Effect of efficient lighting on ergonomic aspects in modern IT offices

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ABSTRACT

This paper attempts to analyze the impact of the new trends in energy efficient lighting design practices on human comfort and productivity in the modern IT offices. This paper is based on the 15 months Joint Research Project on Ergonomic Evaluation of modern IT Offices, conducted by Tata Infotech Ltd. (TIL) and National Institute of Industrial Engineering (NITIE), India during year 2000-2001. This project also took inputs from the Energy Management program run by the primary author at the various offices of Tata Infotech in India during 1998-2001, for analyzing the impact of efficiency and ergonomics on one another.

BACKGROUND

Employee comfort and productivity are of utmost importance in the world of Information Technology. With the arrival of IT revolution, office work is being restructured to take advantages of a host of electronic machines designed to accelerate the flow of information, improve office efficiency and provide opportunities for more challenging responsibilities. The inherent flexible characteristics of modern office systems put more demand on the involvement of the aspect of human factors in lighting designs. Traditionally people believe that energy efficiency has to come with some kind of compromise of the comfort level. Thus a special focus was provided in the study to find impact of energy efficiency improvements on ergonomics.

For a typical lighting system the initial cost (installation cost) is hardly 10 % of the lifecycle cost of the system. Operating cost, (which mainly consists of the energy costs) account for more than 80 % of the lifecycle expenses. This makes a very strong case for using energy efficient lighting design practices to achieve better economics. Now consider the fact that for the IT Industry Operating costs or the infrastructure costs of the buildings and the electrical components (except the computers and the software) are less than 10% of the total costs. The maximum cost for any IT company is the people cost. Thus any improvements in productivity can result in far greater economic benefit for the company.

Considering the fact that productivity gains make much more economic sense, the impact of energy efficiency upgrades on ergonomic factors was a key consideration for the TIL-NITIE research project on modern office ergonomic evaluation.

OBJECTIVE OF THE RESEARCH

- To understand the occupational health and ergonomic problems of employees working in modern offices.
- To analyze the effect of energy management programs on these aspects.
- Develop intervention programs for a healthy, comfortable, productive office system.

The complete study was carried out for 12 month period during which various data was collected compiled and intervention programs were developed. Data collection for

the study was carried out in various offices of Tata Infotech in India.

The research methodical tools used for data collection were:

- Direct and indirect observation,
- Measurement and data collection,
- Interview and survey method with specially designed structured questionnaire and
- Physical / medical checkup.

LIGHTING DESIGN CONSIDERATIONS AFFECTING ERGONOMICS

Illumination is an art as well as a science. It should fulfill aesthetic, emotional as well as economic and functional requirements. Provision of a good and efficient illumination system calls for co-ordination between the architect, the consultant and the illumination engineer. The main objectives of any good lighting system are to provide adequate illumination with uniform light distribution all over the working plane, to provide light of suitable color and avoid glare and hard shadows as far as possible. Before the IT revolution, conventional office work included reading or writing documents on horizontal plane, but with the introduction of computers in modern offices, the lighting designer has to take into consideration lot more factors like glare, static and dynamic imbalance etc.

A well designed illumination system adds to the productivity of its occupant, creates a lively atmosphere and reduces fatigue. On the other hand, side effects directly related to improper lighting include rapid fatigue, lethargy, headaches, eyestrain, eye burn and overall visual impairment. Persons do find difficulty in 'dark adaptation' and the adaptation time may increase due to continuous working in bright light.

Factors important for efficient as well as ergonomic designing for indoor offices

Illumination level

For each type of work there is a range of brightness most suitable i.e. which causes minimum fatigue and gives maximum output in terms of quality and quantity. The degree of illumination necessary, depends upon the size of object and its distance from observer and the contrast between the color of the object and background. The human eye is adaptable to illumination levels from 20 lux to more than 1,00,000 lux. Hence, the quality of lighting is more important than just the illumination level.

The human eye is more sensitive to contrast and difference in illumination than to an absolute illumination level. A common misperception contributing to the proliferation of ineffective and inefficient lighting is that more light equals higher quality light. Illumination level requirements have evolved with the changes in workplaces and our knowledge of lighting fundamentals. Various national organizations such as Illumination Society of North America, Indian Standards Institute, have developed standards, which give the general requirements and recommendations for working interiors.

As the surroundings are different at different locations for the same working activity, the standards recommend a range of illumination level for each work area. Each range consists of three successive steps of the recommended service luminance. For normal working areas, the middle value of each range represents the recommended service luminance. For the areas where the working environment is below the average standard, higher value should be used and for the areas where the working environment is above the average standard, lower value can be used.

The standards also recommend that the values of illumination level be related to the visual requirements of the task to users' satisfaction, to practical experience and to the need of cost-effective use of energy. As far as the practical experience is concerned, the study survey carried out in Tata Infotech Ltd.'s Mumbai offices showed that the illumination level of 250-400 lux is satisfactory for computer offices. The survey carried out during the research project covered responses from 76 individuals in the office. Out of the 76 respondent 43 respondents believed that the illumination level was suitable to level requirement, where as 24 respondents believed that illumination level was slightly higher than the required value. After a further analysis it was observed that 83 % respondents in this category (20 individuals) were working in environment with illumination level higher than 400 lux.

Also from the point of view of cost effective use of energy the illumination level in the lower and middle values of each range given in the IS 3646 represents the recommended service luminance. This is a compromise between the illuminance necessary for reading working documents, which are frequently of poor quality and the most comfortable illuminance of operating terminals. A much higher illuminance will normally produce difficulties because of the difference in the luminance in the document and screen and a much lower illuminance may cause problems in reading documents.

Table 1. Recommended values of Illumination Levels (As per Indian Standard IS - 3646 I : 1992)

Sr. No.	Location	Illumination Level (Lux)
1	Computer work area	300 - 500 - 750
2	Classroom / Library (reading area / tables)	200 - 300 - 500
3	Entrance and Hallways	150 - 200 - 300
4	Bathrooms / Stairs	50 - 100 - 150

Fig 1. Subjective ratings by employees for brightness of the light

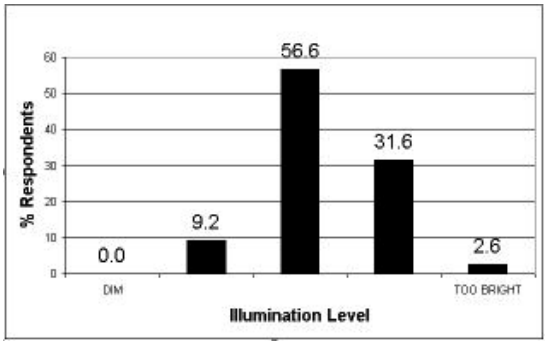
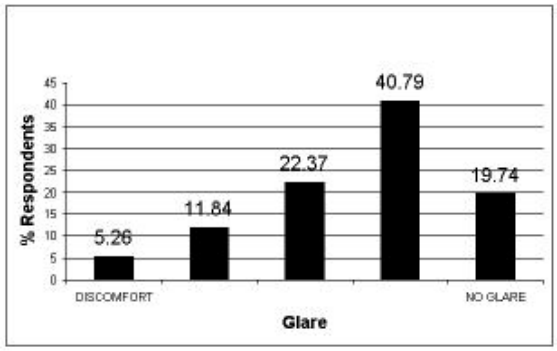


Fig 2. Subjective ratings by employees for direct glare from lights



Uniformity of Illumination

Lack of uniformity of illumination, makes the pupil of the eye adjust more frequently. This causes fatigue and productivity is reduced. Eyestrain and fatigue are caused when the eye is forced to adapt continually to different luminances. Therefore, it is important not only to provide the right level of light but also to ensure that light is evenly distributed across the task area. Balancing light levels also ensures that task lighting levels will be adequate throughout the space. Uniformity on vertical surfaces should also be maintained to avoid a gloomy, cave-like atmosphere.

As far as efficient designing practices are concerned, you can save as much as 50% on the number of lamps required by selecting a uniform lighting layout as compared to the aesthetically pleasing designs where lamps are placed in different geometric shapes. It is observed that these geometric designs result in very large variations in the illumination levels across the room & thus to ensure that the minimum illumination level doesn't fall below the required value, the designer needs to provide a design with higher average illumination level as compared to a design with uniform layout.

The modern trend in efficient designing practices is towards "localized lighting plus general lighting" and towards adaptation of "general lighting oriented towards the working plane". This strategy uses uniform lighting layout for providing the ambient illumination level to the minimum acceptable level and then task lighting using CFLs closer to the working environment for increasing the illumination level at the task to the required level. Common practice is also to provide the controls to the users so that user can operate the localized lighting as per specific requirements. This also helps in lowering the lighting power density.

Uniformity of illumination is required to create the right visual environment for rooms containing *Video Display Terminals*. Luminance relationships between screen and desk is very important and need to be controlled as the eye does not see absolute levels of illuminance, it sees differences in luminance. IS- 3646 recommend that, the ratio of illumination level between the task area and the background should be less than 3. Non-conformance to this may lead to 3 complaints:-

Glare: Glare is the most important quality factor. It is the high luminance reflection on the screen and results when luminance levels or the differences in luminance levels are too high. It may cause a reduction in the visual performance and adversely affect people's satisfaction with the display.

Static Imbalance: It occurs when luminances close to the line of sight vary widely. This may contribute to the sensation of discomfort glare.

Dynamic Imbalance: It occurs when there are very large differences in the luminances of objects viewed by the operator in continuation e.g. source document, monitor and keyboard. This may cause difficulties in seeing the text.

Apart from these lighting design factors, there are various lighting controls and control strategies available to professionals now, which can help them in achieving the optimum combination of efficiency as well as comfort.

The survey carried out revealed that out of the 76 respondents 46 respondents sufferend very little or no problem due to glare. Where as other 30 respondents experienced mild to sevier problem due to the glare from the light source. A detailed analysis showed that all the 46 individuals who experienced little or no glare problem were working in the office with Category II mirror optic foxtures with louvers where as 66% of the respondents who experienced the problem with glare were working in office with lighting fixtures using plastic diffuser.

Lighting System Control Strategies

Many office buildings are designed to have guards and maintenance staff switch on the lights very early in the morning and switch them off again very late at night. At the same time occupants don't have access to controls, most of the areas are over lighted and thus may consume up to 100% more energy than needed. Hence reducing the connected load of the lighting system represents only half of the potential for maximizing energy savings. The other half is minimizing the use of that load through automatic controls. Automatic controls switch or dim lighting based on time, occupancy, lighting-level strategies, or a combination of all three. In situations where lighting may be on longer than needed, left on in unoccupied areas, or used when sufficient daylight exists, you should consider install-

Fig 3. Savings achieved by use of controls by Lighting research Center

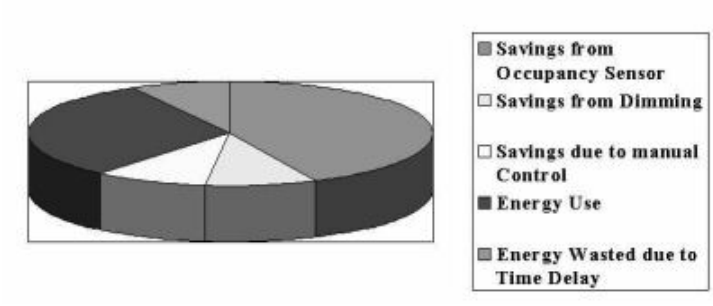


Fig 4 Occupancy pattern observed at TIL's Mumbai office

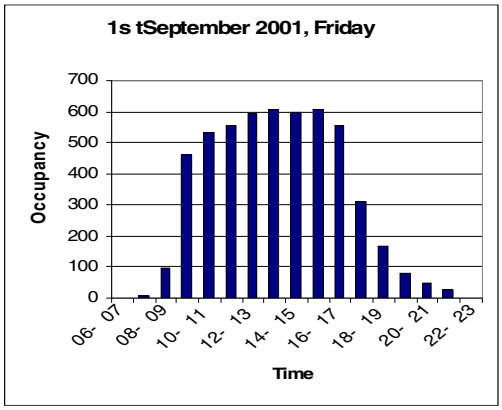
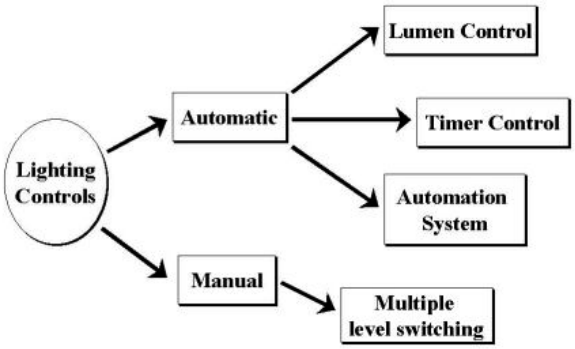


Fig. 5 Different types of Lighting Controls



ing automatic controls as a supplement or replacement for manual controls. Proper control of the lighting system is the key in optimizing energy demand of the system & also eliminating any occupant dissatisfaction. Various control strategies can be used to minimize the wastage of energy in offices with out or minimum interference with the day to day work of the occupants.

- *Scheduling:* This involves turning the lighting systems on or off according to need of program. Manual scheduling involves switching by occupants and automatic scheduling can be achieved by use of time switches, occupancy sensors, photo-sensors, temperature sensors and other automatic control devices.
- *Tuning:* This involves reducing power supplied to the electrical systems as per the requirement. For lighting, this involves use of dimming systems.
- *Zoning:* Control zones are defined depending on the existing wiring methods and occupancy pattern. Smaller the area of zone, the greater the potential for energy saving. Each zone contains at least one switch or other control device easily accessible to the occupant and can have a separate schedule for weekdays, weekends or special events.

Lighting Research Center at Rensselaer Polytechnic Institute, NY conducted an experiment in 1996-97 on 81 private offices to determine the impact of manual switching and dimming controls on occupant behavior and energy use. The results show that:

- 74% of the occupants dimmed their lights and preferred having dimmer at their workstation.
- Occupants often used their offices with the lights off
- Occupants did not change lighting levels as they changed tasks
- Occupants typically used window blinds to allow daylight to enter the offices

The findings also suggest that auto restore motion sensors and manual switching and dimming controls maximizes occupant satisfaction and minimizes the energy wastage up to 60% in private offices. The occupancy sensors can save up to 40% of electricity. Manual controls can further reduce the energy consumption by 10% to 15%, by providing opportunity for occupants to tailor lighting conditions to their individual needs and satisfaction. This may also increase productivity due to optimization of their work environment. Cost effective retrofitting consists of installing control devices and systems into an existing, occupied building, with little or no rewiring required to install the new controls in the existing space with minimum labor cost.

Various types of sensors are currently available for use in control systems. These controls offer a variety of operations that include automatic-on/automatic-off, manual-on/manual-off/automatic-off, 2-level-on/automatic-off, manual-on/ automatic-off/dimmer controls. Sensor economics depends upon occupancy pattern and tariff rates. Performance and reliability depends upon design of rooms, installer's experience, maintenance and compatibility with building components like ballasts and lamps. Occupancy loggers can be used to determine the occupancy pattern.

During the study conducted at Tata Infotech Ltd.'s SEEPZ office the occupancy pattern was determined with help of Attendance Monitoring Software package and finger scanning facility. The data was collected for a period of over 4 months. After analyzing the data it was observed that occupancy pattern remains more or less stable during the working days. The figure shows sample data for a typical working day. It was observed that with help of modern controls around 70% energy spent on lighting could be saved during the non-working hours (i.e. before 8:30 am and after 6:30 pm.) with out causing any discomfort to the occupants.

Time-Based Controls: The most basic controlling strategies involve time-based controls, best suited for spaces where lighting needs are predictable and predetermined. Time-based controls can be used in both indoor and outdoor situations. Common outdoor applications include automatically switching parking lot or security lighting based on the sunset and sunrise times. Typical indoor situations include switching lighting in a production, manufacturing and retail facilities that operate on fixed, predefined operating schedules. Time-based control systems for indoor lighting typically include a manual override option for situations when lighting is needed beyond the scheduled period. Simple equipment, such as mechanical and electronic time clocks and electro-mechanical and electronic photocells, can be independent or part of a larger centralized energy management system. For corporate offices, where the occupancy pattern is some what fixed, we can go for time clock based controls or manual controls. In such offices good amount of savings can be achieved by incorporating well-planned schedules.

Occupancy based Controls: Occupancy sensors can be used for minimizing the energy wasted in un occupied or partially occupied areas with out compromising occupant satisfaction. Occupancy sensors are basically motion detectors, which react to variables like heat and/or sound by turning equipment on or off. Occupancy sensors should first be selected based on the range of body motion expected to occur throughout the entire lighted space. Controls for hallways, for example, need only be sensitive to a person walking down a narrow area, while sensors for offices need to detect smaller upper body motion, such as typing or reaching for a telephone. These can further divided in 3 types: Passive Infrared Sensors, Ultrasonic Sensors and Hybrid Sensors.

All sensors have an adjustable time delay to prevent the lights from switching off when the space is occupied but there is little activity. Some infrared and all ultrasonic sensors also have an adjustable sensitivity setting. Customization of these settings and careful commissioning at installation is necessary to balance energy savings with occupant satisfaction. To achieve cost-effective, user-friendly occupancy sensor installations careful planning of their position, time delay and sensitivity is necessary. Ultrasonic sensors, for example will respond to strong air movement and need to be located away from ventilation diffusers and Infrared sensors should have their line of sight checked to ensure that it is not blocked by room furnishings.

Day-lighting

Sunlight is available in abundance and is free of cost. Economics, esthetics and health, all these factors favor the practical use of day lighting. Thus a good day-lighting design offers a big energy saving potential and has a positive impact on the occupant satisfaction. The use of advanced day-lighting technologies, such as light guides and improved windows, may increase the amount of daylight available inside buildings.

Use of natural light should be promoted as far as possible. The effective day-lighting strategies call for optimized building orientation and form, optimized window size and placement, a light switch, maybe a light shelf. Perimeter day-lighting systems, such as windows, bring daylight about 15 feet into a building. Core day-lighting techniques bring daylight deeper into a building. Also artificial light is not required in staircases during daytime.

In most of the offices of Tata Infotech, it was observed that by opening the window blinds by just 10°-20°, the illumination level was raised by 100-150 lux depending on the building orientation as well as time of the day. Also the concerned employees had no problems of glare. Alternatively instead of using blinders to block the sunlight, use of vertical louver drapes made up of translucent materials should be promoted. This will allow maximum utilization of daylight without causing glare.

Various case studies are available in the international business where organizations have utilized day lighting. Dr. Joseph Romm has included various examples in his book 'Cool Companies – How the best businesses boost profits and productivity by cutting green house gases'. His research suggests while an energy efficient building upgrade that cuts energy use in half can save $1 per square foot in annual energy costs, it can generate more than $10 a square foot in new profits every year if it boosts productivity even 5%. The book examines more than a dozen office and building designs that have boosted productivity from 5 to 15%.

- VeriFone, has achieved 60% energy savings by using day lighting and advanced control systems, while gaining more than 5% in productivity and a drop in absenteeism of 45%.
- A Georgia carpet manufacturer recorded a drop in worker's compensation cases from 20 per year to under one per year after moving into an extensively daylit building.

Daylight controls use photo-sensors to send a signal to main dimming module, which controls the power supplied to luminaires in control zone either by solid-state device or by autotransformer dimming. Illumination level-based strategies take advantage of any available daylight and supply only the necessary amount of electric light to provide target lighting levels. In addition to saving energy, lighting level controls can minimize the unnecessary lighting and glare and help reduce electricity demand charges. The two main strategies for controlling perimeter fixtures in day lighted areas are daylight switching or daylight dimming.

Daylight switching involves switching fixtures off when the target lighting levels can be achieved by utilizing daylight. To avoid frequent cycling of the lamps and to minimize distraction to occupants, a time delay, provided by a dead band, is necessary. Several levels of switching are commonly used to provide for flexibility and a smooth transition between natural and electric lighting.

Daylight dimming involves continuously varying the electric lighting level to maintain a constant target level of illumination. Dimming systems save energy by dimming fluorescent lights down to as low as 10 to 20% of full out-

put, with the added benefit of maintaining consistent lighting levels. Because HID sources cannot be frequently switched on and off, they are instead dimmed for time, occupancy and lighting level-based control strategies.

CONCLUSION

Usually any efforts taken towards improving energy efficiency are looked by people as the cost cutting measures adopted by the management and people assume that since the focus of the activity is on cost cutting, it is going to result in reduced comfort levels for most of the employees. Contrary to this common belief; various case studies available all over the world prove that both these aspects can go hand in hand. For this a proper effort in designing the offices is required, which requires not only the knowledge of the latest trends in efficient design practices, but also the human factors associated with lighting designs. There are no standard solutions available, which can be implemented blindly across the offices. The designer needs to study the requirements of the individual work place, the requirements of the user before arriving at the right techniques for minimizing the energy bills. This is not a very easy job, but not too difficult either. Designers need to learn to achieve this balance if energy efficiency has to become part and parcel of our lifestyle.

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