# Second-Level Post-Occupancy Evaluation Analysis

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Post-occupancy evaluations (POE) have been used by a number of researchers (Harris, 1987; Rubin and Collins, 1988; Markus, 1967) as a tool for documenting, evaluating, and improving environmental conditions in offices. In a project sponsored by the US Department of Energy and the New York State Energy Research and Development Authority during 1984–1986 POE data were collected on lighting power densities, photometric levels, and user attitudes for 912 workstations in 13 office buildings that contained lighting systems somewhat typical of current lighting practice. The purpose of the present evaluation is to examine the relationships between individual lighting system type and these data. Earlier analyses and documentation can be found in Gillette and Brown (1986), Gillette and Brown (1987), Marans (1987), Marans and Brown (1987), and Gillette (1988).

**Approach**

The physical data collection, described by Gillette and Brown (1986), involved detailed illuminance, luminance, and other environmental measures for each workstation. Questionnaire data on the response to the lighting and general environment were collected concurrently from about 150 respondents in each of three buildings and 50 people in each of ten buildings as described by Marans and Brown (1987). The lighting power density (LPD) data were calculated from the actual lamp and ballast characteristics for all the luminaires in a work area, using fixture wattages and associated floor areas with ANSI ballast correction factors as given in Gillette (1988).

In the present analysis, the effect of different lighting systems, as primarily defined by mounting type, on LPD, photometrics, and occupant response variables was examined. Seven different lighting systems were identified: three direct, three indirect, and one direct/indirect.

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

Each system could also be defined in terms of task lighting and daylight. A total of 355 workstations had no task lighting; 376 had furniture-mounted task lighting; 121 had desk-movable lighting; 22 had some other type of task lighting, such as floor-mounted units. Finally, 334 workstations had some daylight and 518, very little daylight. Daylight was defined by the adjacency of a workstation to a window. Workstations closer to a window than 10 ft were considered adjacent to the window, except when blocked by partitions or furniture.

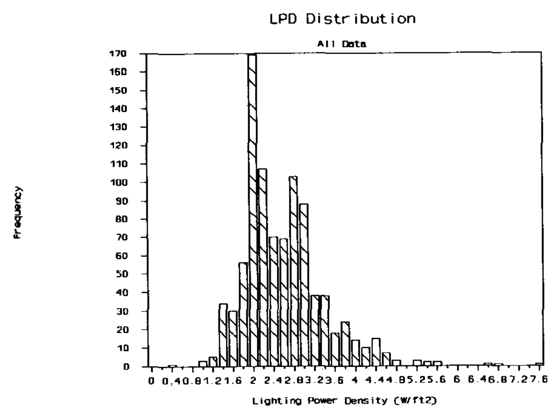


**Figure 1a—Distribution of lighting power densities for the database**

**Lighting power density and photometric data**

***Lighting power density data***

**Figure 1a** presents the frequency of occurrence of the LPDs for the 912 workstations. It shows a great deal of variation in the LPD data for all lighting systems. The range of LPDs 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 workstations had LPDs at approximately 2.0 W/ft$^2$ (W/m$^2$). 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$^2$

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****Fluorescent sources used in the ambient systems were either Warm White or Cool White, while the HID sources were metal halide.***

(20.8 W/m$^2$) and 2.87 W/ft$^2$ (30.9 W/m$^2$), however.

Closer examination of **Figure 1a** 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$^2$. In fact, the direct and indirect lighting systems had very different distributions of LPDs. Thus, the direct recessed, fluorescent with louvers system (DRFLV) had a mean of 2.34 W/ft$^2$ (25.2 W/m$^2$) and the indirect, fluorescent, furniture-mounted system (IFFM) system had a mean of 2.87 W/ft$^2$ (30.9 W/m$^2$). A t-test of the difference between the DRFLV mean and the IFFM mean was significant ($p<0.001$) indicating that the IFFM system had significantly higher LPDs than the DRFLV system.

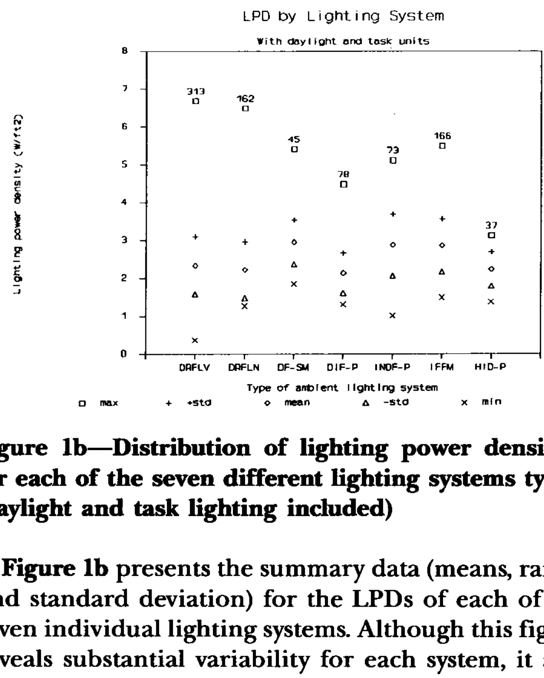


**Figure 1b—Distribution of lighting power densities for each of the seven different lighting systems types (daylight and task lighting included)**

**Figure 1b** presents the summary data (means, range, and standard deviation) for the LPDs of each of the seven individual lighting systems. 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. In addition, workstations with local task lighting (either integrated or movable) had higher lighting power densities. Thus, workstations with movable desk lighting had the highest mean LPD of 3.20 W/ft$^2$ (34.4 W/m$^2$); those with furniture-integrated task lighting had a slightly lower mean LPD of 2.69 W/ft$^2$ (28.9 W/m$^2$); workstations without local task lighting had the lowest mean LPD of 2.02 W/ft$^2$ (21.7 W/m$^2$). Although cool-white sources were used for the furniture-integrated task units, sources used for the movable task units varied from single fluorescents to multiple incandescents, which is one reason why the LPDs were higher for these units.

Although the combination of task and ambient lighting has been advertised for the past decade as being an energy-saving lighting solution, the examples observed in the present study showed that the installed LPDs of this combination in the IFFM system were among the highest of the systems surveyed. Several factors may have accounted for these findings. First, the indirect lighting used for the ambient system was lower in utilization than the direct lighting systems. Second, there were variations in the following: ballast efficiency; luminaire efficiency; room characteristics such as floor area, geometry, ceiling height, reflectance, and obstructions; target illuminance and physical spacing of the luminaires; and the use and type of task lighting. Finally, the furniture-integrated systems may have actually been spaced more closely together in the workstation than the designer intended, resulting in higher LPDs than designed. Since the lighting power package of task/ambient lighting was built into movable furniture, it was not always possible to control the LPDs after the furniture had been installed. All these factors suggest that lighting designers, furniture manufacturers, and facility managers need to work together more closely to achieve design goals for this potentially energy conserving application.

***Illuminance***

The next issue is the relationship between LPD and illuminance with body shadow at the primary work surface. **Figure 2** indicates that there was great variability in illuminance as a function of LPD, making it difficult to make general statements about the relationship between illuminance and LPDs.

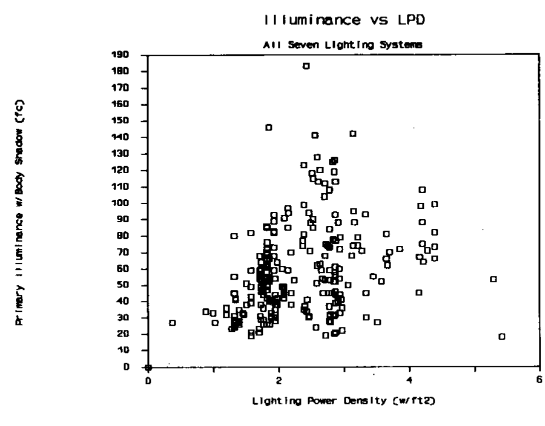


**Figure 2—Distribution of illuminance as a function of lighting power density for all lighting systems (little daylighting; non-system task lighting excluded**

Much of the variability in illuminance as a function of LPD can be explained on the basis of variations in fixture position, room size, partitions, luminaire efficiency, scheduled maintenance, and location of the task relative to the fixture. In addition, workstations at the perimeter of the buildings received part of their task illuminance from daylight which required no lighting power. As a result, higher illuminance was achieved with lower LPDs. Finally, the LPD was calculated for an entire workstation, but the illuminance was measured at only two locations in the workstation, which may or may not have received the full benefit of the power supplied to the luminaire. The net result was that a particular LPD resulted in a wide range of illuminances on the working surface.

**Table 1** presents statistical summaries of the LPDs, illuminance, and several other photometric measurements for the seven different lighting systems. To summarize, the mean illuminances at the primary task were as follows:

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

**Table 1—Photometric summaries for entire database and "pure" case**

Photometric Statistic Summaries—Entire Database

| | | LPD | Illuminance Prim. | Illuminance Secon. | CRF Min | Luminance Ratio Near | Luminance Ratio Far | Brightest Lum. | Surr. Lum. | Task Lum. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $W/m^2$ | lx | lx | | | | $cd/m^2$ | $cd/m^2$ | $cd/m^2$ |
| DRFLV: (n=313) | Mean | 25.2 | 652 | 595 | 0.85 | 4 | 1189 | 2619 | 70 | 163 |
| | Max | 71.9 | 1689 | 1614 | 0.97 | 45 | 20000 | 6235 | 322 | 500 |
| | Min | 4.0 | 151 | 43 | 0.49 | 1 | 8 | 10 | 3 | 41 |
| | Std | 8.1 | 291 | 285 | 0.08 | 5 | 1902 | 1446 | 59 | 78 |
| DRFLN: (n=162) | Mean | 24.0 | 736 | 694 | 0.84 | 3 | 1255 | 3318 | 103 | 191 |
| | Max | 69.8 | 4315 | 1797 | 1.02 | 21 | 14600 | 20213 | 617 | 901 |
| | Min | 13.7 | 204 | 65 | 0.01 | 1 | 12 | 452 | 3 | 55 |
| | Std | 8.0 | 466 | 362 | 0.15 | 4 | 2516 | 1966 | 94 | 116 |
| DFSM: (n=45) | Mean | 31.8 | 589 | 565 | 0.81 | 3 | 305 | 4147 | 92 | 161 |
| | Max | 58.3 | 1442 | 1259 | 0.98 | 11 | 1976 | 28436 | 411 | 514 |
| | Min | 19.9 | 161 | 312 | 0.01 | 1 | 13 | 408 | 14 | 34 |
| | Std | 6.2 | 242 | 209 | 0.17 | 3 | 316 | 4480 | 74 | 86 |
| IFFM: (n=166) | Mean | 30.9 | 805 | 616 | 0.83 | 3 | 830 | 1429 | 68 | 192 |
| | Max | 59.2 | 2055 | 5595 | 1.03 | 12 | 17760 | 17130 | 182 | 541 |
| | Min | 16.2 | 140 | 97 | 0.56 | 1 | 18 | 69 | 10 | 27 |
| | Std | 7.4 | 387 | 642 | 0.09 | 1 | 2695 | 2676 | 38 | 92 |
| IFP: (n=73) | Mean | 30.9 | 702 | 738 | 0.84 | 2 | 347 | 1394 | 124 | 189 |
| | Max | 55.1 | 1291 | 1797 | 0.97 | 13 | 3750 | 4796 | 322 | 439 |
| | Min | 11.0 | 215 | 172 | 0.46 | 1 | 9 | 82 | 7 | 55 |
| | Std | 8.8 | 287 | 354 | 0.11 | 2 | 619 | 951 | 82 | 90 |

**Table 1 Continued—Photometric Data—No task units (except IFFM) and little daylight**

| | | LPD | Illuminance Prim. | Illuminance Secon | CRF Min | Luminance Ratios Near | Luminance Ratios Far | Brightest Lum. | Surr. Lum. | Task Lum. |
|---|---|---|---|---|---|---|---|---|---|---|
| DIFP: | | W/m² | lx | lx | | Near | Far | cd/m² | cd/m² | cd/m² |
| (n=78) | Mean | 23.0 | 599 | 676 | 0.87 | 5 | 639 | 1610 | 69 | 143 |
| | Max | 48.3 | 1173 | 2862 | 0.96 | 25 | 6025 | 5242 | 284 | 278 |
| | Min | 14.2 | 151 | 172 | 0.67 | 1 | 35 | 120 | 3 | 41 |
| | Std | 5.7 | 240 | 360 | 0.06 | 6 | 827 | 952 | 57 | 56 |
| HIDP: | | | | | | | | | | |
| (n=37) | Mean | 24.2 | 498 | 222 | 0.82 | 6 | 147 | 2129 | 69 | 121 |
| | Max | 33.6 | 1969 | 269 | 1.04 | 21 | 343 | 2820 | 367 | 418 |
| | Min | 15.0 | 194 | 194 | 0.32 | 1 | 1 | 27 | 3 | 48 |
| | Std | 4.8 | 357 | 33 | 0.17 | 5 | 103 | 900 | 77 | 76 |
| DRFLV: | | W/m² | lx | lx | | Near | Far | cd/m² | cd/m² | cd/m² |
| (n=91) | Mean | 18.7 | 513 | 506 | 0.87 | 4 | 1106 | 2563 | 54 | 116 |
| | Max | 27.8 | 1044 | 979 | 0.97 | 35 | 6950 | 5824 | 127 | 230 |
| | Min | 4.0 | 258 | 151 | 0.57 | 1 | 51 | 387 | 3 | 55 |
| | Std | 3.9 | 188 | 172 | 0.07 | 5 | 1020 | 1411 | 32 | 42 |
| DRFLN: | | | | | | | | | | |
| (n=24) | Mean | 20.4 | 421 | 387 | 0.87 | 5 | 563 | 2599 | 55 | 105 |
| | Max | 35.8 | 689 | 753 | 1.02 | 21 | 1700 | 5824 | 178 | 171 |
| | Min | 13.7 | 204 | 65 | 0.58 | 1 | 123 | 857 | 3 | 55 |
| | Std | 5.1 | 130 | 161 | 0.12 | 5 | 443 | 1140 | 50 | 33 |
| DFSM: | | | | | | | | | | |
| (n=5) | Mean | 36.9 | 340 | 538 | 0.69 | 3 | 347 | 1718 | 45 | 86 |
| | Max | 58.3 | 452 | 678 | 0.97 | 7 | 708 | 2912 | 106 | 103 |
| | Min | 31.3 | 194 | 463 | 0.01 | 1 | 47 | 644 | 14 | 58 |
| | Std | 10.7 | 105 | 75 | 0.35 | 2 | 220 | 925 | 32 | 17 |
| IFFM: | | | | | | | | | | |
| (n=93) | Mean | 32.6 | 793 | 603 | 0.85 | 3 | 359 | 806 | 68 | 193 |
| | Max | 57.0 | 1969 | 1668 | 1.03 | 6 | 7367 | 17130 | 182 | 411 |
| | Min | 19.9 | 204 | 129 | 0.61 | 1 | 10 | 69 | 10 | 41 |
| | Std | 6.9 | 344 | 430 | 0.08 | 1 | 1064 | 2128 | 36 | 87 |
| IFP: | | | | | | | | | | |
| (n=4) | Mean | 25.2 | 635 | 312 | 0.89 | 2 | 330 | 41 | 111 | 139 |
| | Max | 29.9 | 882 | 441 | 0.93 | 3 | 567 | 82 | 192 | 195 |
| | Min | 16.9 | 398 | 194 | 0.86 | 1 | 94 | 0 | 31 | 82 |
| | Std | 5.0 | 237 | 118 | 0.03 | 1 | 236 | 41 | 81 | 57 |
| DIFP: | | | | | | | | | | |
| (n=28) | Mean | 19.4 | 623 | 581 | 0.84 | 3 | 852 | 1477 | 80 | 143 |
| | Max | 23.0 | 915 | 915 | 0.95 | 17 | 6025 | 3303 | 219 | 195 |
| | Min | 18.4 | 280 | 291 | 0.69 | 1 | 119 | 473 | 7 | 69 |
| | Std | 1.0 | 119 | 140 | 0.05 | 4 | 1165 | 601 | 46 | 29 |
| HIDP: | | | | | | | | | | |
| (n=10) | Mean | 22.7 | 381 | 194 | 0.90 | 5 | 171 | 703 | 46 | 90 |
| | Max | 27.8 | 667 | 204 | 0.96 | 10 | 532 | 1045 | 89 | 154 |
| | Min | 15.0 | 226 | 194 | 0.80 | 1 | 34 | 510 | 7 | 51 |
| | Std | 4.3 | 146 | 0 | 0.05 | 4 | 155 | 151 | 34 | 34 |

**Notes:**
Illuminance = illuminance with body shadow.
CRF Min = minimum contrast rendition factor at primary location.
Luminance Ratio, Far = ratio of the brightest/darkest luminance in the field of view.
Luminance Ratio, Near = ratio of the task/surrounding luminance.
Darkest Luminance = darkest luminance in field of view.
Brightest Luminance = brightest luminance in field of view.
Surr. Lum. = luminance of local surround about task (normally desk top).
Task Lum. = luminance of white bond paper at primary location.

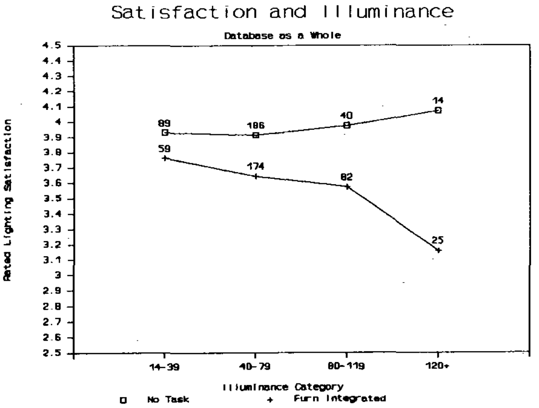


**Figure 3—Mean satisfaction rating as a function of illuminance category for all workstations in the database (daylighting included)**

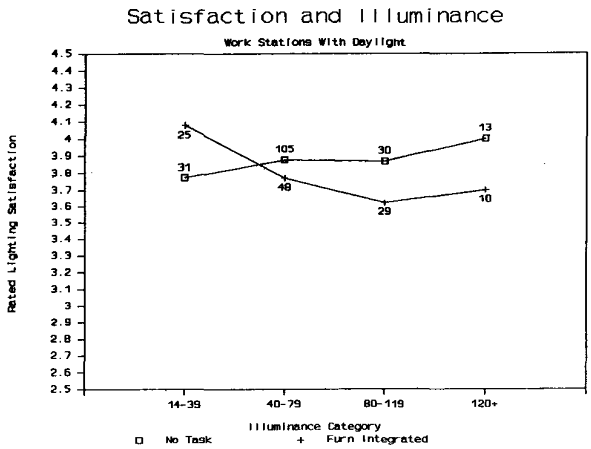


**Figure 4a—Mean rated satisfaction as a function of illuminance category for workstations with daylight**

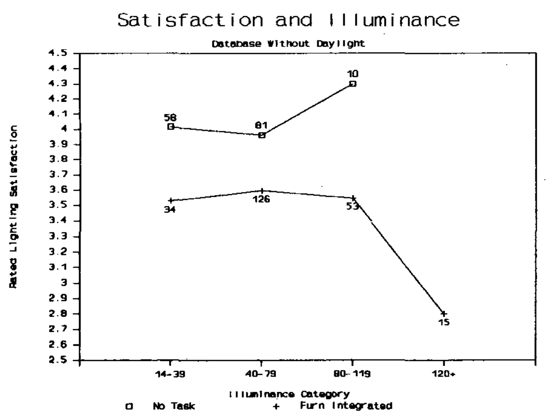


**Figure 4b—Mean rated satisfaction as a function of illuminance category for workstations without daylight**

The mean illuminances in the work stations with direct lighting systems were generally lower than for the indirect systems. They were also substantially lower for direct systems that did not have daylight or task light. Of the seven lighting systems, the IFFM system had the highest mean illuminance as well as the greatest variation in illuminance at both the primary and secondary work surface. The maximum illuminance for the IFFM system, 1969 lx (183 fc), was over twice the maximum illuminance found for any of the other lighting systems. In general, the luminance contrasts and the near-surround luminance ratios (task luminance to surround luminance) shown in **Table 1** were within acceptable limits. Across all lighting systems, the lowest CRF was 0.57, with mean values 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 one-to-one and a maximum of 35-to-one. But the means were between two-to-one and five-to-one, quite close to the desired three-to-one ratio recommended by the IESNA (1987). In addition, the luminances of the brightest area in the field of view and surround tended to be lower for the IFFM system, while the mean illuminance was higher.

## Occupant response data

### *Lighting satisfaction*

A critical question to designers is the occupant's overall satisfaction with the lighting system and reaction to different design and illumination parameters. Although an original objective of the present research was to determine whether the effects of LPDs on occupant satisfaction with the lighting could be directly assessed, there was great difficulty in making a direct connection between the two variables. Since it is reasonable to hypothesize that occupants responded to lighting variables, rather than power variables which they could not see, occupant reaction was examined in relationship to lighting variables such as illuminance or luminance, rather than LPDs.

**Figure 3** plots the mean ratings of lighting satisfaction as a function of illuminance for workstations without task lighting and for workstations with furniture-integrated task lighting. **Figure 4** plots similar data for work stations with daylight and without daylight. In each figure, illuminance was separated into the four categories of 0–39, 40–79, 80–119, and over 120 fc (10–420, 420–850, 850–1280, and over 1280 lx). The mean rating of lighting satisfaction (where one = not at all satisfied and five = very satisfied) was then calculated for each illuminance category.

As **Figure 3** demonstrates, lighting satisfaction was consistently lower for workstations with furniture-integrated task lighting (IFFM). Furthermore, satisfaction tended to decrease with illuminance for these workstations. Conversely, satisfaction was always higher for workstations without task lighting, and also tended to increase with illuminance. A $\chi^2$ test, in which the distribution of lighting satisfaction ratings for work stations with task lighting was compared to those without task lighting, was significant ($p < 0.0001$), indicating that ratings of lighting satisfaction were lower for task lighting. Thus, not only was the mean rating of lighting satisfaction higher for work stations without task lighting, the frequency of people giving higher ratings (fours and fives) was also greater.

**Figure 4a** presents the mean satisfaction ratings for the four illuminance categories for workstations with and without furniture-integrated task lighting with some daylight, while **Figure 4b** presents similar data for work stations without daylight. Both figures confirm the data of **Figure 3**: People at workstations without task lighting generally had higher satisfaction, which tended to increase with illuminance. The decline in satisfaction with illuminance was greatest for those workstations without daylight.

Although about 69 percent of all respondents were either fairly or very satisfied with their lighting (12 percent being neutral), it is important to determine the reasons that 19 percent were either not very or not at all satisfied with their lighting. An examination of the distribution of lighting satisfaction ratings indicated that people with daylight were significantly more satisfied than those without daylight using a $\chi^2$ analysis ($p < 0.001$). A similar comparison of the ratings for task lighting also indicated a significant difference ($p < 0.0001$). Thus, 26 percent of those with task lighting at their workstation were not at all or not very satisfied with their lighting, as compared with only 13 percent of those who did not have task lighting. These comparisons suggest strongly that, although most occupants were satisfied with their lighting, the absence of windows and the presence of task lighting, particularly fixed systems, were major contributors to dissatisfaction with the lighting as implemented in the workstations studied.

**Figure 5** plots the satisfaction ratings for five of the seven systems. This figure indicates that 46 percent of the occupants with the IFFM system were dissatisfied as compared with only 5 percent of those with the direct system with louvers (DRFLV) and 10 percent of those with the direct system with lenses (DRFLN). People tended either to like or dislike the IFFM system, with relatively few (7 percent) neutral about it. At least two-thirds of those with each lighting system expressed satisfaction with their lighting, except for the IFFM

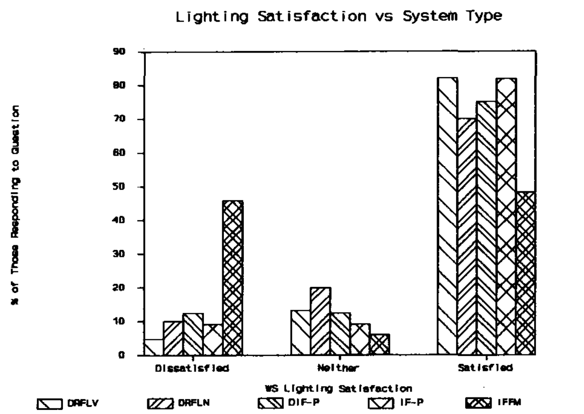


**Figure 5—Percentage of respondents rating satisfaction with their lighting systems for five different lighting systems (non-system task lighting excluded)**

system which satisfied only 56 percent. No one with the HIDP system (not shown in **Figure 5**) expressed dissatisfaction, while 88 percent expressed satisfaction. These latter findings are very limited since only 37 workstations had this system. **Table 2** presents the occupant response measures for the different lighting systems.

Over two-thirds (68 percent) of the occupants with the IFFM system gave low ratings of the amount of light available for work, even though the direct illuminances at the primary workstation were actually the highest of the seven systems in the database. One-third (34 percent) of those with this system also felt the lighting for reading and writing was either poor or not very good. The presence of daylight (adjacency to a window) in the workstation did improve the overall satisfaction with the IFFM lighting system, however.

Although many occupants gave negative ratings for the lighting in the IFFM system, the average task illuminances of 793 lx (74 fc) and minimum task contrasts of 0.85 were within acceptable ranges. The average near-surround luminance ratio of three-to-one (maximum of six-to-one) was also within recommended practice. Yet examination of the photometric data indicated that some of the highest and lowest illuminances occurred in workstations with the IFFM system. The large differences between the illuminance at the primary and secondary workstation may have influenced some of the occupants unfavorably.

Thus far, the discussion suggests that the use of task lighting, particularly furniture-integrated lighting,* resulted in less satisfaction with the lighting at the

**These workstations with DRFLV and IFFM systems had little daylight.*

**Table 2—Occupant Response Measures: No task Units (except IFFM), Little Daylight**

| | DRFLV | (percent) | DRFLN | (percent) | DFSM | (percent) | IFFM | (percent) | IFP | (percent) | DIFP | (percent) | HIDP | (percent) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 VDT 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 2 Continued—Occupant response measures for seven ambient systems daylight and task lighting included**

| | DRFLV | (percent) | DRFLN | (percent) | DFSM | (percent) | IFFM | (percent) | INDFP | (percent) | DIFP | (percent) | HIDP | (percent) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LIGHTING SATISFACTION: | | | | | | | | | | | | | | |
| Not at all | 7 | 2 | 6 | 4 | 0 | 0 | 16 | 11 | 3 | 4 | 0 | 0 | 0 | 0 |
| Not Very | 30 | 11 | 26 | 18 | 6 | 16 | 39 | 26 | 9 | 13 | 11 | 16 | 0 | 0 |
| Neither | 37 | 13 | 17 | 12 | 4 | 10 | 10 | 7 | 9 | 13 | 9 | 13 | 4 | 12 |
| Fairly | 113 | 41 | 68 | 48 | 20 | 53 | 60 | 40 | 30 | 42 | 25 | 36 | 15 | 47 |
| Very | 91 | 33 | 26 | 18 | 8 | 21 | 23 | 16 | 20 | 28 | 24 | 35 | 13 | 41 |
| GLARE FROM CEILING LIGHTS: | | | | | | | | | | | | | | |
| Bothersomeness | | | | | | | | | | | | | | |
| Not at all | 116 | 43 | 58 | 42 | 12 | 32 | 86 | 61 | 24 | 35 | 34 | 49 | 16 | 53 |
| Not Very | 105 | 39 | 33 | 24 | 13 | 35 | 37 | 26 | 25 | 37 | 28 | 41 | 10 | 33 |
| Fairly | 27 | 10 | 32 | 23 | 9 | 24 | 11 | 8 | 15 | 22 | 4 | 6 | 3 | 10 |
| Very | 23 | 8 | 16 | 12 | 3 | 8 | 6 | 4 | 4 | 6 | 3 | 4 | 1 | 3 |
| Total | 271 | 100 | 139 | 100 | 37 | 100 | 140 | 100 | 68 | 100 | 69 | 100 | 30 | 100 |
| GLARE FROM WORK SURFACE: | | | | | | | | | | | | | | |
| Bothersomeness | | | | | | | | | | | | | | |
| Not at all | 106 | 39 | 64 | 47 | 6 | 16 | 50 | 35 | 25 | 37 | 28 | 40 | 17 | 57 |
| Not Very | 109 | 40 | 41 | 30 | 16 | 42 | 47 | 33 | 20 | 29 | 28 | 40 | 8 | 27 |
| Fairly | 35 | 13 | 21 | 15 | 9 | 24 | 30 | 21 | 18 | 26 | 10 | 14 | 4 | 13 |
| Very | 23 | 8 | 11 | 8 | 7 | 18 | 17 | 12 | 5 | 7 | 4 | 6 | 1 | 3 |
| Total | 273 | 100 | 137 | 100 | 38 | 100 | 144 | 100 | 68 | 100 | 70 | 100 | 30 | 100 |
| GLARE FROM TASK LIGHTS: | | | | | | | | | | | | | | |
| Bothersomeness | | | | | | | | | | | | | | |
| Not at all | 121 | 47 | 82 | 71 | 16 | 47 | 59 | 43 | 34 | 52 | 36 | 55 | 21 | 70 |
| Not Very | 93 | 36 | 22 | 19 | 11 | 32 | 42 | 31 | 22 | 33 | 21 | 32 | 6 | 20 |
| Fairly | 27 | 10 | 8 | 7 | 6 | 18 | 23 | 17 | 7 | 11 | 5 | 8 | 2 | 7 |
| Very | 18 | 7 | 3 | 3 | 1 | 3 | 12 | 9 | 3 | 5 | 3 | 5 | 1 | 3 |
| Total | 259 | 100 | 115 | 100 | 34 | 100 | 136 | 100 | 66 | 100 | 65 | 100 | 30 | 100 |

workstation. Because two ambient lighting systems, direct and indirect, were used at a substantial number of work stations with identical systems of furniture and furniture-integrated lighting, the effects of the directionality of the ambient lighting could be explored. Comparison of the responses to the two lighting systems revealed that 68 percent of those with the direct ambient system were satisfied with their lighting, while only 46 percent of those with the indirect ambient system were dissatisfied. Thus for identical furniture systems with integrated task lighting, satisfaction with lighting was higher where the ambient lighting consisted of recessed ceiling luminaires with louvers, than where the ambient lighting was provided by indirect furniture-mounted luminaires, indicating that the directionality of the lighting affected the occupant's response.

### *Lighting quality*

The previous discussion has centered on occupant satisfaction with the lighting system in terms of the question, "Overall, how satisfied are you with the lighting at your office or work space?" Satisfaction with lighting, however, does not provide complete information about the overall quality of the lighting system. Lighting quality is justifiably viewed as encompassing factors such as brightness, color, design, luminance ratios, task illuminances, visual comfort, visibility, and emotional reaction to a space.

Consideration of lighting quality suggests that it will be directly affected by perceptions of the brightness of a space as well as by the task illuminance, daylight conditions, view out, and the task performed. One way of assessing these influences is to examine the responses to three other questions asked of the participants in the POE study. In the study, people were also 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. Responses to these questions were strongly correlated with one another and with the one about lighting satisfaction, 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, participants who were satisfied with their lighting were also likely to rate the amount of light for work and the amount for reading high ($r=0.78$, $r=0.81$) and feel that lighting did not hinder their job performance ($r=0.54$).* Conversely, those dissatisfied with their lighting also rated

***The r is a measure (coefficient) of the correlation between two sets of data, which goes from −1, a perfect negative correlation, to +1, a perfect positive correlation. Coefficients near zero have little correlation***

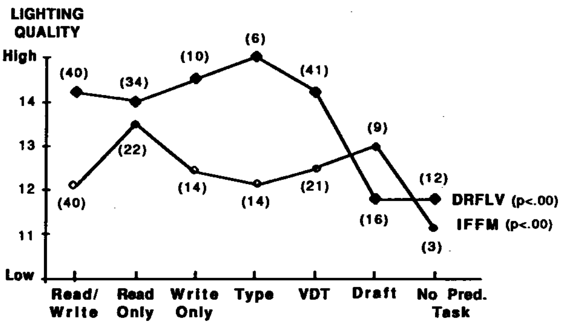


**Figure 6a—Assessments of lighting quality as a function of predominant task performed in the work station for the DRFLV and IFFM systems**

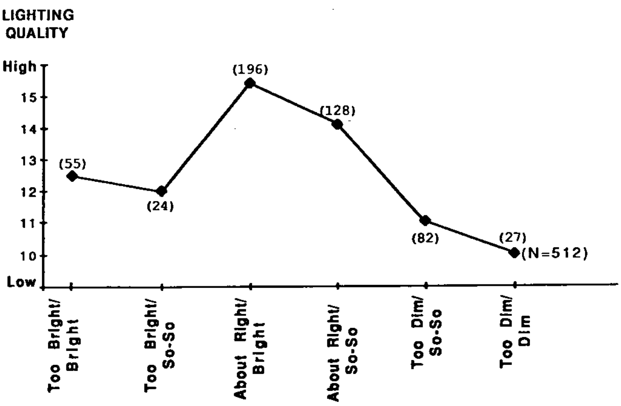


**Figure 6b—Lighting quality as a function of lighting control assessment for respondents with and without task lighting**

as poor the amount of light and felt that their lighting interfered with their ability to work.

A lighting quality index was developed in which the ratings for the four questions were combined on a scale of 4–20. The higher the lighting quality score, the more favorably a person viewed the lighting system at his/her work space. **Figure 6a** presents assessments of lighting quality for 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 was not due to differences in illuminances since no significant relationship was found between illuminance and lighting quality assessments for either the IFFM system ($r=0.07$) or the DRFLV system ($r=0.19$).

***Brightness***

Another dimension of the occupant response to lighting is contained in the response to the question "Please describe your space on a seven-point scale of bright to dim." Responses to this question reflected the occupants' perception of the brightness of their spaces. Although the mean primary and secondary task illuminances were higher for the IFFM system (**Table 7**), nearly half (43 percent) of the occupants in these spaces rated their workstation as being dim as compared to 21 percent of those with the direct system (DRFLV). Ratings of harshness were virtually the same for both lighting systems.

Lighting quality may also be related to the perceived brightness of a work station. In the survey, two subjective measures of brightness were obtained for 512 workstations.* One measure covered the perception of brightness at the workstation, using the bright-dim scale discussed above. The second measure dealt with the assessment of brightness and was determined by a rating of the amount of light available on a five-point scale ranging from too bright to too dim. Responses to the two questions were combined to form one measure of subjective brightness.

**Figure 6b** presents the relationship between the combined measure of subjective brightness and lighting quality. This figure indicates clearly that those spaces judged to be too dim for working and which had average or low brightness had the lowest lighting quality, while spaces viewed as too bright received higher assessments of lighting quality. The assessments of lighting quality were highest for those spaces judged to be about right in brightness availability and perceived as bright or average. About 49 percent (251) of those responding to these questions felt that their space was bright, with only 11 percent (55) of these feeling that it was too bright and giving it a lower lighting quality score. Subjective brightness was clearly an important contributor to perceived lighting quality: no space that was perceived as dimly lighted was considered to have the right amount for work.

***Glare***

Another important component of workstation

***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 satisfaction and hence, lighting quality, is the reaction to glare from lights, tasks, and surfaces. Ideally, a high-quality lighting environment will be free of annoying glare.

Responses were tabulated to three questions about glare: glare from ceiling lights, work surfaces, and task lights. This tabulation given in **Table 2** indicated that ratings of workstation lighting satisfaction were higher for workstations rated as having less glare from the task lights, ceiling lights, and work surfaces. Glare from the work surface bothered a higher percentage (16–42 percent) of people in each lighting system type (except DRFLN) than glare from ceiling or task lights. Thus, glare from ceiling lights was most bothersome to those with the DFSM and DRFLN systems (28–35 percent); glare from the work surface was most bothersome to those with the INDFP, IFFM and DFSM systems (33–42 percent); glare from task lights was most bothersome to those with the DFSM and IFFM systems (21–26 percent). The extent to which bright lights were bothersome influenced people's assessments of lighting quality except for those whose primary task was writing. The more people were bothered by bright lights, the more likely they were to give lower assessments of lighting quality.

A comparison of rated ceiling light positions for the different lighting systems using the $\chi^2$ statistic, was significant ($p < 0.0001$) with indirect systems (such as the IFFM), rated as poor to fair by 72 percent, but direct systems (such as the DRFLV) rated as good to excellent by 68 percent. The relationship between rated ceiling light position and lighting satisfaction was also significant ($p < 0.0001$). These analyses indicated that as the rating of ceiling light position improved from poor to fair, workstation lighting satisfaction increased from not at all to very satisfied. Thus, 81 percent of those who were not at all satisfied with their lighting system rated the ceiling light position as poor. Conversely, 42 percent of those who were very satisfied with their lighting rated the ceiling light position as excellent.

***Analysis of the response to luminance***

The discussion thus far indicates that occupants with task lighting, particularly the IFFM system, frequently rated their lighting as neither satisfactory nor bright. Furthermore, they gave this system the lowest score on the lighting quality index. Yet, as noted earlier, workstations with this configuration had higher task illuminances and luminances than most other work stations. In addition, the negative ratings for the IFFM system did not appear to relate to any single classical field measures such as CRF, illuminances, task luminance ratios, and field luminances. Because no single luminance measure, such as ceiling luminance or luminance directly ahead or to the side, could be related to lighting satisfaction ratings in any meaningful way, a summary measure of luminance, average luminance, was created to explore the relation between lighting satisfaction and luminance patterns in the space. Average luminance appeared to be a reasonable way of summarizing the ten luminance values* taken for a space, and providing a better estimate of what the occupant saw than one luminance measure alone.

In the analysis, luminances in the work stations were averaged and then placed into the following average luminance categories: 0–49, 50–99, 100–199, 200–299, 300–399, 400–499, and over 500 fL (0–167, 168–339, 340–682, 683–1024, 1025–1367, 1368– 1709 and over 1710 cd/m$^2$). **Table 3** presents the average luminance data for the subset of 417 work stations with common systems furniture, or direct lighting to compare the effects of position and directionality of the lighting. These included the DRFLV system without task lighting (Set 1), the DRFLV with furniture-integrated task lighting (Set 2), and the IFFM system (Set 3).

Examination of **Table 3** indicated that the majority of work stations (68 percent) with the indirect system and task lighting were located in the lowest average luminance category (0–49 fL), as compared with 14 percent and 2 percent of those with the direct system with and without task lighting, respectively. In fact, 80 percent of the data for the IFFM system were in the average luminance category of 0–99 fL. Comparison of the mean ratings for workstation lighting satisfaction revealed that the ratings were always the highest for the direct system without task lighting.

Also, they were always greater than ratings for the same system with task lighting, while ratings of the indirect system were always less than either of the two direct systems. A similar consistency in the three systems was found for the brightness ratings. This trend was reversed for glare ratings, however. As might be expected, the two systems with task lighting had higher ratings for glare from the work surface and task light than the direct-only system, but lower ratings for glare from the ceiling lights.

The IFFM system had an overall average luminance that was less than half of that for each of the other systems, while the means of the luminance of the ceiling and brightest area in the field of view were also substantially below those for the two DRFLV systems.

**Average luminance is a composite variable created by averaging ten luminances: ceiling between luminaires; light source; brightest area on ceiling; darkest area in field of view; task luminance; surround luminance; wall luminance straight ahead, right, and to the left; and sky luminance.*

**Table 3—Average luminance analysis**

Direct System without Task Units:

| $LUM_{avg}$ | n | (percent) | LUMAV | ILPBS | ILSBS | LPD | LITSAT | WSBRT | GLWSF | GLTLT | GLCLT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0–49 | 2 | 2 | 16 | 53 | 52 | 2.1 | 5.0 | 7.0 | 1.5 | 1.0 | 1.0 |
| 0–99 | 25 | 23 | 73 | 46 | 47 | 1.7 | 4.3 | 5.4 | 1.8 | 1.5 | 1.8 |
| 100–199 | 45 | 42 | 140 | 48 | 45 | 1.7 | 4.1 | 5.5 | 1.8 | 1.6 | 1.8 |
| 200–299 | 26 | 24 | 232 | 44 | 41 | 1.7 | 4.3 | 5.8 | 2.0 | 1.6 | 2.0 |
| 300–399 | 6 | 6 | 335 | 57 | 59 | 1.6 | 3.2 | 3.8 | 2.0 | 1.3 | 2.2 |
| 400–499 | 3 | 3 | 441 | 83 | 104 | 1.7 | 4.0 | 5.7 | 2.0 | 1.7 | 2.0 |
| 500+ | 1 | 1 | 517 | 97 | 85 | 2.1 | 4.0 | 6.0 | 2.0 | 2.0 | 2.0 |
| | 108 | 100 | 167 | 49 | 47 | 1.7 | 4.2 | 5.5 | 1.9 | 1.5 | 1.9 |

Direct System with Task Units:

| $Lm_{avg}$ | n | (percent) | LUMAV | ILPBS | ILSBS | LPD | LITSAT | WSBRT | GLWSF | GLTLT | GLCLT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0–49 | 23 | 14 | 28 | 65 | 40 | 2.6 | 3.8 | 4.7 | 2.0 | 1.6 | 1.9 |
| 50-99 | 28 | 17 | 80 | 59 | 51 | 2.7 | 3.9 | 4.4 | 2.0 | 1.9 | 2.0 |
| 100–199 | 63 | 39 | 143 | 65 | 64 | 2.6 | 3.8 | 5.0 | 2.0 | 1.9 | 1.9 |
| 200–299 | 35 | 21 | 246 | 70 | 53 | 2.5 | 4.0 | 5.3 | 1.8 | 2.0 | 1.8 |
| 300–399 | 14 | 9 | 333 | 90 | 71 | 2.4 | 3.3 | 4.8 | 2.1 | 2.4 | 2.1 |
| 400–499 | 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 |
| | 163 | 100 | 154 | 67 | 57 | 2.6 | 3.8 | 4.9 | 2.0 | 1.9 | 1.9 |

Indirect System without Task Units:

| $Lm_{avg}$ | n | (percent) | LUMAV | ILPBS | ILSBS | LPD | LITSAT | WSBRT | GLWSF | GLTLT | GLCLT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0–49 | 99 | 68 | 31 | 74 | 47 | 2.8 | 3.3 | 4.4 | 2.0 | 1.7 | 1.5 |
| 50–99 | 19 | 13 | 62 | 76 | 46 | 3.0 | 2.6 | 3.4 | 2.3 | 2.4 | 1.6 |
| 100–199 | 16 | 11 | 144 | 95 | 68 | 2.5 | 3.3 | 4.8 | 2.5 | 2.3 | 1.5 |
| 200–299 | 9 | 6 | 242 | 109 | 120 | 2.7 | 3.4 | 5.2 | 1.9 | 2.0 | 1.8 |
| 300–399 | 2 | 1 | 348 | 62 | 24 | 2.5 | 4.0 | 3.0 | 1.5 | 1.5 | 1.5 |
| 400–499 | 0 | 0 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 500+ | 1 | 1 | 581 | 81 | 45 | 3.6 | 3.0 | 1.0 | 2.0 | 2.0 | 2.0 |
| | 146 | 100 | 68 | 78 | 55 | 2.8 | 3.3 | 4.3 | 2.1 | 1.9 | 1.6 |

LITSAT = work station lighting satisfaction
WSBRT = work station brightness
GLWSF = glare from work surface
GLTLT = glare from task lighting
GLCLT = glare from ceiling lighting
LUMAV = average of measured luminances
ILPBS = illuminance at primary location with body shadow
ILSBS = illuminance at secondary location with body shadow
LPD = lighting power density

Yet, task luminance as well as primary and secondary illuminances were consistently higher. Overall lighting satisfaction and brightness ratings were consistently lower for the IFFM system than for the other two systems. While rated glare from the work surface tended to be higher for this system, rated glare from the ceiling lighting was lower for each average luminance category. This analysis suggests that the distribution of luminances in a space was an important factor influencing occupant satisfaction and brightness perceptions. Similar results were obtained by Hawkes, Loe, and Rowlands (1979) and Flynn (1977). Such considerations appeared to be even more important than the amount of light on the task for the participants in the present study in determining satisfaction with lighting.

The rationale for averaging all the luminances is based on the hypothesis that an occupant's response to the brightness of the space is a response to the whole space as opposed to a single luminance value. There are limitations to this approach; for instance, there are likely to be better ways of summarizing the data than averaging. The average does provide a preliminary way of evaluating the hypothesis that there were photometric measures that could be meaningfully related to occupants' perceptions of brightness and satisfaction with their lighting. Exploring this hypothesis in greater detail would require a luminance meter, such as that developed by Kambich and Rea (1987), capable of measuring all the luminances in a scene and then weighting them appropriately for the occupant response.

### *Impact of office characteristics*

Another important component of lighting satisfaction and quality is people's feelings about their ability to control their lighting. As shown in **Figure 7a**, lighting quality was rated as poor when the assessment of the ability to control the lighting was also rated as poor. People without task lighting rated their ability both to control the lighting and the quality of lighting as poor. 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.

The lighting quality associated with a particular lighting system was determined not only by design factors but also by task characteristics, such as VDT monitors. Lighting a workstation with a VDT imposes certain constraints, including the effect of ceiling lights on the screen, not found in offices with conventional paper tasks. **Figure 7b** indicates that lighting quality scores for occupants with the DRFLV system were lower the longer they used a VDT during the day. This figure also indicates that lighting quality scores were consistently lower for those with the IFFM systems 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 developed problems for the occupants such as reflections on the VDT monitors over long periods of time. Nonetheless, lighting quality scores for the DRFLV system were consistently higher than for the IFFM system, even for those who used VDTs for 5 hrs or more a day.

Another way of evaluating the impact of lighting on occupant response was to examine the data on the selection of ten possible improvements that could be made to the workstation. Examination of the choices allows one to determine the importance of changes to lighting relative to other factors in the environment.

**Figure 8**, which presents the choices for occupants with two lighting systems, the DRFLV and the IFFM, indicates that the desire for increased privacy was selected by 25 and 30 percent of the respondents with these systems. Yet, a high percentage of occupants (22 percent) with the IFFM system also picked improved lighting as a desired improvement. Only privacy was selected by more people who had this lighting system (25 percent). In comparison, only 9 percent of those with the DRFLV system selected lighting as a desired improvement, but 30 percent selected increased privacy. This comparison suggests that for those with the IFFM system, the desire for improved lighting was almost as great as that for privacy, 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 for the DFSM system, improved temperatures for the DIFP system, greater privacy for the INDFP system, and improved view and temperature for the HIDP system. Analysis of a similar study by Rubin and Collins (1988) also indicated that the desire for improvements in temperatures, privacy, noise, lack of windows, and lighting were paramount to many of those participating in their study.

Another influence on satisfaction with offices and lighting was the amount of space of a workstation. Those who were not satisfied with their lighting (gave it ratings of 1 or 2) had the smallest workstation floor area, while those who were most satisfied had larger floor areas, as shown in **Figure 9**. Similarly, floor area was about the same for overall work station satisfaction until ratings of fairly and very satisfied were reached. Those who were very satisfied with their workstation had much larger work areas than did those who were very satisfied with their lighting. Differences in the amount of space in the work stations were highly significant according to a $\chi^2$ analysis, with workstations having the HIDP system afforded the smallest area and those with the DFSM system, the

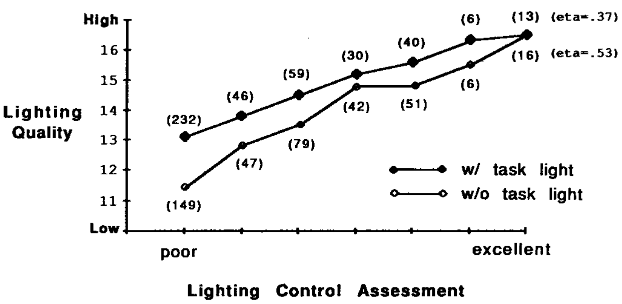


**Figure 7a—Lighting quality as a function of lighting control assessment for respondents with and without task lighting**

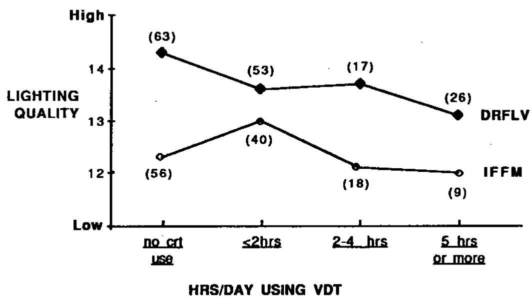


**Figure 7b—Lighting quality as a function of hours spent per day using a VDT for the DRFLV and IFFM systems**

largest. About 80 percent of those with the furniture-mounted systems (and direct or indirect lighting) had less than 100 ft$^2$ per workstation, as compared with 60 percent of those with the other lighting systems.

Occupant ratings of spaciousness were also related to their work station floor area. 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 110 ft$^2$. When the ratings of not at all or not very satisfied with lighting were compared with rated spaciousness, 10 percent of those rating their lighting as unsatisfactory also rated their work space as confined (1, 2, or 3), as compared with only 17 percent who rated it as spacious (5, 6, or 7). Conversely, 39 percent of those who rated their lighting fair or very satisfactory also rated their work space spacious as compared with 5 percent who rated it confined. This relationship is in line with studies of spaciousness that have indicated that lighting plays an important role in the perception of the amount of space in an area (Inui and Miyata, 1973; Flynn, 1977).

**Other factors**

Other factors that might have influenced workstation lighting satisfaction were related to the demographic characteristics of the respondents. Such factors include age, sex, job type, and use of corrective lenses.

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. They did not, however, have noticeably higher task illuminances or fewer task lights. Although there was an almost equal mix of males and females, the women tended to be slightly less satisfied with their lighting systems, particularly the IFFM system which evoked 53 percent dissatisfaction of the females as compared with 32 percent of the males. They also had smaller average floor areas (73 ft$^2$ vs 108 ft$^2$), were younger, and held secretarial or clerical positions (54 percent). No significant relationship was found between job type and workstation lighting satisfaction, although larger workstation floor areas were associated with professional and managerial jobs as shown in **Figure 9**. No significant relation was found between lighting satisfaction and corrective lenses, either.

A $\chi^2$ analysis of other environmental factors that might have influenced occupant responses indicated that all occupants had spent at least 1 yr in their workstation before the survey was done. This suggests that the response to the lighting systems was not based on the novelty of the workstation; occupants had time to become accustomed to their workstations before the survey was done. Although there were significant differences in noise, chair comfort, and workstation size between lighting systems, these were not associated with any one particular system, suggesting that the dislike of lighting provided by the IFFM system was related primarily to lighting variables rather than other environmental factors. For example, the HIDP system had the smallest workstation floor area, but the highest ratings of lighting satisfaction. On the other hand, the variable that was most closely related to workstation lighting satisfaction was workstation brightness, which was perceived to be lowest for the IFFM system.

**Conclusions**

The first conclusion to be reached from the analysis of the post-occupancy data from 912 workstations is that the majority of the occupants (69 percent) were

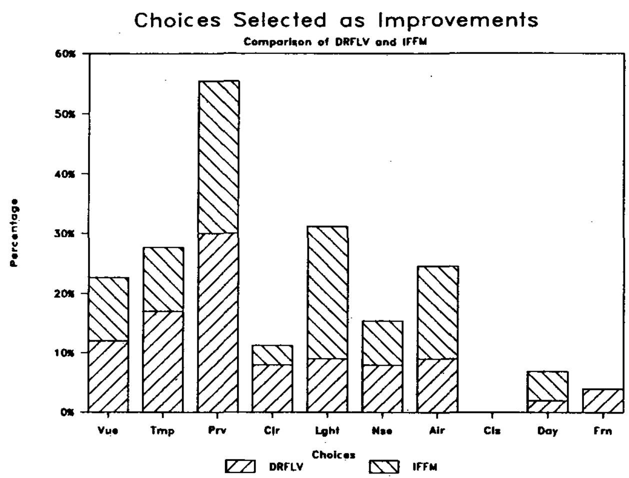


**Figure 8— Improvements to the workstation selected by respondents with the DRFLV and IFFM systems**

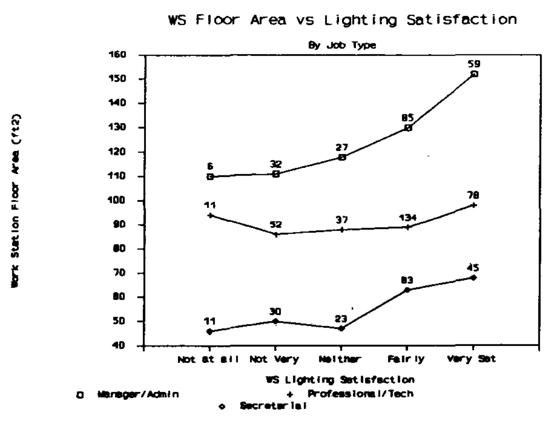


**Figure 9—Relationship between mean workstation floor area, job classification, and lighting satisfaction**

satisfied with their lighting. Second, the mean illuminances at the primary task location were generally within the IESNA target values for office tasks with a range of mean illuminances from 32–75 fc (344–807 lx), depending on the lighting system. Third, the median LPD was about 2.36 W/ft$^2$, with about one-third of the work stations having LPDs at or below 2.0 W/ft$^2$.

Analysis of the responses associated with the individual lighting systems revealed that one particular system, the IFFM system, was characterized by a series of negative responses. Rated lighting satisfaction was lower; perceived brightness was lower; ratings of amount of light for work were poorer; rated lighting quality was lower; glare from work surfaces was higher; and feelings of control were lower. Rated satisfaction also tended to decrease with increasing illuminance for these workstations. Yet, at the same time, the LPDs and task illuminances were higher. Comparisons with a similar furniture system implemented with a direct (DRFLV) lighting system indicated more favorable responses to the latter. Examination of the data of another indirect system (HIDP) without task lighting indicated that lighting satisfaction was higher for the HIDP than for any other system. These comparisons suggest that the combination of integrated furniture lighting with an indirect ambient system was particularly unsuccessful both from an occupant and an energy-conservation viewpoint. A possible reason for the unfavorable response may be found in the luminance data of these workstations. An examination of the average luminances in work stations with the IFFM system indicated that they were much lower than for any other system, while the mean task illuminances were higher. This suggests that these spaces were characterized by extremes, very bright tasks, and very dim surroundings. As a result, it appears that the pattern of luminances in the space was a more important factor in influencing occupants' satisfaction with their lighting and perceptions of brightness in their spaces than the amount of light on the task.

Although there were significant differences in noise, chair comfort, and workstation size in offices with similar lighting systems, the differences were not associated with any one particular system, suggesting that the dislike of the lighting provided by the IFFM system was related primarily to lighting variables. In fact, the variable most strongly related to workstation lighting satisfaction was workstation brightness, which was perceived to be lowest for the IFFM system.

The data analysis indicates that many of the negative responses to lighting 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, concealed under an upper shelf, so that light was directed toward the task and could easily cause specular reflections on the task, thereby reducing task contrast and visibility. Occupants had no control over the position or direction of the task light. In addition, the ambient lighting that was located in the top of the furniture system and directed up to the ceiling often resulted in a non-uniform pattern of ceiling luminance with many dark areas. The result appears to have been an unsatisfactory lighting system for many occupants. By contrast, the DRFLV system was rated much more favorably, even with the same type of systems furniture. In conclusion, the analysis of the data suggests that the pattern of luminances in the space, rather than the illuminance on the task, was a major determinant of lighting quality and satisfaction.

**Implications for future research**

Although the findings discussed in the present report represent an extensive analysis of the data obtained from the 912 workstations of the POE 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, furnishings, colors, chairs, wall treatments, pictures, plants, mementos, temperature, humidity, and noise. Analysis of the responses to these questions would provide information about the effectiveness of a space in meeting user requirements other than lighting.

Of course, the analysis of the data on the 912 workstations has also raised further questions that cannot be answered simply by re-examining the existing database. For example, one issue that should be addressed in future POE research is the extent to which physical conditions vary in an office over time, and the occupants' reaction to such changes. Another issue is the need to measure the physical characteristics of any space that is part of a POE analysis with greater precision. Although ten measures of luminance and four measures of illuminance were taken, measurements only began to describe the visual space that the user inhabited. The incongruent responses of the people with the IFFM system who had high task illuminances but described their spaces as dim were explained in part by the average luminance concept. Yet, the average luminance concept does not go far enough. Average luminance does not provide enough information about the patterns and balance of luminances in the space; neither does it pretend to define which portions of the space an occupant is judging when describing it as dim. Average illuminance clarifies 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 an occupant's desk. At the same time, weighting factors should be developed to relate occupant responses to meter measurements. In other words, what 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, the walls, the desk surface, or some combination of the three? Is there an optimal ceiling luminance? And finally, what is the role of brightness in determining satisfaction. Such questions are more properly explored in a controlled laboratory setting, such as those used by Hawkes, et al (1977); Flynn and Subisak (1978); and Tregenza, Romaya, Dawe, Heap, and Tuck (1974), and verified by field techniques such as POE analyses, attitude surveys, and behavioral observations.

Further questions arise concerning the role of task lighting in meeting user needs for lighting. Responses to the questionnaire reported by Rubin and Collins (1988) indicated that occupants desired greater control over their lighting and felt that localized, controllable task lighting would answer their needs. Yet, McKennan and Perry (1979) found that movable task lights were less acceptable than localized lights. In the present study, the response was also 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 low levels of brightness in the space, further research is needed to evaluate means of increasing the effectiveness of task lighting.

Another area for investigation is that of the best way to investigate the subjective response to a space. Much of the research has involved different types of scaling and subjective judgements, a procedure that Poulton (1979) questioned. 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 suggest 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 is developed for assessing subjective response and relating it to physical conditions in a space, subjective scaling techniques and POE analyses are among the few procedures that 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 will not be exactly replicated in another study with a different subject population and different 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 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.

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**Discussion**

This paper moves the fledgling subject of field analysis of actual lighting and power lighting density ahead, and this is to be appreciated. While the large number of data points (over 900) is impressive, and a large number of workers can be surveyed, is it not somewhat misleading compared to the number of buildings involved? One would think there would be at least some measure of consistency within each building in terms of lighting system types, workstation design, job type, etc. In another paper being presented this year, which I have co-authored, 20 buildings were surveyed and evaluated on a basis of lighting power density.

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This paper presents an ambitious effort to make some sense of the large volume of data collected a few years ago in the DOE/NYSERDA post-occupancy evaluation project. It is a great improvement over the earlier reports from this study. However, some fundamental issues must be raised.

It is a mistake to believe that POE data can lead to the conclusion that lighting system type causes certain user responses. In fact, the authors mention that there are many variations between the spaces evaluated: floor area, geometry, ceiling height, reflectances, room size, partitions, and maintenance to name a few. They further note that uniformity of illuminance seemed to be important to the users' evaluations. Yet it is lighting system type that serves as the basis for association with user responses, implying that it is lighting system type that has caused the responses.

POE studies are very important to lighting, but not to establish cause-and-effect relationships. Instead, POE studies must be seen as an integral part of the design process, used to evaluate the extent to which design decisions have been successful in accomplishing the stated goals of the design. A POE does not seek to manipulate certain variables and control others, which is necessary to show causation; it simply attempts to describe the results of design decisions, hopefully leading to improvements in the environment evaluated and in future designs. The Rubin and Collins work for the Army cited in the paper is a good example of this use of POEs. This writer uses POE techniques to evaluate in-house facility design work, as do many other companies and lighting designers. In these cases, the POE serves as a design appraisal, examining the extent to which objectives were met and offering suggestions for improving the environment studied. This is a very different philosophical approach to POE than that demonstrated in this paper.

The question showing lighting hindering job performance shows a much lower level of correlation than the other questions used in the lighting quality measure. Why was it included in this measure? Is the level of correlation stable across all the lighting system types? If not, the lighting quality measure may be emphasizing completely different responses for different systems.

The authors conclude the paper by asking a series of questions regarding brightness perception, luminance distribution, and user satisfaction. I strongly agree that these are the questions that must be answered to further advance lighting research and practice, and I agree with the authors' contention that these questions should be explored in a controlled setting. I hope the Lighting Research Institute and the industry in general will devote more of its resources to these issues. But I am not sure that we needed a project of this magnitude to bring us to these questions; I suspect we already knew them. I hope that the LRI will very carefully consider the issues raised here before devoting even more of our limited resources to further pursuit of projects which by their very nature cannot answer these questions.

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The findings related to luminance levels and pat-