems.

Another POE survey of attitudes toward environmental conditions was conducted by Rubin and Collins (1988) and Collins and Rubin (1988). They administered questionnaires to 621 occupants in three U.S. Army field stations, and took physical measures of lighting, temperature, noise, and other environmental conditions at the three sites. Analysis of their results indicates that concerns about temperatures, privacy, noise, lack of windows, and lighting were paramount to many of those who participated in the study, perhaps because the facilities were crowded and cramped for space.

Unlike the Steelcase study, a number of questions were asked specifically about lighting both in terms of overall quantity and general quality. The results indicated that lighting quality was considered to be fair to poor by about 20% of the respondents. About 30-40% felt that the overall amount of light was fair to poor, although this depended on the nature of the task. Location of the ceiling lights and glare from these lights, however, was a problem to about 40% of those who used VDT's extensively, while as many as 60-80% of all respondents considered their ability to adjust light for their tasks to be fair to poor. In fact the ability to adjust task lighting (or lack thereof) emerged as one of the most salient concerns for all respondents. Thus, when people were asked to select desired changes to their environments, improvements to overall lighting, and the addition of task lighting emerged as frequent choices.

Inspection of the physical measurement data for the three field stations reveals that overall light levels were typically low with mean illuminances of 220-280 lux (20-26 fc) for all areas; 310 to 570 lux (29 to 53 fc) for purely administrative areas; and 120-200 lux (11-19 fc) for areas where primarily VDT-type tasks were performed. Illuminances were typically very low in these areas because of problems with reduced screen contrast and visible screen reflections from overhead ceiling lights. In fact, in these areas the occupants had deliberately reduced the overall light levels by removing fluorescent tubes or by adding paper diffusers to the fixtures. Of particular relevance to the present study is the emphasis that respondents placed on controlling their lighting - both in the response to the questionnaire and in their actual behavior.

6.2.2 Subjective Effects of Lighting

Aldworth and Bridgers (1971) challenged the idea of providing largely uniform lighting in work areas, saying that the time had come to design variety into lighting to maintain alertness and reduce monotony. To assess their ideas, Aldworth and Bridgers created a lighting installation in which the effects of both static and dynamic lighting could be assessed. Static lighting was provided by recessed fluorescent fixtures with louvers (similar to the DRFLV system in the present POE study), while dynamic lighting was provided by fluorescent lighting on 3 walls and an array of tungsten lights controlled by a series of dimmers which randomly varied the lamps. The data analysis revealed no significant differences in the performance of a visual task for the two lighting systems, although both the work rate and the percentage of errors improved slightly under the varied lighting. The workers also rated the lighting system as they finished each of the eight tasks. They tended to rate the varied lighting as "good", "comfortable", "pleasant", and "cheerful". The authors concluded that:

> "it has been found in earlier experiments by others that the measurement of differences in work rate and accuracy is seldom rewarding and that subjective tests provide a more sensitive means of indicating change" (Aldworth and Bridgers, 1971, p.15).

Flynn, Spencer, Martyniuk, and Hendrick (1973) evaluated the effects of different lighting installations on user impressions and behavior using judgements on semantic differential rating scales for 96 observers. They identified five factors - evaluative impression, perceptual clarity, spaciousness, spatial complexity, and formality, with the first three factors being significantly related to different lighting installation designs. An analysis of additional multidimensional scaling data identified three response dimensions of "bright/dim", "peripheral/ overhead", and "uniform/non-uniform". Flynn, et al. found that ratings of perceptual clarity were closely correlated with the "bright/dim" dimensions, while ratings of pleasantness were closely correlated with the "overhead/ peripheral" and "uniform/non-uniform" dimensions. Lighting installations identified as pleasant scored higher on the peripheral and non-uniform ends of the scales, while spaciousness appeared to be predicted best by a combination of the three dimensions. Flynn, et al. also observed that people tended to select seats in darker areas of a lunchroom that were oriented toward the light, even when the lighting of the lunchroom was markedly altered.

In a subsequent paper, Flynn (1977) evaluated the effects of different illuminances, color temperatures, and lighting distributions on subjective responses to provide information for meeting lighting energy budgets while maintaining acceptable interior lighting. Flynn's analysis demonstrated that a central overhead design at 2.1 W/ft^2 received higher ratings for visual clarity and spaciousness than a peripheral overhead design (at 2.4 W/ft^2). The impressions of spaciousness and satisfaction were reinforced by the use of peripheral lighting, particularly wall washing. Use of warm light tones with non-uniform peripheral lighting also reinforced positive evaluative impressions. Of importance to the present study are Flynn's conclusions regarding the subjective response to the distribution of light. He found that the "central overhead" lighting received higher ratings of spaciousness and clarity compared with a "peripheral overhead" design, even from people who sat in the darker portion of the room. When luminance in the central area was reduced, the impression of clarity was reduced. Wall lighting was rated more favorably than ceiling lighting at the room end, and produced positive impressions of spaciousness and evaluation. Flynn noted that subjective ratings seemed to correlate more with the pattern of light than with precise physical measures. As such, lighting could be used to cue different types of subjective impressions such as relaxation, clarity, or spaciousness. These findings appear to be supportive of those from the present study which determined that respondents were less satisfied with the combination of indirect ambient and fixed task lighting provided by the IFFM system.

Flynn and Subisak (1978) noted that impressions of clarity seemed to relate to the brightness of the periphery, "whiteness" of the light source, and illuminance at the seated position. They also observed that several groups of observers who entered a classroom to take a "test" tended to sit in areas of the room with higher illuminance. They concluded that extremely nonuniform lighting design may result in areas with poor subjective clarity which in turn creates negative subjective impressions. Bernecker and Mier (1985) reported that use of a side lens with an indirect luminaire relative to an indirect luminaire alone significantly increased the perceived brightness of the space (even though the overall illuminance was not altered) and improved the subjective assessment of the space. These data suggest that subjects tended to rate a space as brighter if they could see a light source (and may have been one reason why the spaces with the IFFM system in the POE study were rated as dimmer, since all the lighting was indirect or recessed).

Tregenza, Romaya, Dawe, Heap and Tuck (1974) assessed preferred lighting levels and arrangements in a simulated office with 32 secretarial workers. The experiment used a laboratory configured as a single-person, windowless office in which the illuminances on six surfaces - walls, ceiling, and desk - could be controlled separately. In each of five experimental sessions, participants performed a set of three office tasks (typing, reading, and sorting) under an initial illuminance level (either low or high), and then directed the experimenter to change the lighting (both in level and configuration) as desired. They completed a detailed questionnaire about their lighting preferences and attitudes about lighting in a sixth session.

Tregenza, et al. found a statistically significant difference between the participant's selection of lighting level as a function of initial setting, with lower levels set following an initially low setting, and higher levels set after an initially higher setting. Despite the effect of the initial level, individuals were highly consistent in their choice of illuminance, with no significant difference in settings on different days for the same initial setting. In addition, 27 of the 32 subjects were able to select a preferred lighting setting, with an overall mean of 2297 lux (213 fc). Finally, there was a positive correlation between the subject's age and illuminance setting - with older people tending to choose higher desk illuminances when the initial light setting was low.

The data indicated that two-thirds of the subjects preferred a situation in which light reflected from the walls was the dominant component of the desk illuminance, one quarter preferred light reflected from the ceiling, and only three preferred light from the lamps directly overhead. Analysis of the choice settings indicated that wall:desk illuminance ratios were higher than recommended (often 0.8 to 1.0) as were wall:task and ceiling:task luminance ratios (0.51 to 0.55), although there was little variation as a function of desk illuminance. The authors commented that subjects seemed to prefer diffuse lighting, rather than light directly incident on their desk. Participants tended to adjust illuminances on the four walls to be consistent with levels of desk illuminance, although they had a definite preference for the wall behind them to be twice as bright as any other wall. Of interest is that about half the subjects with windows in their normal offices sat with the window behind them (and also tended to pick a higher illuminance for the wall behind them in the experiment). The questionnaire results indicated that subjects felt that their major concern was to light their task area, primarily by using light from the ceiling.

Although Tregenza, et al. expressed some reservations at the idea of setting lighting recommendations based on preference (and behavioral) studies and suggested that people instead should be given the freedom to select a desired lighting level, their results demonstrated some interesting similarities to the present POE study. For example, subjects tended to pick "bright" settings, with high ratios of wall to task illuminance. They appeared to want the room and the task lit to similar levels. Furthermore, they tended to select rather high illuminances for their offices.

Taylor, Sucov, and Shaffer (1975) had 77 subjects perform an addition task under three different types of lighting; uniform fluorescent, non-uniform incandescent, and psychedelic lighting (a combination of incandescent, flickering pendant, rotating shade, and christmas tree lighting). The results indicated no difference in addition accuracy between the lighting conditions and slight (but non-significant) trends in addition speed and performance of a secondary task (in which subjects responded to one of two randomly lit red lamps) with the non-uniform lighting showing slightly better results than either the uniform or the psychedelic responses. Analysis of the semantic differential rating data indicated that the nonuniform lighting condition was rated as more unsociable. The authors concluded that office work performance could be increased by using a non-uniform lighting system, although the data to support this contention were only trends that were not statistically significant.

In an experiment by Hawkes, Loe, and Rowlands (1979), subjects used semantic differential scales to judge a series of 18 different lighting designs, involving recessed luminaires (with four different types of diffusers), wall lighting, down lights, desk lights, and track lighting in a windowless office with a constant illuminance (500 lux) on the working surface. Analysis of the semantic differential data revealed that two factors-subjective brightness and interest - accounted for 79% of the variance. The semantic data also provided information on preferences, obtained from judgements on the pleasant-unpleasant and attractive-unattractive scales.

Hawkes, et al. found that the bright-dim data were highly correlated with illuminance (r=0.69). The correlation improved to 0.81 when one lighting situation was excluded from the analysis. This design, although having high illuminances, was perceived as "dim", perhaps because only one side wall was illuminated. The authors found that designs using only diffuse sources were rated as more uninteresting than situations which used focused sources. Hawkes, et al. suggested this may have occurred because there were sharper boundaries between dark and light areas in the more "interesting" situations; and because variations in luminance distributions in a space determine its "interestingness". Together, the data suggest that situations that are judged as being brighter and more interesting (or complex) are also preferred. The authors commented that although spaces became more attractive as they became brighter and more complex, it is not clear if this relationship would continue to extremes or diminish beyond certain levels. Finally, Hawkes, et al. noted that regular arrays of luminaires were the least preferred way of lighting an office - an effect which may have been enhanced because of the windowless experimental room. "Complexity and brightness together: perhaps that is what people want in the lighting of their offices" (Hawkes, et al., 1979, p. 120). Of interest to the present study is the finding for one lighting system which was measured as having high illuminances, yet judged to be dim. This result suggests that luminance patterns in the overall space were important determinants of occupant lighting preferences and perceptions of brightness - a finding consistent with the results of the present POE study. Hawkes et al in fact suggested that analyzing the patterns of luminance in a space and developing histograms would be a valuable way of predicting interest. More "interesting" situations should show more than one peak in luminance.

Using a four person simulated office, McKennan and Perry (1984) evaluated the response of 30 office workers to ten different types of lighting installations. The installations included six local systems with desk and wall mounted luminaires, three localized systems with ceiling mounted luminaires or downlights, and one uniform lighting system. Where possible 200-250 lux (19-23 fc) was provided as background illuminance, while 500 lux (46 fc) was provided on the task itself. In addition to performing routine office tasks, subjects completed a subjective evaluation of each lighting installation and two visual search tasks, as well as 35 semantic differential scales.

Analysis of the comments about the lighting systems indicated that comments about sufficiency, evenness, and lack of shadows were made more frequently for the uniform and localized systems than for the local systems. When all subjects rank ordered the lighting systems, two localized systems were among the highest ranked while four local systems were among the lowest. These latter included three desk mounted luminaires. No correlation was found between test performance and illuminance on the desk, although there was a negative correlation between one test performance measure for draftspeople and satisfaction with the lighting system. Localized task lighting appeared to be a reasonable alternative to uniform lighting with people being about equally favorable to both, but local task lighting installations were regarded less favorably. The authors suggested that this may have occurred because the illuminance ratios for the local systems were outside the recommended practice. In addition, the local systems were placed on the desks and created some clutter. When subjects were forced to choose between lighting systems, they preferred the direct uniform installation, but there was no difference in their ratings of the direct and indirect background lighting. The authors concluded that a task/background lighting scheme could be effective providing that it was carefully designed.

The research into the subjective impressions of lighting systems tends to reinforce the findings from the present POE study; namely, that patterns of luminance in spaces are an important determinant of lighting satisfaction (once the basic needs for task visibility have been met). Furthermore, in the studies cited, task and local lighting were not always successful in meeting user requirements for ambient luminance in a space. The research also suggests some consistencies between the studies in the occupant responses to different lighting systems with a definite indication that there are preferences for brighter, more interesting spaces.

6.3 Implications for Future Research

Although the findings discussed in the present report represent an extensive analysis of the data obtained from the 912 work stations of the database, there are still areas within this particular database to be explored. For example, both occupant response and physical data were obtained for other non-lighting aspects of the space, such as the use of window coverings, type of furnishings, colors, chairs, and wall treatments, pictures, plants, and mementos, temperature, humidity, and noise. Occupants were also questioned about the overall attractiveness and functionality of their office space, as well as about their own health and job attitudes. Further analysis of the responses to these questions would provide information about the overall effectiveness of the space in meeting user requirements beyond lighting. It might also assist in understanding the responses to questions about lighting and general environmental quality in the work stations.

In addition to the physical measures and occupant responses, data were also obtained on the reactions of a set of four lighting experts to work stations in the first three buildings. While these data have been transcribed, they have not yet been analyzed in any detail. This analysis is needed for information on the ways in which lighting experts view spaces and comparison with the long-term occupants' reaction to the same spaces.

Of course, the analysis of the data on the 912 work stations has also raised further questions that cannot be answered simply by re-examining the existing database. For example, one issue that was not addressed in the current report is the extent to which physical conditions vary in an office over time, and the occupant's reaction to such variability. Ideally, future POE analyses would take physical measures in temperature, air movement, illuminance and luminance at several times to determine whether there are wide variations in these parameters, and whether these are annoying or interesting to the user.

Another issue suggested by the present analysis is the need to define the physical characteristics of any space which is part of a POE analysis in much greater detail. Although 10 measures of luminance and 4 measures of illuminance were taken, these only began to describe the visual space that the user inhabited. The incongruent responses by the people with the IFFM system who had high task illuminances but described their spaces as "dim" was explained in part by the "average luminance" concept. Thus, people in these spaces had quite low levels of luminance in the rest of their space. Yet, the average luminance concept does not go far enough - it does not provide enough information about the patterns and balance of luminances in the space, nor does it pretend to define which portions of the space the occupant is judging when he/she says that it is "dim". It does clarify that task luminance is not the critical determinant of the "brightness" of a space; it does not clarify whether the occupant weights ceiling, wall, and surface luminances equally in this judgement. For this analysis, use of a overall contrast meter such as the CapCalc meter (Kambich and Rea, 1987) is needed to define the physical distribution of luminances visible at a person's desk. At the same time, the occupant (or research subject) should make psychophysical judgements of the brightness of different portions of the room so that weighting factors can be developed to relate occupant responses to the measurements. In other words, research should be done to determine which portions of the space are critical in determining that an occupant sees the space as "bright" or "dim". Is it the overall range of luminances in the space from brightest to dimmest? Is it the luminance of the ceiling? walls, desk surface? or some combination of the three? Is there an optimum luminance for particular areas?

Further questions arise concerning the role of task lighting in meeting user needs for lighting. Data from a POE study reported by Collins and Rubin (1988) indicated that occupants desired greater control over their lighting, and felt that localized, controllable task lighting would answer their needs. Yet, response in the present POE study was not particularly favorable to task lighting, particularly when it was part of a furniture integrated system with indirect ambient lighting. Although the reasons for this dislike may lie in the lack of control, presence of glare on the work surface, or the apparently low levels of brightness in the space, further research is needed to define the effectiveness (or lack thereof) of task lighting.

While the POE analysis suggested the importance of the distribution of luminances in a space in determining the occupant's perception of its brightness and overall satisfaction with the lighting, it did not define the physical variables responsible. A detailed laboratory investigation is needed for answering these questions as well as ones about task lighting.

Another area for investigation is the whole question of the best way of investigating the subjective response to a space. Much of the research to date has involved different types of scaling and subjective judgements, a procedure which Poulton (1979) called into question. Poulton discussed the issue of biases in subjective ratings scales of different sensory dimensions, and suggested that occupant responses are governed by the size of the scale provided as well as by the magnitude of the physical stimuli presented. His comments reinforce the need for research into other methodologies to substantiate data obtained from rating scales and subjective evaluations. Flynn (1977), for example, obtained interesting results from behavioral observations, while others have used physiological measures. Yet, until such time as a reliable and accurate battery of procedures for assessing subjective response and relating it to physical conditions in a space, POE analyses and subjective scaling techniques are among the few procedures that do seem to provide useful insights into people's responses to environmental conditions.

Of course it is important to understand that findings from one POE study may not be exactly replicated in another study with a different subject population and environmental conditions. Yet, the findings provide a fertile ground for suggesting further research under more controlled conditions as well as for modifying the environment in which negative findings were obtained. For example, the negative response in the present study to the lighting conditions prevailing with the IFFM system suggests the need to consider adding additional directional and/or controllable lighting to these particular installations, as well as performing laboratory research on the response to varied patterns of luminances in spaces. In such situations, POE analyses provide valuable insights into problems that should be "fixed" in particular spaces, as well as suggesting ideas for research to avoid such problems in subsequent lighting designs.

7. References

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Appendix A. Lighting Power Definitions

1. Lighting Power Density (LPD). This factor is expressed in watts per square foot (or in watts per square meter). In the present report, LPD is used to denote the connected lighting power of a general (ambient) lighting system or a task lighting system, or both, divided by the specific area covered by the ambient and/or task lighting system. The power and area covered could be expressed in terms of a work station, a specific part of a room, an entire room, a complete floor of a building, or an entire building. The LPD could also include certain environmental lighting such as wall or accent lighting. To obtain the LPD for such lighting, its connected power should be divided by the area it serves, which could be small in a private office, or large in a general office. Since there can be several elements to the lighting power and variations in the space covered, whenever LPD is used, what is included in the measure should be described precisely to avoid confusion about what is meant.

The lighting power figures used in this analysis are estimated to be those of the steady state power consumed by lamps and ballasts in the specific luminaires where they are employed while they are in an operating mode. They are not the nominal power values for individual lamps and ballasts as published in manufacturers' catalogues.

2. Unit Power Density (UPD). Unit Power Density is an allotment of lighting power to a space in watts per square foot (or watts per square meter), usually as a limit to the power, so that a Lighting Power Budget may be computed for the space. A "Base" UPD figure is usually obtained from a standard or code. It represents a power limit that is assumed to be sufficient to satisfy the lighting requirements for specific visual tasks in a space, assuming the power is utilized effectively in a large and unobstructed area. Base UPD values may be obtained from the Illuminating Engineering Society's LEM-1 publication or from the ANSI/ASHRAE/IES 90.1.

Note that the Base UPD values are power limits for large spaces with minimum obstructions to the distribution and utilization of light. Medium-sized and small rooms are considerably less efficient in the utilization of light than large ones; while spaces with partitions of less than ceiling height around work stations, even though they may be in large rooms, can also be considerably less efficient in utilization of light than open, uncluttered spaces.

To allow for reasonable lighting power values in smaller spaces, a multiplier called an Area Factor (AF) is employed with the UPD. Area Factors range between 1.0 and 1.55 and are defined under item 3, below. The IES suggests three categories of office UPD's as shown under item 4, to provide reasonable lighting power values in offices with partial-height partitions.

3. Area Factor (AF). The Area Factor is a multiplier for Unit Power Density values. It is necessary to allow for the lower utilization of light in small rooms compared with large ones. The Area Factor has its origin in lighting design procedures and takes into account the room configuration (area, ceiling heights) in establishing the Area Factor for a room. To provide, even greater stringency in calculating lighting power budgets, the

maximum Area Factor permitted is 1.55, although from a design standpoint, Area Factors in excess of 2.0 could be derived for some rooms. Further, in open plan offices of more than 900 square feet which have partitions higher than 4.5 feet below the ceiling, the Area Factor is defined as 1.0, even though Factors as much as 20% higher could be derived in practice. Charts from which Area Factors may be selected are found in IES LEM-1 and in ANSI/ASHRAE/IES 90.1.

4. UPD'S For Offices. The IES defines three categories of offices with different UPD values because of the wide use of partial-height partitions in open plan offices. These reduce the utilization of light so that more power is required to provide the necessary illuminance on tasks. The three categories are described below and the UPD values are given for the tasks of reading, typing and filing:

a. Office Category 1 UPD=1.8w/sq.ft.*

Enclosed offices, all open plan offices without partitions or with partitions lower than 4.5 feet below the ceiling.

b. Office Category 2 UPD=1.9w/sq.ft.**

Open plan offices 900 sq. ft. or larger with partitions 3.5 to 4.5 feet below the ceiling. Offices less than 900 sq. ft. shall use Category 1.

c. Office Category 3 UPD=2.2w/sq.ft.**

Open plan offices 900 sq. ft. or larger with partitions higher than 3.5 feet below the ceiling. Offices less than 900 sq. ft. shall use Category 1.

* Area Factor shall not exceed 1.55
** Area Factor of 1.0 shall be used for these spaces

<u>Lighting power density values obtained from the present POE study</u>

As used in the present report, the lighting power values obtained from the thirteen buildings of the study are lighting power density figures for the specific work stations surveyed. It may be useful to compare these numbers with the UPD values from the IES and ASHRAE sources given previously to see how stringent he lighting design of these buildings was in the allotment of electric power. This can be done, but several things must be kept in mind.

1. LPD's may be compared with UPD's after the Area Factor has been applied to the Base UPD. If the AF is 1.0, the Base UPD may be compared directly with the LPD. IF the Area Factor is something other than 1.0, it must be determined from the physical characteristics of the room using the category descriptions above.

2. If a work station has an area of 150 square feet, for example, but is one of many work stations in an open plan office, the area to use in

determining the Area Factor is that of the entire office. To determine the Base UPD, the entire area identified above, together with the height of the partitions employed, if any, is used.

3. If the LPD of the work station in question is less than the Base UPD times the Area Factor, then the lighting could be considered energy-efficient by today's standards, even though the design and installation of the lighting was done some years prior to the development of the current UPD standards.

4. If the LPD of the work station in question is greater than the Base UPD x AF, then the lighting power is in excess of that which would be considered energy-efficient practice today. However, the UPD procedure allows for trade-offs in lighting power allotments in determining compliance with its values: that is, some work stations may exceed the UPD x AF criterion, while others may be less, if, on the average, they are equal to or less than the UPD x AF value. Therefore, the entire area of a space or room should be checked before making a judgment as to whether or not it complies with the UPD procedure.

5. The checking of the lighting power against larger and larger building areas for compliance with the UPD x AF criteria can proceed until the entire building is surveyed. (This did not occur with the buildings of this study). However, the Base UPD's for other areas such as corridors, lobbies, rest rooms, etc. would be less than that allotted to the lighting of visual tasks. Therefore, the LPD average for an entire building would normally be less than that in the working areas.

6. Another exercise which could be performed is to take the LPD's as found for the various work stations and divide them by the appropriate Area Factor. The resulting figure would be similar to a UPD and comparing it to current published UPD's would be a measure of how appropriate these consensus values are when compared with lighting practice. Such comparisons should be done with caution: (1) the values derived from a single work station or even an entire building may not be appropriate to base any conclusions on; (2) the quality of the lighting in the building(s) involved should be appraised carefully to determine if it is worthy of being compared with consensus UPD's.

7. At the outset of the POE studies, the matter of comparing LPD's with UPD's as suggested above was not an objective. Hence, the computation of Area Factors for all work stations was beyond the scope of the project. Time and expense did not allow such comparisons to be made. If some future studies are attempted with the data base (and there appear to be a great many promising areas still to explore) perhaps this can be performed. Indeed, it would seem that the lighting power for entire buildings should be surveyed and compared with current power limits (IES/LEM-1 or ASHRAE/IES 90.1).

Definitions have been adopted from the IES Lighting Handbook, Reference Volume, 1984, except where noted.

Ambient lighting - Lighting throughout an area that produces general illumination.

Contrast (Luminance Contrast) - The relationship between the luminances of an object and its immediate background. It is equal to $(L_1 - L_2)/L_1$, $(L_2 - L_1)/L_1$, or $\Delta L/L_1$ where L_1 and L_2 are the luminances of the background and object, respectively. The form of the equation must be specified. The ratio $\Delta L/L_1$ is known as Weber's fraction.

Contrast Rendition Factor (CRF) - The ratio of visual task contrast with a given lighting environment to the contrast with sphere illumination. Also known as "contrast rendering factor".

Direct Glare - Glare resulting from high luminances or insufficiently shielded light sources in the field of view. It usually is associated with bright areas, such as luminaires, ceilings and windows which are outside the visual task or region being viewed.

Direct-indirect lighting - A variant of general diffuse lighting in which the luminaires emit little or no light at angles near the horizontal.

Direct lighting - Lighting by luminaires distributing 90 to 100 percent of the emitted lighting in the general direction of the surface to be illuminated. The term usually refers to light emitted in a downward direction.

Disability Glare - Glare resulting in reduced visual performance and visibility. It often is accompanied by discomfort.

Discomfort Glare - Glare producing discomfort. It does not necessarily interfere with visual performance or visibility.

Footcandle (fc) - The unit of illuminance when the foot is taken as the unit of length. It is the illuminance on a surface one square foot in area on which there is a uniformly distributed flux of one lumen, or the illuminance produced on a surface all points of which are at a distance of one foot from a directionally uniform point source of one candela. (IESNA, 1984)

Footlambert (fL) - A unit of luminance equal to $1/\pi$ candelas per square foot, or to the uniform luminance of a perfectly diffusing surface emitting or reflecting light at the rate of one lumen per square foot, or to the average luminance of any surface emitting or reflecting light at that rate. The use of this unit is deprecated.

Glare - The sensation produced by luminance within the visual field that is sufficiently grater than the luminance to which the eyes are adapted to cause annoyance, discomfort, or loss in visual performance and visibility. Note; the magnitude of the sensation of glare depends upon such factors as the size, position and luminance of a source, the number of sources and the luminance to which the eyes are adapted.

Illuminance - The density of the luminance flux incident on a surface; it is the quotient of the luminous flux by the area of the surface when the latter is uniformly illuminated. The unit of measurement is the fc or lux (SI).

Indirect lighting - Lighting by luminaires distributing 90 to 100 percent of the emitted light upward.

Luminaire - A complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps and to connect the lamps to the power supply.

Luminance - Luminous flux in a beam, emanating from a surface, or falling on a surface, in a given direction, per unit of projected area of the surface as viewed from that direction, per unit solid angle. (from ASTM E284, 1987). The unit of measurement is the fL or the cd/m^2 (SI).

Luminance Ratio - The ratio between the luminances of any two areas in the visual field.

Luminous efficacy - The quotient of the total luminous flux by the total radiant flux. It is expressed in lumens per watt.

Photometer - an instrument for measuring light.

Quality of lighting - Pertains to the distribution of luminance in a visual environment. The term is used in a positive sense and implies that all luminances contribute favorably to visual performance, visual comfort, ease of seeing, safety, and esthetics for the specific visual tasks involved.

Task Lighting - Lighting directed to a specific surface or area that provides illumination for visual tasks.

Task-ambient Lighting - A combination of task lighting and ambient lighting within an area such that the general level of ambient lighting is lower than and complementary to the task lighting.

Appendix B. Numerical Weights for Occupant Response Data

As previously noted, numerical weights were used in the analysis of the lighting data conducted at the University of Michigan. These weights are important when the data from more than one building are pooled for analysis purposes. The weights are used since the data represent work stations which were selected from buildings with unequal probabilities. That is, all occupied work stations were selected in some buildings whereas one in six or one in seven were selected in others. Without the weights, the statistics (means, percentage, etc.) would be biased estimates of parameters of the population of 13 buildings. As noted in footnote 4, page 2 of Marans and Brown (1987), the analytical weights used in this study reflect the different sampling fractions and differences in response rates among buildings. The weight for each work station in a particular building is equal to the selection weight times a non-response adjustment rate and is reflected in the following formula:

Weight for each Building Work Station = Selection Weight x Non Response Adjustment Weight

$$W = \left(\frac{n_h}{N_h}\right)^{-1} \times \left(\frac{r_h}{n_h}\right)^{-1}$$

N_h = building size (total number of work stations)

n_h = number (size of building sample)

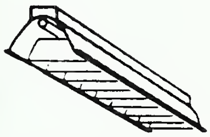
r_h = number of building respondents

This formula reduced to: $\frac{N_h}{n_h} \times \frac{n_h}{r_h} = \frac{N_h}{r_h}$

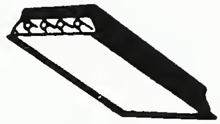
The principle of weighting is discussed in Cochran (1963: Section 5.1) and Kish (1967: Section 3.2). These discussions focus on stratified sampling. In the design of the lighting study, each building was treated as a sampling strata from the total population of the 13 buildings.

The introduction of a weight reflecting the different response rates of the selected buildings is a relatively new concept in the analysis of survey statistics and is described in an article by Kalton and Kasprzyk (1986).

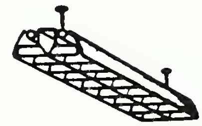
Appendix C. Sketches of the Seven Individual Lighting Systems.



Direct recessed fluorescent w/parabolic louvers (DRFLV)

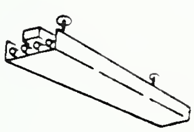


Direct recessed fluorescent w/prismatic lenses (DRFLN)

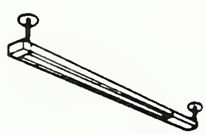


Direct fluorescent surface mounted w/egg crate (DFSM)

Indirect fluorescent furniture integrated (IFFM)



Direct/indirect fluorescent pendant mounted (DIFP)



Indirect fluorescent pendant mounted (INDFP)

Indirect metal halide HID pendant mounted (HIDP)

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Data from a post-occupancy evaluation (POE) of 912 work stations with lighting power density (LPD), photometric, and occupant response measures were examined in a detailed, second-level analysis. Seven types of lighting systems were identified with different combinations of direct and indirect ambient lighting, and task lighting and daylight. The mean illuminances at the primary task location were within the IES target values for office task with a range of mean illuminances from 32 to 75 fc, depending on the lighting system. The median LPD was about 2.36 watts/ft^2, with about one-third the work stations having LPD's at or below 2.0 watts/ft^2. Although a majority of the occupants (69%) were satisfied about their lighting, the highest percentage of those expressing dissatisfaction (37%) with lighting had an indirect fluorescent furniture mounted (IFFM) system. The negative reaction of so many people to the IFFM system suggests that the combination of task lighting with an indirect ambient system had an important influence on lighting satisfaction, even though task illuminances tended to be higher with the IFFM system. Concepts of lighting quality, visual health, and control were explored, as well as average luminance to explain the negative reactions to the combination of indirect lighting with furniture mounted lighting.

12. KEY WORDS (*Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons*)

Contrast, daylighting, environmental assessment, illuminance, lighting, lighting power density (LPD), luminance, post-occupancy evaluation, photometric measurement, task lighting, VDT's, work station

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