Potential Productivity Benefits from High Quality Lighting in Federal Buildings

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ABSTRACT

This paper looks at the possible impacts of changes in lighting conditions on the productivity of Federal office workers. Federal offices constitute 36% of the Federal building square footage but house a disproportionate 66% of the Federal employees. The high density of workers in Federal office buildings magnifies any effects that the physical environment has on labor productivity.

Results from a recent set of experiments on the effects of lighting conditions on short-term worker productivity are discussed, and extrapolated to the larger context. The probable effects of changes in lighting conditions on worker productivity are found to be significantly more valuable than any potential energy savings.

The probable upper and lower bounds of effects are presented, for both the Federal sector as a whole, and per square foot of building area. The range of potential budgetary impacts is estimated to be from $220 million per year to $1.3 billion per year. The potential productivity impacts per square foot of office building are estimated to be from $0.57/SF to $3.30/SF.

Introduction

The relative presence or absence of lighting quality in Federal buildings is a matter of increasing importance as it relates to energy savings, worker productivity in the built environment, and labor economics in the Federal sector.

When one considers the cost of labor in the workplace compared to the cost of electricity, it becomes immediately apparent that it is appropriate to consider lighting impacts on Federal workers. Potential productivity improvements are possible *if* the relighting is an improvement to the quality of the lighted environment; this can create incentive for relighting above and beyond the environmental benefits of energy savings. While this has been understood in general terms, this paper quantifies the value of these non-energy benefits in the Federal sector for the first time.

The theory behind improving productivity with quality lighting is based on the fact that lighting has a direct and powerful impact on the occupants of an environment, unlike some other types of energy-using appliances, such as refrigerators and duplicating machines. From a conceptual perspective it is easy to understand that lighting affects humans in many ways, including but not limited to: speed and accuracy of task performance; health (i.e. headaches, eye strain); safety; and mood. Aspects of a lighting system that impact humans include elements such as glare, color, temperature, color rendering, brightness ratios, flicker, daylighting, etc. Some of these impacts are related to visual performance, and many are related to non-visual impacts such as psychological needs, preference, circadian rhythms, and Seasonal Affective Disorder (SAD).

For the sake of clarity, a few hypothetical examples follow. Flicker from certain kinds of fluorescent ballasts (usually not perceptible by the human eye) could be causing eyestrain, thereby adversely affecting performance, and may result in headaches, leading to absenteeism. Glare from overhead fixtures could create similar problems. The presence of daylight and/or access to a window is likely to positively impact the morale and motivation of workers, whereas inadequate vertical illuminance on walls can create a perception of a dim and gloomy space, possibly diminishing morale, motivation, and performance. Excessive brightness contrast ratios can cause disturbing reflections in VDT screens, impeding computer task performance.

It is important to understand that research in this area is in its infancy, and this paper cannot quantify the above scenarios individually. As a first step, it is necessary to find a range of impacts based on the research that has been done, and to prove decisively the economic importance of energy *effective* lighting. Just as important is the awareness that energy efficiency and lighting quality are not inversely related. It is possible, with current lighting technology, to achieve a win-win balance between energy savings and lighting quality. There is a tremendous prevalence of information about lighting energy efficiency, and far too little information about lighting quality. This paper shows that efficiency and quality should be dual goals of every lighting installation, and emphasizes the importance of proactively harnessing both energy and non-energy benefits as a means to save taxpayer dollars.

Background: Past Studies on Office Productivity

In a study done in 1991 by the Center for Architectural Research at Rensselaer, the productivity levels of insurance workers who were moved from an existing building to a new building were monitored and analyzed. (Kroner, Stark-Martin & Willemain 1992) The new building featured improved lighting, better furniture, and, most notably, individual control of a number of environmental factors at personal workstations. Using pre-existing productivity measurements of forms processed per week, which were maintained by the insurance company, the study followed 118 workers for one year, half in the old building and half in the new. Since the productivity measurements were an ongoing practice of the company, workers were not aware of the nature of the study.

The researchers found that after the move to the new building there was a sustained improvement in productivity of 13% which was specifically attributable to the change in overall building environment. After the move, the individual controls at the workstations, including a radiant heat panel, a ventilation control, and a white noise maker, but excluding the task lighting, were periodically disabled to isolate their impact on the workers. An additional 2% increase in productivity was attributed to these individual environmental controls at the workstations.

The study also found an important correlation between worker satisfaction ratings with their environment and measured productivity. The individuals with the highest measured productivity improvements also reported the highest satisfaction ratings with their workspace. Unfortunately, this study does not allow us to isolate the effects of the lighting system. Lighting is just one component of an improved environment that probably included better desk arrangements, more comfortable furniture, better temperature control, better acoustics, etc.

In another study, workers were asked to rate the relative importance of ambient environmental factors to their overall satisfaction with office space. (Rolhes, Woods & Morey 1989) The researchers tested two groups, a group of graduate students and a group of clerical workers, and asked them to rate the relative importance of various environmental factors for their comfort, satisfaction, and self-assessed productivity. Using this methodology, 24% of overall satisfaction with indoor environment conditions was attributed to lighting issues. Concern over the quality of lighting is widespread, and may be growing with the increasing transformation of the office into electronic work processes. (NRC Commission 1983) In a nationwide study for Steelcase, Inc., pollster Louis Harris found that 80% of the workers questioned said lighting affects their performance, and that having good lighting was important to them. (Harris 1988) Another study by Fortune Marketing found that corporate facility executives also are concerned with lighting quality; 87% of the facilities executives believe that a high quality work environment increases worker productivity, morale, and safety. Furthermore, 93% believed that improved lighting could enhance worker productivity by 10% or more. (Custom Research, Inc. 1996)

Scope: The Federal Workforce

In this paper, we discuss the implications of improved lighting quality for the Federal workforce, using the data from the NRC study to make productivity impact projections. Why look at the Federal workforce? There are a number of reasons for focusing on this group of workers. *First*, the government workforce is substantial and thus the potential impact of lighting retrofits is enormous. *Second*, many of the Federal employees engage in work with a high visual content that is likely to be directly affected by lighting quality (e.g., paper work, reports, computer data processing). *Third*, Federal office buildings have very high density of employees per square foot, and thus the effects of lighting improvements on productivity are potentially magnified. *Fourth*, the tremendous increase in the use of computers in the past decade places even greater demands on the visual environment and lighting ergonomics. And *fifth,* the government has an opportunity to set an example for high quality energy efficiency in the workplace. If the Federal government can demonstrate the potential benefits that accrue from high quality energy efficient lighting in its own buildings, then it will be easier to convince the private sector to follow.

Methodology

Application of Recent Experimental Findings

Researchers at National Research Council Canada, led by Drs. Jennifer Veitch and Guy Newsham, recently completed a carefully constructed laboratory experiment concerning the effects of lighting conditions on the performance of office workers. (Veitch & Newsham 1998) Veitch and Newsham have shown that, all other things being equal, lighting quality does have a measurable impact on workers performance and attitudes.

We have used the data from the NRC study to assess the potential productivity impacts of lighting in the US Federal sector for several reasons. First, the NRC study used highly realistic settings that are typical of workspaces in US government offices. Second, the NRC study conducted tests with clerical workers rather than college students. Third, the tasks used in the research are realistic and typical of what clerical workers would likely be asked to do in a real work setting. And finally, the experimental design (e.g., testing alternative lighting systems with all other environmental aspects remaining the same and random assignment of subjects to varying lighting conditions) provides greater confidence that the outcome variables were affected by the differences in lighting conditions and not by other experimental artifacts.

Experimental Setup

Nine groups of randomly assigned temporary office workers performed a wide variety of tests and tasks, typical of clerical and administrative office workers. Each group consisted of 30 to 36 people who worked eight hours in the laboratory. Two categories the tasks used in the NRC study (clerical tasks and verbal-intellectual tasks) form the basis of the productivity analysis presented in this paper.

The workers were tested at six identical work stations in a windowless room. The design and set up of the work stations is similar to those currently used throughout the Canadian government. The only variable in the physical set up was the lighting systems and, thus, the lighting conditions created by these different systems. Each of the nine groups of subjects worked under a different lighting system. The lighting systems varied by the fixture type, and by the lighting power density, measured in watts/M^2. The specific systems were selected by a team of lighting designers to represent three levels of quality and three levels of lighting power density. The systems included recessed troffers with prismatic lenses, recessed troffers with parabolic louvers, and indirect or direct/indirect systems. For each fixture type, three lighting power densities (LPD) were also tested: a common practice level at about 1.8 W/SF, a lower level at 1.2 W/SF and a very low level at about 0.8 W/SF. The fixtures with the highest LPDs used magnetic ballasts; the other two groups used electronic ballasts. The lighting systems with the lowest LPD also used two task lights per station, one linear fluorescent under counter fixture and one CFL swivel neck lamp. Color characteristics of the lamps (CRI and °K) were the same for all test conditions.

Clerical Tasks

Two representative clerical tasks were presented to participants: typing and proofreading. Both tasks were computer-based, and were presented in sessions in the morning and afternoon over the course of one day. In half of the sessions, the screen conditions were black text on a white background; in the other half, white text was on a blue background. (There was one additional typing session, using dark grey text on a light grey background, which is not considered here.) The typing and proofreading software recorded both the speed and accuracy of performance.

Verbal-Intellectual Tasks

Two types of verbal-intellectual performance were assessed, to capture more complex aspects of office work. Participants completed a reading comprehension test, reading text on paper and recording answers to multiple-choice questions on paper forms. The number of questions attempted, the number correct, and the percentage of correctly-answered attempts were measured. Creative writing was the other verbal-intellectual task. Participants wrote stories, typing them on the computer, based on their interpretation of ambiguous pictures printed on high-quality card. The number of characters typed, number of words, number of words per sentence, and the grade level of the composition, were outcomes used in the statistical analyses.

Findings

Veitch and Newsham conducted extensive statistical analyses of the data collected in this experiment (which included measures of mood, satisfaction, physical health, and other variables in addition to those described here). These analyses revealed many statistically significant effects of lighting conditions on performance and satisfaction. For example, people who worked under systems with electronic ballasts attempted more questions on a reading test, typed more in a creative writing task, and showed less visual fatigue at the end of the day, than people who worked under magnetic ballasts. The statistical tests tell us that the effects were likely to be real effects of lighting on behavior, and not chance fluctuations.

The relevant question for this paper is, "How large are these effects?" These effects are our best guide to estimates of the performance effects likely to follow lighting design upgrades in Federal office buildings. Veitch and Newsham found statistically-significant effects on the verbal-intellectual and clerical tasks for several different comparisons between various lighting systems. Overall, these effects ranged in size from 1% to 25% improvements in the group mean scores on various tasks, with the majority of effects falling in two clusters, around 4-6% and around 16-19%. (Veitch & Newsham 1998, Tables 5&6, 113-14) For the purposes of this benefits predictor, we have chosen the middle of this range, 9-13%, as the starting point for estimates of lighting system effects on overall office task performance.

Results

Projecting Productivity Impacts on the Federal Workforce

In order to calculate the potential impact of improved productivity in the Federal workforce using the data from the NRC study, we made a number of restrictions and assumptions. First, we focused on clerical workers because this was the focus of the NRC research. Second, we assumed that 80% of their workload would combine typing, proofreading, reading, and writing tasks. Third, we assumed that the overall effect of lighting conditions on performance of these tasks would fall in the middle of the observed range, R=.10. We also assumed that over the long term any gain in individual task productivity could be reduced by as much as 50% due to general organizational factors or other inefficiencies. Thus, the net probable long term improvement in clerical productivity from the most appropriate lighting condition was estimated to be 4% (.10*.80*.5=0.04).

These results can also be extrapolated to the general office work force, who engage in clerical-type computer tasks for part of the work day. Using the outcome results for specific tests discussed above, we can make predictions for general office workers. So, for example, if the average Federal office worker spent only an average of 45 minutes per day in computer related clerical type tasks (typing and proofreading) with an improvement of 11%, this could equate to a direct 1% increase in productivity. Or, if they spent an average of 60 minutes per day in intellectual tasks (reading and writing) and saw a 9% improvement, this would also equate to a direct 1% improvement overall. Both activities at these levels would equate to a 2% improvement.

Individual productivity can also be gauged in terms of additional work accomplished within the normal workday or work year, rather than fewer errors or performing tasks more quickly. A 1% increase in office worker productivity is equivalent to 5 minutes more of productive work per day, or, at the macro level, 20 hours of more productive work over the course of a year. This is well within the realm of influence of good lighting conditions that promote health, comfort, and good morale among workers. Thus, if an office worker takes shorter coffee breaks, has fewer headaches or less eye strain, can sustain focused thinking for a little longer, and/or has fewer sick days or trips to the doctor during the course of a year, a 1% increase in productive working hours is easily achievable.

Upper and Lower Bounds

Given the range of magnitudes of the effects observed for the various tasks categories (a low of 9% and a high of 17%), and given our lack of information about long term health and morale impacts, it is possible that the effects of high quality lighting may be even higher. For instance, researchers and lighting designers increasingly agree that lighting affects not only performance on specific tasks, but also workers' motivation and well-being. Although research in this area is just beginning, it is evident from a number of field studies that quality of work life is greatly influenced by lighting quality. (Collins et al. 1989; Heerwagen et al. 1996) Specific features of lighting that increase overall satisfaction include luminance of vertical surfaces in the field of view and the presence of some variability in lighting as one moves through an office environment. Light on vertical surfaces appears to influence the overall perception of brightness and, in particular, reduces the negative sensations of gloominess.

Thus, it is not inconceivable that the long term productivity impacts of high quality lighting systems may be closer to 2% if the lighting design takes into consideration not only the direct impacts on task performance, but also the potential impacts on satisfaction, morale, and quality of work life. Thus, we will define 2% as an upper bound of potential productivity impacts.

The lower bound will be the direct effects on only the limited clerical population directly related to the specific tasks, calculated above at 4%. A mid level, most probable range, is a 1% improvement for the overall office worker population.

Federal Office Buildings

Lighting efficiency in office buildings has been a major focus of the Federal initiative to reduce overall energy consumption. Lighting in Federal office buildings represents 7-9% of total Federal building energy use, but 12-14% of total Federal building energy costs.

While lighting energy use is a significant cost, and a significant target for savings, productivity effects are potentially far more significant. Total Federal office lighting energy use represents energy costs of about $170 million per year, while Federal office worker employee costs represent about $70 billion per year, or over 400 times more.

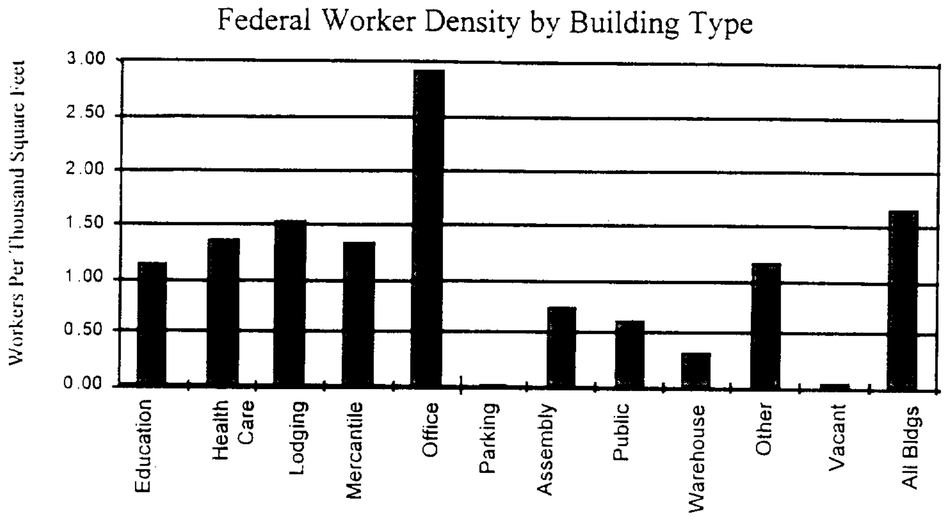

Figure 1. Worker Density in Federal Buildings

Figure 1 shows that Federal office buildings have almost twice the worker density of any other Federal building type. This means that the issues of productivity in relation to lighting energy use and lighting costs are significantly more important for office buildings than other Federal building types.

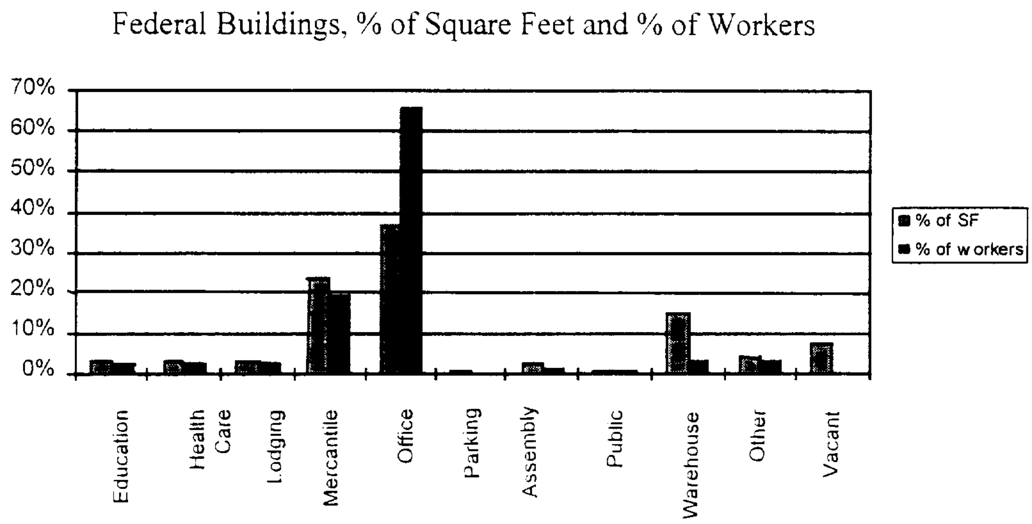

Figure 2. Federal Building Square Footage vs. Worker Population

Figure 2 shows similar information, but in a slightly different format. Here we see that while office buildings constitute a little over one third of the Federal building square footage, the employees who work in them represent fully two thirds of the Federal civilian workforce. The worker density in Federal office buildings (340SF/worker) is 2.3 times that of Federal buildings in general (800SF/worker). Because of the high density of workers in office buildings, the importance of labor costs is magnified for office buildings. Clearly, office worker productivity is a key issue for the Federal sector. If we were also to consider the government buildings run by state and local governments, with a 1,641 SF and 4,335 additional workers, we would quadruple the potential national impacts.

Buildings Included in Analysis

Figures for the density of workers in Federal office buildings and the average costs of electricity for those buildings are derived from the 1992 Commercial Buildings Energy Consumption Survey (CBECS), a national energy survey of buildings in the commercial sector conducted by the Energy Information Administration of the U.S. Department of Energy. E-CBECS, an electronic search engine created by Pacific Northwest National Laboratory for the CBECS data was used in this analysis.

The survey includes data from 44 Federal office buildings that were surveyed in detail to represent conditions for the 11,400 Federal office buildings, which encompass 437 million SF of office space. An additional 3% of Federal employees who work overseas are not included in our calculations.

For our analysis we assumed that not all Federal office buildings are candidates for lighting retrofits. There are about 437 million square feet of Federal office buildings built before 1992, of which 95% is lit with fluorescent fixtures. We don't have any figures on the percentage of Federal office buildings that have had recent efficient lighting retrofits, let alone those with appropriate high quality lighting retrofits. As a proxy, we used the square footage of Federal office buildings constructed before 1980 as the potential retrofit market for our analysis. Thus, we have excluded impacts from all office buildings built since 1980, and also the employees who work in those buildings.

Federal Salaries

The average Federal office worker earned $41,500 per year in 1995, and the average Federal clerical worker earned $22,500 per year. (US Bureau of Labor Statistics 1996) Of the Federal white collar work force (i.e. those employees most likely to work in office buildings): 28% is professional, 32% administrative, 22% technical, 16% clerical, and 3% is classified as other.

In addition to direct salary, each worker was also paid employee benefits that average 32% of their direct salary. Thus in calculating the value of the Federal workforce we have used these 1995 average salaries times a 1.32 benefit factor.

Costs per Square Foot

It is useful to think of the magnitude of various costs and savings in terms of dollars per square foot of building area. The average site electricity costs for Federal office buildings built before 1980 is $1.28/SF, at an average electricity rate of $.063/kWh. (E-CBECS 1994) (For Federal offices built between 1980 and 1992, the electricity use per building is considerably higher, resulting in higher costs of $1.55/SF.)

Lighting typically constitutes from 25-35% of the total site electricity usage for office buildings, which would equate for Federal buildings to $.32 to $.45/SF in lighting electricity costs per year on average. For an office building operating an equivalent of 55 hrs per week, or 2,860 hrs/yr, this equates to somewhere between 2.5 to 1.8 W/SF, a lighting power density believed to be typical for older Federal office buildings. A lighting retrofit that resulted in a reduction in lighting power density to 1.2 Watts/SF would thus produce energy savings on the order of $0.11-$0.23/SF/yr, or an average savings of $0.17/SF/yr.

A complete relighting project, such as installation of new parabolic fixtures along with 3-T8 lamps and electronic ballasts, might cost on the order of $2.00/SF, and save on the order of $0.20/SF in energy costs, for a simple payback period of 10 years. If, on the other hand, the relighting was seen to increase productivity by 1%, the additional labor savings could equal $1.60/SF, or 8 times more. The payback period for energy savings plus productivity savings is then 13 months.

The flip side of this logic is that if a lighting retrofit is done poorly such that it negatively influences productivity of the office workers, the cost of the decrease in productivity will swamp all energy savings. Careful attention to the quality of the relighting is critical; the overall design must take into consideration appropriate conditions for the type of work done in the office space. A poor lighting retrofit will do far more harm than good, while a high quality relighting can have enormous financial benefits.

The terms retrofit and relighting as they are used here are intended to convey two different approaches to lighting renovation, and the difference between them can be significant. The relighting example above includes the cost of new parabolic fixtures, which is often a cost not incurred in a typical retrofit. Retrofit indicates only a changeout of old components in an existing fixture layout. Performing a retrofit without consideration of the lighting design can be problematic because it assumes: 1) that the existing layout produced acceptable quality in the first place, and 2) that the optical performance and change to the lighted environment will be acceptable without a change to the layout. Unfortunately this is not always the case. Applying a broader economic view of human productivity costs viewed in context with energy savings and costs, it is likely that relighting (redesign) should be a much more common solution.

Future Escalations

It should be noted that with deregulation the cost of electricity is expected to go down in many areas, and rise in others, with an overall reduction of 10-15%, perhaps resulting in a Federal average of $.05/kWh. Thus, lighting energy savings are not expected to increase in value over time in the near horizon.

The cost of Federal salaries, on the other hand, has been rising at a steady pace of about 5% per year. Thus, the value of productivity savings is expected to steadily increase over time, by about 25% in 5 years or 60% in 10 years. Thus, a careful investment in high quality lighting that improves worker productivity is likely to be vastly more significant in the future.

Conclusion

The potential range of impacts from improved productivity due to lighting are presented below in Table 2. The low estimate accounts for potential impacts on lower paid clerical workers only, who are 16% of the Federal white collar workforce. Clerical improvements are assumed to be

4%. The medium estimate assumes a 1% improvement in productivity for the overall office workforce, and the high estimate assumes a 2% potential impact on all workers.

Table 1. Upper and Lower Bounds of Productivity Estimates

Productivity Impacts from High Quality Lighting	**Low Estimate**	**Medium Estimate**	**High Estimate**
Total potential budgetary impact, in $ /year	$220 million	$640 million	$1,300 million
Potential value in $/SF of office building.	$0.57/SF	$1.64/SF	$3.30/SF

These findings underscore the importance of harnessing both energy savings and non-energy benefits when making changes to a lighting system. It is also important to recognize that the results presented here are based on one study. Further research is needed to validate the potential productivity impacts. At the present time, researchers are working on similar studies that will provide additional data for productivity estimates.

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