Research Into Office Illumination Levels Within

The Orville L. Freeman Office Building

St. Paul, Minnesota

by

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A Research Paper
Submitted in Partial Fulfillment of the
Requirements for the
Master of Science Degree
in

Risk Control

Approved: 3 Semester Credits

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December, 2010

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Title: ***Research Into Occupational Office Illumination Levels Within The Orville L. Freeman Building, St. Paul, Minnesota***

Graduate Degree/ Major: MS Risk Control

Research Adviser: **Brian J. Finder, D.I.T.**

Month/Year: **December, 2010**

Number of Pages: **61**

Style Manual Used: **American Psychological Association, 5th edition**

ABSTRACT

The objective of this study is to analyze overhead lighting standards and practices in relation to the currently designed system within the Orville L. Freeman State Office Building located in St. Paul, Minnesota. The significance of the light study is to examine illumination levels at employee work surfaces by identifing and compare them to established standards for the purpose of minimizing eye strain and loss of productivity. The methodology used in this study was to identify relevant standards, foot candle levels, work surface heights and Visual Display Terminal (VDT) viewing distances commonly encountered by employees working in an open office cubical setting. The illumination measurements obtained from sampling were then evaluated and compared to relevant standards and the architectural lighting design plan.

The major findings of this study indicated an overall deficiency of the installed lighting system to meet the architectural design plan and relevant standards.

The research presented in this study adds to the body of knowledge for improvement of ergonomic light design within office settings for future building projects both publicly and private.

ACKNOWLEDGMENTS

A sincere thank you is extended to the Minnesota Department of Health for providing the opportunity to assist with their office task lighting assessment. Additionally, I would like to thank my family and colleagues for their patience, encouragement and suggestions throughout the research process.

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Chapter I: Introduction

Introduction

With the emergence of computer technology, work place lighting has significantly changed over the past 50 years. Visual Display Terminals (VDT's) are now the predominant media that people utilize to process data. In today's workplace, electronic documents are likely viewed as a more effective method of communication verse traditional paper publications. Probably more now than throughout history, workers are tasked with reading both hardcopy and electronic publications and are thus potentially becoming susceptible to eyestrain and fatigue if work areas are poorly illuminated. To put this in perspective, office furniture manufacturer, Herman Miller, estimated the computer terminal to staff ratio in the early 1970's as being approximately 1:30, and by 1990, expected it to be 1:5, climbing even higher into the future (Herman Miller, 2001).

Paper documents are traditionally viewed on horizontal surfaces such as desks while electronic data is displayed through alternative media liquid crystal display (LCD), light emitting diode (LED) or cathode ray tube (CRT) monitors. According to Kohn (1988), both types of media require different lighting levels for healthy ergonomic viewing. Paper documents require task specific lighting to supplement horizontal viewing while electronic data is displayed through media having its own source of illumination (as cited in Herman Miller, 2001).

Document distance, font type and poor illumination are thought to be the main causes of eye strain in the workplace, which can lead to fatigue, lost time and diminished productivity (Herman Miller, 2001). In a lighting study entitled "Video Display Units and Visual Function," author's Rosner and Belkin (1989), state, "document viewing distances and poor illumination contribute to work place eyestrain," (p. 519). Rosner and Belkin (1989) further state, "the distance between documents within a VDT workstation may result in a worker's eye having to shift in and out of focus up to 33,000 times per day, between three different visual objects: the screen, keyboard and document. Over time, the shifting focus of the eye overworks ocular muscles creating eyestrain and fatigue, which in turn may lead to lost productivity and occupational injury," (p. 519). As a result, it appears poor work place illumination can directly affect employee health and productivity, potentially leading to increased organizational costs.

With today's soaring operating costs, organizations are driven to conserve resources more than ever before. As a result of increased energy costs and public motivation, organizations are being driven towards more efficient lighting systems in new building design and construction. Conservative cost reductions, often labeled as energy incentive strategies, can be misleading by focusing on energy savings per square foot rather than an employee's dynamic interaction within the work place (Herman Miller, 2001).

In an attempt to reduce operating costs, single source illumination systems are often preferred, yet when used alone, they potentially affect quality and productivity brought on by worker eyestrain and fatigue (Weston, 1945). Additionally, inadequate work place illumination can result in more frequent employee accident rates leading to increased workers compensation costs, both having the capacity to outweigh any perceived energy savings (Cakir, 1991).

The Orville L. Freeman Office Building, located at 625 Robert Street North in St. Paul, Minnesota, operates with a semi-ambient, overhead lighting system as the single source of work place illumination. Initial employee occupancy occurred throughout the Freeman Building between 2005 and 2006. Within the initial occupancy period, over 120 complaints were received regarding work surface illumination, thus indicating the need for further investigation. A workplace illumination survey conducted in 2006 confirmed low light levels as the root cause of employee complaints and eventually lead to this analysis. Consequently, the semi-ambient overhead lighting system as a single source of illumination within the Orville L. Freeman Office Building is potentially causing employee occupational eyestrain and other forms of lost productivity.

Purpose of the Study

The purpose of this study is to measure, analyze and compare work surface illumination levels within the Orville L. Freeman Office Building to recognized standards for determining if the addition of office task lighting would be a cost effective strategy.

Goals of the Study

The Objectives of this study are to:

1. Identify typical lighting standards used for office buildings.
2. Through random sampling, identify typical work surface illumination levels within the Orville L. Freeman Building whose only source is the semi-ambient, overhead lighting system.
3. Identify work surfaces within the Orville L. Freeman Building requiring task lighting.

Background and Significance

As costs rise in the future, it is likely that organizations will be driven by stakeholders to reduce operating expenses. As a result of increased operational costs and public motivation, organizations will probably demand more energy efficient systems in new building design and construction.

In a large office complex, lighting is an area offering substantial savings through the installation of modern and efficient systems. Building owners and architects most likely work with utility companies to accomplish operating cost reductions through energy incentive plans. Under this type of a plan, cash incentives are offered by local utility companies to participating property owners for installing the most modern and efficient building operating systems.

Often in the pursuit of these savings, established health and safety standards are inadvertently pushed to the limit, overlooked or simply not met. Problems often result when minimum health and safety standards are overlooked in the selection of energy efficient systems. From an occupational health and safety perspective, inadequate lighting systems affect the workplace environment eventually leading to decreased productivity and quality brought on by ergonomic discomfort. As operational costs increase, existing health standards will likely be challenged and redefined to better meet the needs of energy conservation goals. While the practice of proving a health standard's current validity is necessary in relation to emerging technology, inherent risks are associated with being eager to cut costs.

Limitations of the Study

1. This study is limited to office illumination standards pertaining to the Minnesota Occupational Safety and Health Act (MNOSHA) and the American National Standards Institute (ANSI), A132.1-1973, *Practice for Office Lighting, RP-1-04*, sponsored by the Illumination Engineering Society of North America (IESNA).
2. This study is also limited to illumination levels measured within the Orville L. Freeman Building office areas located at 625 Robert Street North, St. Paul, Minnesota, 55155.

3. This study is additionally limited by the lack of available data reported from studies on comparable sized groups.

Assumptions of the Study

It is assumed all lighting standards and recommended illumination levels found within Minnesota State Statutes and ANSI represent current best practices.

It is also assumed that the Freeman Building's 2nd floor, open office area c, represents typical office lighting found throughout the building's work place environment. Therefore this study assumes that the office lighting measurements taken in this study will typically represent office area illumination levels found throughout the remainder of the Freeman Building and as result will benefit from the conclusions and recommendations of this study.

Definition of Terms

Accent Lighting: "Directional lighting to emphasize a particular object or draw attention to a part of the field of view," (ANSI, 2004, p. 37).

Ambient lighting: "Primary lighting throughout an area that provides general illumination. Ambient lighting can be provided through a direct, an indirect, or a direct-indirect (semi-ambient) lighting system. One of the three critical components of a lighting system." (Steelcase, 2006, p. 14).

Candela (cd): "(formerly candle) the unit of luminous intensity," (ANSI, 2004, p. 37).

Foot candle: One footcandle is the illumination produced by one lumen uniformly distributed over one square foot of a surface, or conversely this is the illumination at the point of a surface which is one foot from, and perpendicular to, a uniform point source of one candela. So, footcandles incident on a surface = Lumens/Area (sq.feet). (Dubinovskiy).

Illumination: "The density of luminous flux on a surface. This parameter shows how "bright" the surface point appears to the human eye. The appropriate units of measure are *Footcandle* and *Lux*. Lux is used in the International System. Both have a similar objective, but meters are used for Lux and feet are used for Candelas. Therefore, one lux = 0.0929 footcandles or approximately, 1 Fc=10 Lux. (Dubinovskiy).

Lumen, (lm): "The unit of luminous flux." (ANSI, 2004, p. 39)

Luminaire: "A complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps, and to connect the lamps to the power supply." (ANSI, 2004, p. 39)

Luminous intensity: Luminous intensity (or candlepower) is the light density within a very small solid angle, in a specified direction. In other words, this is the total number of lumens from a surface emitted in a given direction. The unit of measure is candela. In modern standards, the candela is the basic of all measurements of light and all other units are derived from it. Candlepower measurements are often taken at various angles around the source and the results plotted to give a candlepower distribution curve. Such a curve shows luminous intensity (how "bright" the source seems) in any direction. (Dubinovskiy).

Lux, (lx): "The International System (SI) unit of illumination." (ANSI, 2004, p. 39)

Task light: "Lighting directed to a specific surface or area that provides illumination for specific tasks. One of the three critical components of a complete lighting system." (Steelcase, 2006, p. 15).

Visual Display Terminal (VDT): i.e. computer monitor, screen, liquid crystal display (LCD). Device displaying data images and pictures electronically (Hedge, 2003).

Wavelength: The distance between two corresponding points of a given wave. Wavelengths of light are measured in nanometers (1 nanometer = 1 billionth of a meter, or 1 X 10^{-9} m) (Rensselaer Polytechnic Institute, 2006).

Chapter II: Literature Review

Introduction

The purpose of this study is to analyze office lighting within the Orville L. Freeman Office Building, which potentially is causing occupational eyestrain to employees and lost productivity. Chapter II is a review of literature related to ergonomic work surface illumination and is subdivided into the following categories:

1. History and overview of lighting
2. Lighting ergonomics
3. Technical standards related to work place illumination
4. Types of indoor lighting systems
5. Work surface illumination through multiple lighting systems
6. Instrumentation for measuring work place lighting

History and overview of lighting

Approximately 4.5 billion years ago, a cloud of dust and gas contracted to form the sun, this solar system's first form of illumination. Since the beginning of man approximately 1 million years ago, the environment has been illuminated using everything from ancient fire to modern electricity (Williams, 2005). Author Bill Williams, in the article entitled "A History of Light and Lighting," suggests the following timeline regarding the evolution of lighting:

- 400,000 BC - Fire, flame and torch was used by prehistoric man
- 400 AD - Candles were allegedly invented and would be the main source of illumination other than sunlight until the 1600's.
- 1814 AD – Gas lighting
- 1878 AD - Edison light company was incorporated giving birth to the electric light bulb.

- 1930's AD – Fluorescent light bulb.
- 1994 AD – Sulfur lamp (Williams, 2005)

On December 21, 1905, a group of 25 businessmen with an interest in lighting standards met at The Hotel Astor in Times Square, New York, for the purpose of forming a society focused on light and its distribution. The Illumination Engineering Society of North America (IESNA) was consequently established and held its first official meeting on January 10th, 1906, at the Hotel Astor in New York City (Hibben, 1956). For over 100 years, the Illuminating Engineering Society of North America (IESNA) has been the recognized technical authority on illumination and serves as a forum to guide professionals and lay persons via consensus-based lighting standards (IES Profile, 2006). As lighting systems improved over the past 200 years, a correlation between illumination levels and work quality evolved. Scientific studies originally designed to identify optimum illumination levels for productivity during the early 1900's, eventually lead to the development of health and ergonomic standards for work place tasks after World War II (Weston, 1945).

Several standards now exist for work place illumination. The most notable of these include:

- The Illumination Engineering Society of North America (IESNA)
- The American National Standards Institute (ANSI)
- The Occupational Health and Safety Administration (OSHA)
- The American Optometric Association (AOA)

In conjunction with these nationally recognized standards, many state and local government organizations appear to have adopted similar illumination guidelines for the working environment (Herman Miller, 2005).

Lighting ergonomics

The ergonomics of lighting is primarily concerned with human eye interaction, which constantly adjusts in response to our ever-changing environment. Comprised of two biological functions, the eye has both a physiological and a nervous system. The physiological system of the eye is concerned with the healthy functioning of blood flow, tissue and cellular conditions. The nervous system within the eye is primarily focused on sensory information pertinent to perception, coordinated movement and visual signals (Herman Miller, 2004).

Vision-related problems created by too much light or lack of it, could affect both of the eye's biological systems. Reduced eye flexibility, medically termed *presbyopia*, is a chronic physiological eye condition that increases with age, eventually requiring prescription glasses and the need for increased lighting. An example may be an older person who puts on a pair of glasses prior to reading their daily newspaper under a desk lamp. The medical term *Asthenopia*, or more commonly called eyestrain and fatigue, is an acute eye condition primarily caused from overworking sensory functions when attempting to focus within low light or extremely bright conditions. Asthenopia may also result in blurred vision, ocular spasms or headaches. A good example is the squinting affect automatically induced when attempting to look directly at the sun or when viewing objects that are shadowed for prolonged periods of time. Eyestrain and fatigue may also result in secondary physiological effects such as dryness, light sensitivity/tissue damage, and neck/back aches. Therefore, illumination levels are an important ergonomic factor in determining healthy eye function (Herman Miller, 2004).

Additionally, mood, motivation and sleep cycles, often called circadian rhythms, are thought to be directly influenced by changing environmental light levels. Circadian rhythms are defined as physical, mental and behavioral changes related to a 24 hour cycle and driven by human's internal biological clocks at the molecular level (National Institute of Health, 2010). Seasonal Affective Disorder (SAD) is a type of depression caused by a disruption to these circadian rhythms, which are directly influenced by changing light levels. Light therapy is now a suggested method for alleviating depression, changing moods and increasing motivation (Steelcase, 1999).

Some of the first studies originally designed to correlate worker productivity with task illumination levels came from IESNA members. Studies such as "The Relation Between Illumination and Visual Efficiency - The Effect of Brightness Contrast," published by H.C. Weston and other IESNA members, inadvertently provided data for identifying ergonomic lighting standards after World War II. Over the years since, poorly illuminated work areas have been identified as one of the causes for employee eyestrain and fatigue with the potential effects being personal injury and/or lost productivity (Weston, 1945).

Personal injury from poor work surface illumination often occurs in the form of musculoskeletal disorders resulting from eyestrain. Repetitive motions while in static or awkward postures primarily cause musculoskeletal disorders. In the work environment, musculoskeletal disorders may occur while an individual is bending closer and straining to complete a poorly illuminated task. Leaning or peering towards the work surface to get a clearer view may lead to back and neck-related injuries, which ultimately have the potential to increase an organization's worker compensation costs (ANSI RP-1-04, 2004).

Lost productivity may occur as a result of eyestrain created from inadequate work surface illumination, with the primary contributing factors appearing to be eye irritation, fatigue and focusing. Some of the irritation symptoms may include red, teary, sore and scratchy eyes. Fatigue usually is indicated by tired, aching and heavy eyelid sensations. Difficulty focusing is often identified by blurriness accompanied with poor depth perception (Rosner & Bilken, 1989). Recent studies have also attempted to quantify the dollar cost of poor illumination by correlating employee irritation and discomfort with lost productivity. In the Cornell University Study performed between 1989 and 1990 at a Xerox facility in upstate New York, 24 percent of workers experienced lost time of up to fifteen minutes per day due to inadequate illumination. Another study performed in 1986 at the Reno Nevada Post Office, replaced existing direct lighting with an indirect system resulting in saved energy costs and a six percent increase in employee productivity, which paid for the upgrade within a year (Steelcase, 1999). Both studies suggest that the type of lighting systems and levels utilized in the workplace can greatly influence the occurrence of personal injury and lost productivity.

Standards related to work place illumination

Several national organizations were researched to provide an overview of recognized illumination standards in reference to workplace light levels. All of these organizations are considered credible even though they may differ in their recommendations and are listed as follows:

- The American National Standards Institute - ANSI
- The Illumination Engineering Society of North America - IESNA
- The Occupational Health and Safety Administration - OSHA
- The American Optometric Association (AOA)

The American National Standards Institute (ANSI) adopts recommendations for work place illumination levels in conjunction with the IESNA Office lighting committee. The American National Standards Practice for Office Lighting, ANSI RP-1-04, recommends the most current work place illumination levels to date. Current IESNA and ANSI standards recommend work place illumination levels be designed specifically toward the task performed. Some of these considerations include:

- The task itself
- Task duration
- Task difficulty

ANSI Standards are derived from a culmination of scientific research and recommendations from contributing technical organizations along with participating member committees. ANSI's main goal is the development of consensus based, task-specific work place standards for use within all industry types. In regard to work place lighting standards, ANSI recommends overhead illumination for VDT work minimally meet 3 footcandles (fc) while more complex paper reading requires up to 50 fc. In general, IESNA/ANSI recommends no more than a 3:1 luminance ratio between paper tasks and adjacent VDT screens (ANSI, RP-1-04, 2004). Luminance can be described as "the amount of light reflected or emitted from a surface while 'illuminance' is the opposite and described as the amount of light striking a surface, although both are measured in candles per square foot (footcandles, fc) " (Gordon, 1987, p. 106). The 3:1 contrast ratio suggested by ANSI indicates the adjacent surface where the paper is being viewed to be illuminated three times that of the level directly over the VDT screen. "Contrast is measured as a ratio of the luminance of an object to the luminance of adjacent objects or background" (Gordon, 1987, p.106). Therefore, based upon the minimum VDT illuminance level of 3 fc's suggested by ANSI, the adjacent work surface minimum recommendation will be 9 fc's.

The Occupational Health and Safety Administration (OSHA), Safety and Health Regulations for Construction, part 1926, Subpart D, are concerned with workplace illumination levels. Under the section of "Occupational Health and Environmental Controls," OSHA standard

1926.56 lists recommended work place illumination levels in Table D-3 entitled, "Minimum Illumination Intensities in Foot-Candles (fc)." OSHA goes on to specifically state: "General. Construction areas, ramps, runways, corridors, offices, shops, and storage areas shall be lighted to not less than the minimum illumination intensities listed in Table D-3 while any work is in progress." OSHA more specifically specifies the minimum illumination for office areas to be "not less than" 30 fc's (OSHA, 2006, p. 2).

As a general rule (OSHA) states the following guidelines for office illumination levels:

> "Generally, for paper tasks and offices with CRT displays, office lighting should range between 20 to 50 foot-candles. If LCD monitors are in use, higher levels of light are usually needed for the same viewing tasks (up to 73 foot-candles) (OSHA, 2006, p. 2)."

The American Optometric Association (AOA) in a study entitled "Light, Vision and Aging," suggests workers over 50 years of age require twice the light levels of young adults for comfortable work (*Werner et al, 1990*). While the AOA doesn't specifically recommend minimum illumination levels, under their concept of aging, they could fluctuate more than the ANSI and OSHA recommended minimums. Office supply manufacturer Herman Miller, in a technology report entitled "Lighting in the workplace, vision and aging," also suggests office lighting be increased proportionally to a worker's age, which further supports the AOA's and Werner et al's findings (Herman Miller, 2001). A 1977 study conducted by Mary Cristarella for the "American Journal of Occupational Therapy," suggests as people age their eyes become rigid, resulting in more effort to focus at close range along with an increased need for lighting as compared to younger individuals (Cristarella, 1977). In a recent study conducted by office supply manufacturer Steelcase, 47 percent out of 1008 employees surveyed ranked eyestrain as the most serious health hazard in the office environment over other cumulative trauma disorders.

In addition, 92 percent felt adequate lighting was a significant factor for workplace health and productivity (Steelcase, Inc. 1991). As these studies suggest, the minimum illumination levels recommended by ANSI, IESNA and OSHA standards for office work and VDT usage may be higher depending upon the work force age.

The most specific guidelines pertaining to office illumination levels for the Orville L. Freeman building are concerned with Minnesota state standards. When building lighting systems are designed, not only do they have to meet or exceed national standards like ANSI & OSHA, but also state building guidelines. The State of Minnesota standards applicable to the Freeman Building include the following:

- Minnesota OSHA (MNOSHA)
- The Minnesota Department Of Employee Relations (DOER)
- The Minnesota State Employees Union, AFSCME, Council No. 5 Contractual Agreements

Minnesota OSHA (MNOSHA) under State Rule 5205.0120 (App. C, p. 47-49) recommends a 50 fc minimum illumination level at the work surface. In comparison, this exceeds the ANSI and OSHA required minimums by 20 fc's. MNOSHA also recommends the following for supplemental task lighting: "Add task lighting without creating glare and reflection on the VDT screen" (MNOSHA, 2005, p. 1). This suggests there is a potential need for increased illumination, although it does not specify why.

The Minnesota Department of Employee Relations (DOER) (App. B, p. 45-46) is the primary worker's compensation insurer for State employees. DOER makes recommendations for workplace illumination in an effort to reduce eyestrain and potentially related injuries. They also enter into contractual agreements with employee-unionized organizations such as The Minnesota State Employees Union, AFSCME (App. A, p. 43-44) to make certain guidelines for employee safety are legally met. DOER recommends 20 –50 fc's in computer office areas with additional task lighting for non-computer related tasks. Consequently it is no surprise The Minnesota State Employees Union, AFSCME, Council No. 5, recommends 20 –50 fc's for office illumination similar to DOER's guidelines (DOER, 2005).

Types of indoor office lighting systems

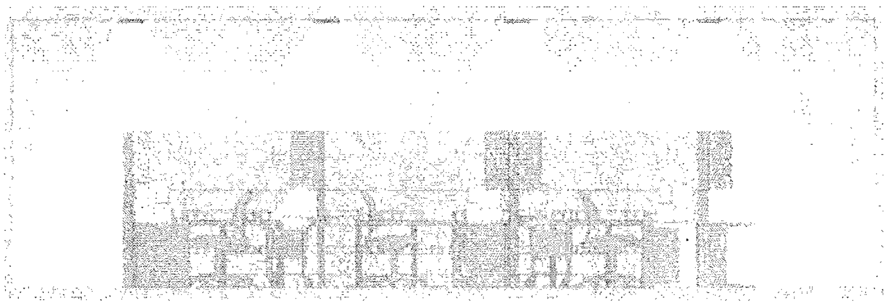
There are several types of indoor lighting systems which are available for the workplace. The following types are often suggested and installed for the work environment:

- Natural light
- Direct ambient
- Ambient
- Semi-ambient
- Task lighting
- Accent lighting

Natural light is provided by drawing sunlight into a work area through windows. The advantage of using natural light is the decreased dependence upon artificial sources resulting in monetary savings. The disadvantage of natural light is the unpredictable environmental changes produced by the weather. Day light illuminates surfaces both vertically and horizontally to provide the contours and textures responsible for the characterization of the environment. Research which has been performed on circadian rhythms and the human endocrine system indicate daylight entering through the eyes greatly influences our biological processes, moods and overall well-being (Herman Miller, 2001).

Direct ambient lighting is recessed in a ceiling and directly angled downward. This type of lighting is characteristic of fluorescent lamps where the luminaries (bulbs) directly face the employee and illuminate the general working area. Direct ambient lighting offers a consistent pattern, color and downward direction and is commonly found throughout the work place. A disadvantage of direct ambient lighting is that the direct angle of illumination often produces work surface glare and shadows (Steelcase, 1991). Figure 1 is an example of direct ambient lighting.

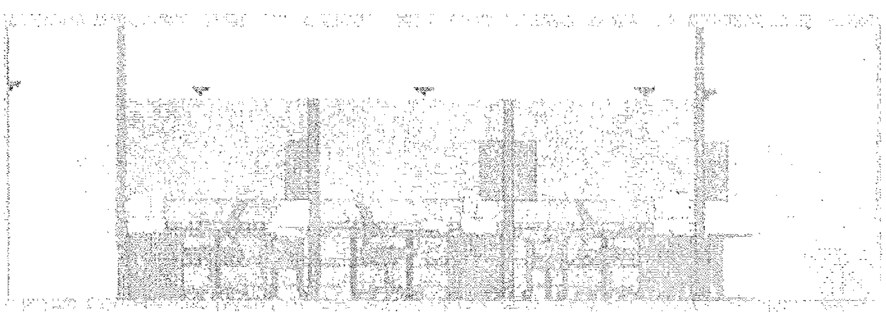
Figure 1, Direct Ambient Lighting



Steelcase, 1991.

Indirect ambient lighting fixtures are suspended from a ceiling and angled towards it to reflect light throughout the work environment. Indirect ambient light is intended to generally fill an area without direct intensity and is best suited for creating a softer feel within the work environment. Indirect lighting is best suited for use as a supplement to direct lighting sytems for the purpose of shadow reduction yet ultimately is more appropriate where detailed tasks do not occur, such as in office, conference or reception areas (Steelcase, 1991). Figure 2 represents a typical example of indirect ambient lighting.

Figure 2, Indirect Ambient Lighting

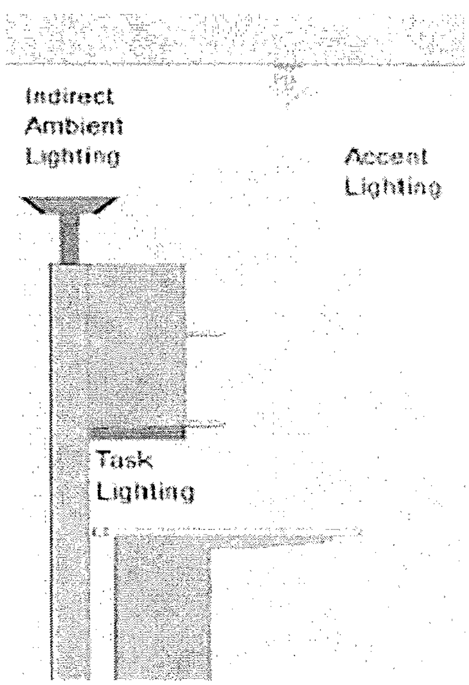


Steelcase, 1991.

Semi-ambient lighting reflects the majority of light towards the ceiling from the fixture yet allows a certain percentage to diffuse directly downward. Semi-ambient lighting is a combination of both direct and indirect lighting and offers an advantage over multiple systems with its single source of operation and for illuminating a broad range of work place tasks for minimal cost. The disadvantage of semi-ambient lighting is that it may not provide enough illumination for some work place tasks, often requiring the addition of task specific lights (Steelcase, 1991).

Task lighting is designed to supplement or illuminate a specific work surface and are typically mounted vertically above a desired area such as on an adjacent wall or underneath an overhead cabinet. Task lighting offers workers more control by being able focus increased illumination on a desired task while minimizing its effect on the surrounding environment. Potential drawbacks of task lighting appear to be in identifying where they are most needed along with increased installation and operational costs (Steelcase, 1991). An example of task light illumination is shown in Figure 3.

Figure 3, Indirect Ambient, Accent and Task Lighting



Steelcase, 1991.

Accent lighting is primarily used for illuminating non-essential areas where ambient and task lights don't provide enough light. Accent lighting is mainly utilized for decorative purposes to alter the feel or mood in a room by illuminating specific objects and/or areas. Illumination of art work in a gallery is a good example of how accent lighting is best utilized. The drawbacks of accent lighting are in identifying areas for installation along with increased energy/operational costs (Steelcase, 1991).

As a rule, ambient lighting is more concerned with illuminating vertical spaces while task specific lighting focuses more on a horizontal surface or area (ANSI, RP-1, 1973). While the many different types or combination of lighting systems are very important aspects of illumination, environmental surroundings such as color and surface finish significantly can influence the visual work environment. Brighter colors are more reflective while darker tones tend to absorb light. Additionally high gloss surfaces reflect light, (i.e., produce glare) more readily than matte or dull finishes (Gordon, 1987).

Work surface illumination through multiple lighting systems

Quality lighting that supports productivity yet minimizes eyestrain and fatigue requires three key considerations: ceiling uniformity, horizontal and vertical illuminance.

- Light fixtures should be placed uniformly and appear evenly across the ceiling through the use of indirect or semi-ambient luminaries to reduce work surface glare.
- Horizontal lighting needs to be of sufficient levels in order to read printed material laying flat on the work surface. Effective methods for illuminating horizontal surfaces are achieved by using both ambient and task lights.
- Vertical illumination on objects such as VDT screens is created by a combination of overhead lighting systems offering versatility in adjustment (Steelcase, 1999).

A properly designed and balanced work place ideally incorporates a combination of all illumination systems. Windows correctly positioned can also take advantage of natural light. Ambient overhead systems can supplement natural sources while task specific light allows for increased visual acuity on horizontal surfaces (Kohn, 1990).

In regard to recommended illumination systems, office equipment manufacturer Herman Miller states the following opinion:

> "General, overhead lighting cannot provide the major source of light for offices, especially now that computers are the focus of many people's jobs. General light needs to be lower than task light, and complementary to it. Twenty-five to fifty foot-candles, supplemented by task lighting of an additional 25 to 75 foot-candles, is now thought to be the extent to which direct or indirect general lighting should be used. More is a waste of energy and, frequently, a drain on health and productivity (Herman Miller, 2001, p. 3)."

Herman Miller's opinion advocates the use of combination lighting systems to coincide with work place technological changes in order to provide an optimal balance between resource utilization, productivity and health. In general, single source overhead illumination systems are no longer the norm.

Additional recommendations also call for utilizing more neutral color tones in selecting office furniture and wall finishes for the purpose of increasing contrast and glare reduction (Cakir, 1991).

Instrumentation for measuring work place lighting

Lighting measurement instrumentation is equipment designed for measuring the radiation emitted from a source, called luminance, in relation to the degree it is absorbed and reflected by other objects, called illuminance. Luminance is the intensity of a source emitting radiation in a general or specific direction and typically is measured in units called the candela (cd), which is defined by the International System of Units (SI) as; 540 X 10^{12} hertz of monochromatic radiation of frequency and an intensity of 1/683 watt per steradian (Encyclopedia Britannica, 2010).

There are several forms of instrumentation available for work place light measurement ranging from industrial to scientific applications. The focus of this study is primarily concerned with the type of instruments capable of measuring and metering illumination within the office environment. The following meters are examples of the many types that are available for measuring light sources found within the work environment: (Konica Minolta, 2010)

- ***Spectral irradiance meters*** are typically used in a laboratory work environment for the measurement of light sources such as those found as part of the physical spectrum in chemical components and elemental materials. Spectral meters measure wavelength emission of a light source in nanometers (nm) which can then be translated into the appropriate color for comparison to the physical properties of chemical elements.
- ***Illuminance meters*** measure workplace environmental light intensity or brightness from sources such as overhead, task or ambient light systems. Illuminance instrumentation is more commonly called a "lux meter," and light strength is displayed in units of footcandles or lux (lx) depending upon the user's preference. The physical characteristics of this meter type consist of a small hand sized display module with a backlit liquid crystal display (LCD) screen for viewing the results along with a removable, tethered

sensor. An illuminance meter is capable of measuring natural, incandescent, and fluorescent light sources and offers environmental versatility. The lux meter is the instrument of choice for measuring office lighting.

- ***Luminance meters*** measure the amount of light emitted from a source. Light sources potentially include the sun, incandescent, fluorescent, light emitting diodes (LED's), cathode ray tubes (CRT's), and liquid crystal display (LCD's) screens. The main use of a luminance meter is found in areas of research or product development and design. Units of luminance are measured in candelas per square meter (cd/m^2) and are adaptable to a wide range of environmental conditions.
- ***Incident color meters*** measure illuminance, color temperature and chromaticity simultaneously from all light sources and are multi-functional by combining many of the same characteristics of the other meter types. Measurement results are typically displayed in lux or footcandle units. Incident color meters are very useful for measuring organic luminescence, which is commonly found in marine environmental work and analysis.
- ***Ultra Violet (UV) radiometers*** measure the intensity of UV light and is commonly used in work areas using chemically reactive substances such as in photography, film development, and medical research. The ultra violet radiometer displays light emission reaction measurements in nanometers (nm) (Konica Minolta, 2010).

Within office areas the source of luminance is typically provided by overhead incandescent or fluorescent light fixtures. As light fills an area, the luminated energy is absorbed and reflected by the objects within it. Objects absorbing and reflecting luminated energy are then defined as being illuminated by the amount of light falling on their surface. The intensity of this relationship can be quantified by measuring the amount of candelas objects receive and dividing it by the surface area it falls upon. The intensity of light emitted from a source one foot in distance away from an object and illuminating one square feet of its surface area is a measurement unit called the footcandle. Another unit of measurement, called the lux, is equal to approximately 0.0929 foot candles of light (Encyclopedia Britannica, 2010).

An Illuminance or lux meter is typically used for measuring office lighting. A lux meter is comprised of a sensor, called a radiometer, which is capable of turning absorbed light into an electrical charge and then displaying its results digitally on a monitor in footcandle units. A lux meter will be the type of equipment used in this study to measure the amount of footcandles emitted by the Freeman Building's lighting system and falling upon an employee's work surface.

Summary

In reviewing lighting standards and systems, illumination levels appear to influence and play an important part in worker's health, productivity and an organization's efficient resource utilization. Multiple illumination systems such as ambient, task specific and accent lighting offer the versatility to keep pace with a changing work place environment. Comparing work place environmental conditions and tasks to established standards plays an important part in determining which combination of illumination systems provide balanced and quality lighting. Therefore an organization can benefit by analyzing the work place environment by measuring illumination levels for the purpose of selecting optimal lighting systems focused on providing a healthy and cost efficient work place based upon established industry standards.

Chapter III: Methodology

Introduction

The purpose of this study is to measure, analyze and compare work surface illumination levels within the Orville L. Freeman Office Building to recognized standards for determining if the addition of office task lighting would be a cost effective strategy. The goals of this study are to identify office lighting standards used for work surface illumination and then through actual work place sampling and comparison, recommend whether additional task lighting is required in the identified areas.

The identification of recommended office lighting illumination levels will be obtained by researching independent industry standards, federal and state occupational safety statutes. The Orville L. Freeman Building's semi-ambient, overhead lighting system will then be measured to determine actual work surface illumination levels and compared to the previously established standards. Based upon work surface illumination levels in comparison to established standards, recommendations will be made to add additional task lighting where necessary.

Subject Selection and Description

Open office cubicles were selected for work surface illumination measurement based upon standard 8' x 8'configurations within the Freeman Building. In total, data was sampled from 39 cubicle work surfaces on the 2nd floor of Pod C and in the areas identified on figure 4, (p. 24). Data was collected during different times and dates to provide greater randomization of external environmental conditions potentially affecting illumination levels.

Instrumentation

Equipment used:

Gossen Panlux Electronic 2 light meter

Serial # PAN-94-12103

Measurement units: footcandles (fc)

Pre-calibration in the absence of light = 0 fc's

Post-calibration in the absence of light = 0 fc's

External Environmental Conditions:

4/19/06 - Sunny to partly cloudy

4/21/06 - Cloudy/rain

Data Collection Procedures

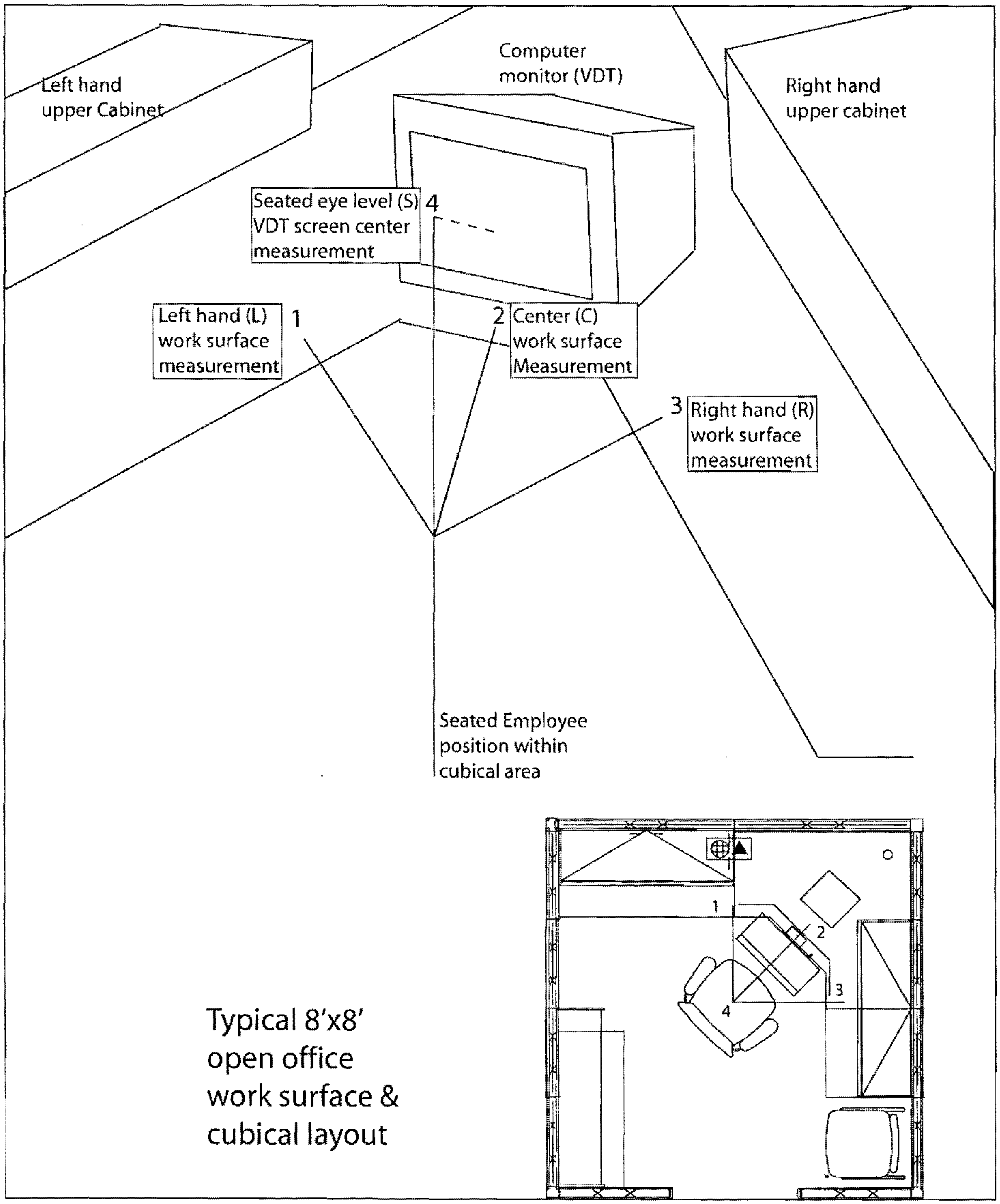
Open office cubicles were selected for work surface illumination testing based upon accessibility in Area C, floor 2, of the Freeman Office Building located at 625 Robert Street North, ST. Paul, Minnesota. In all, 39 cubicle work surfaces were measured. Typical office cubicles are 8' x 8' in size and office walls are covered with a woven, light tan colored fabric. Data was collected during different times and dates to provide greater randomization of external environmental conditions potentially affecting illumination levels.

Illumination levels in fc's were measured consistently at four points within each open office cubical at the following described work surface locations and as shown in Figure 4, (p. 24):

1. Left (L) - Left hand desk surface was measured 22" from the center work surface position and 6" in from the desktop edge nearest employee.
2. Center (C) - measured from the work surface 6" in from the desktop edge, front and center of the visual display terminal (VDT), nearest employee.
3. Right (R) - right hand desk surface measured 22" from the center work surface position and 6" in from the desktop edge nearest employee.

4. Eye Level Seated (S) - measured 22" from the approximate eye level position (16" above the work surface while employee is seated) to the center of the VDT screen.

Figure 4: Cubical layout/Data measurements points



Tim Myers, MDH, 2006

Data Analysis

Illumination levels were recorded in tables 1 & 2, (p. 28 & 29). The total average footcandles were then computed and displayed at the top of table 3, (p. 30). The average illumination achieved from measuring each work surface area was then compared to the building design plan and Minnesota State Rule 5202.0120 as a percentage and displayed in table 3, (p. 30). The data was then exported to Minitab©, a data analysis software program, where a histogram was performed and the results displayed in figure 5, (p. 31). Consequently the Anderson-Darling test was performed on all data obtained during sampling from tables 1 & 2, (p. 28 & 29) and used to display the descriptive statistics in figures 6-9, (p. 32 & 33).

Limitations of the Study

1. This study is limited to office illumination standards pertaining to the Minnesota Occupational Safety and Health Act (MOSHA) and the American National Standards Institute (ANSI), A132.1-1973, *Practice for Office Lighting, RP-1*, sponsored by the Illumination Engineering Society (IES).
2. This study is also limited to illumination levels measured within standard cubical design configurations within open office areas of the Orville L. Freeman Office Building located at 625 Robert Street North, St. Paul, Minnesota.
3. This study is additionally limited by the lack of available data reported from studies on comparable sized groups.

Assumptions

Consistent work surface measurement results in floor 2C within the Orville L. Freeman Office Building will be assumed to represent similar conditions elsewhere throughout the building. The conclusions and recommendations assumed for floor 2C will be applicable to all similar areas within the Orville L. Freeman Office Building.

Summary

The methods described in this section are intended to provide a process for the independent and systematic determination of illumination levels at office work surfaces within the Freeman Building located in ST. Paul, MN. The methods used will provide illumination data for the primary areas an employee typically will interface while at work rather than non-essential or unoccupied space. The data obtained from measurement sampling in the Freeman Building open office cubicles will help identify any illumination deficiencies with the building design plan under Xcel Energy strategy, objective 16 (App. D, p. 50-51), and the State of Minnesota statutory minimums. Future use of this methodology may be replicated to capture additional data on larger population samples.

Chapter IV: Results

Introduction

The purpose of this study is to identify work surface illumination levels by analyzing the current lighting system effectiveness based upon measurements obtained from within the Freeman Building open office cubicles. The following activities were performed in the analysis:

- Measurement of employee work surface illumination levels
- Comparison of measured data to established standards
- Determination if adding task lights will help meet established standards

Presentation of Collected Data

Illumination levels in fc's were measured consistently at four points within each open office cubical at the following described work surface locations and as shown in figure 4, (p. 24):

1. Left (L) - Left hand desk surface was measured 22" from the center work surface position and 6" in from the desktop edge nearest employee.
2. Center (C) - measured from the work surface 6" in from the desktop edge, front and center of the visual display terminal (VDT), nearest employee.
3. Right (R) - right hand desk surface measured 22" from the center work surface position and 6" in from the desktop edge nearest employee.
4. Eye Level Seated (S) - measured 22" from the approximate eye level position (16" above the work surface while employee is seated) to the center of the VDT screen.

Illumination levels were recorded in Tables 1 & 2, (p. 28 & 29). The overall average of illumination achieved for each work surface area was then compared to the building design plan and Minnesota State Rule 5202.0120 as a percentage in table 3, (p. 30).

Table 1: Illumination data taken on 4/19/06

Work Surface Illumination Data Obtained 4/19/06, 9:00 - 11:00 a.m.
Freeman Building 2nd Floor - Open Office Area C

Cubicle Tested	Left (L)	Center (C)	Right (R)	Eye Level Seated (S)	*# of task lights required to meet 45 fc's*	*# of task lights required to meet 50 fc's*
2C - 1a	47	50	45	70	0	2
2C - 1b	43	43	37	60	2	2
2C - 1d	45	43	38	65	1	2
2C - 1e	53	58	48	80	0	1
2C - 1f	58	47	49	80	0	1
2C - 1h	42	50	43	70	2	2
2C - 2a	40	47	39	65	2	2
2C - 2b	33	39	53	60	1	1
2C - 2c	40	53	52	70	1	1
2C - 2d	38	44	42	70	2	2
2C - 2e	39	53	52	70	1	1
2C - 2f	37	45	40	65	2	2
2C - 2g	33	44	40	60	2	2
2C - 2h	34	40	34	60	2	2
2C - 3a	40	49	45	70	1	2
2C - 3b	32	35	40	60	2	2
2C - 3e	47	55	49	75	0	2
2C - 3f	41	49	44	70	2	2
2C - 3g	30	42	36	58	2	2
2C - 3h	29	32	30	55	2	2

Table 2: Illumination data taken on 4/21/06

Work Surface Illumination Data Obtained 4/21/06, 1:00 - 4:00 p.m.
Freeman Building 2nd Floor - Open Office Area C

Cubicle Tested	Left (L)	Center (C)	Right (R)	Eye Level Seated (S)	*# of task lights required to meet 45 fc's*	*# of task lights required to meet 50 fc's*
2C - 11c	43	49	41	63	2	2
2C - 12a	31	35	28	60	2	2
2C - 12d	29	39	36	47	2	2
2C - 12e	36	44	35	58	2	2
2C - 12f	35	40	29	46	2	2
2C - 13a	41	47	33	62	2	2
2C - 13b	33	43	38	54	2	2
2C - 13c	36	43	36	60	2	2
2C - 13d	39	49	38	59	2	2
2C - 13e	27	28	35	46	2	2
2C - 13f	43	41	32	50	2	2
2C - 14a	40	47	43	67	2	2
2C - 14b	40	48	50	68	1	1
2C - 14c	30	35	38	53	2	2
2C - 14d	44	45	41	70	2	2
2C - 14e	35	42	35	57	2	2
2C - 14f	36	49	58	62	1	1
2C - 15b	53	57	40	50	1	1
2C - 15f	28	35	40	50	2	2

Table 3: Illumination data totals for 39 cubicles

Work Surface Illumination Data Totals for 39 cubicles surveyed on 4/19 & 4/21/06
Freeman Building 2nd Floor - Open Office Area C

	Left (L)	Center (C)	Right (R)	Eye Level Seated (S)
Avg. fc's =	38	44	41	62
Percent of overall work surfaces achieving Xcel Energy 45 footcandle plan minimum =	85%	99%	90%	138%
% Deficient =	15%	1%	10%	-38%
Percent of overall work surfaces achieving current Minnesota State Rule 5205.0120, 50 footcandle minimum =	77%	89%	81%	124%
% Deficient =	23%	11%	19%	-24%

Figure 5: Histogram of cubicle illumination levels

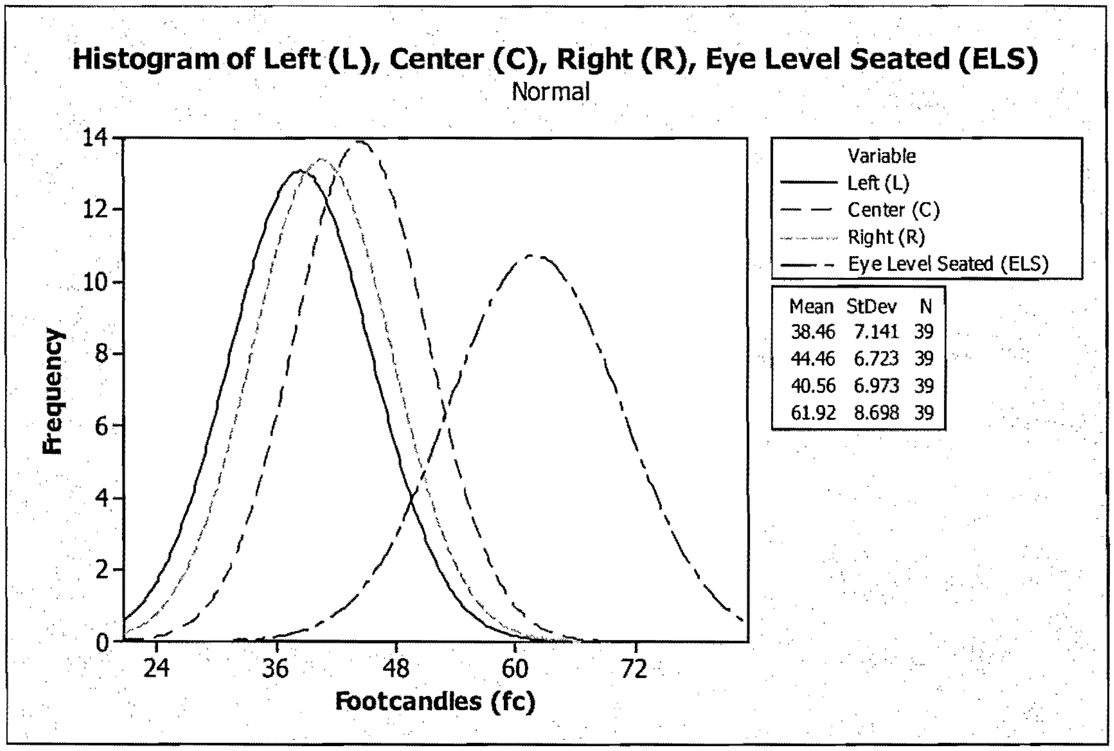


Figure 6: Left hand work surface illumination levels

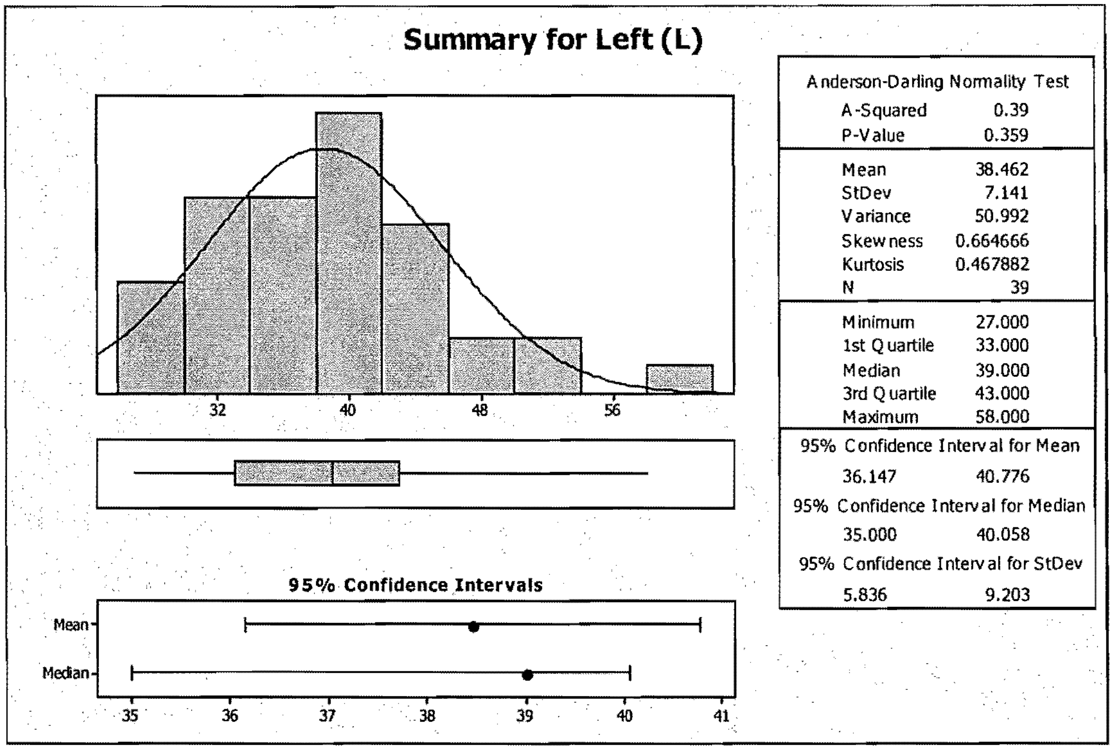


Figure 7: Center work surface illumination levels

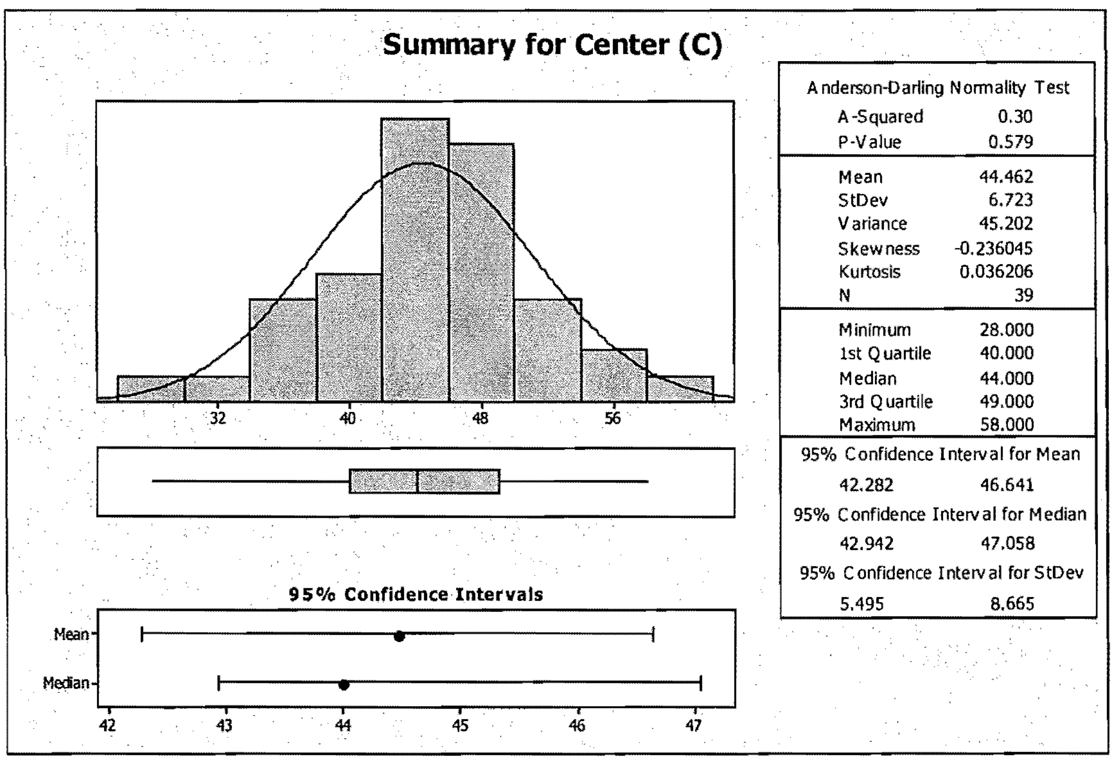


Figure 8: Right hand work surface illumination levels

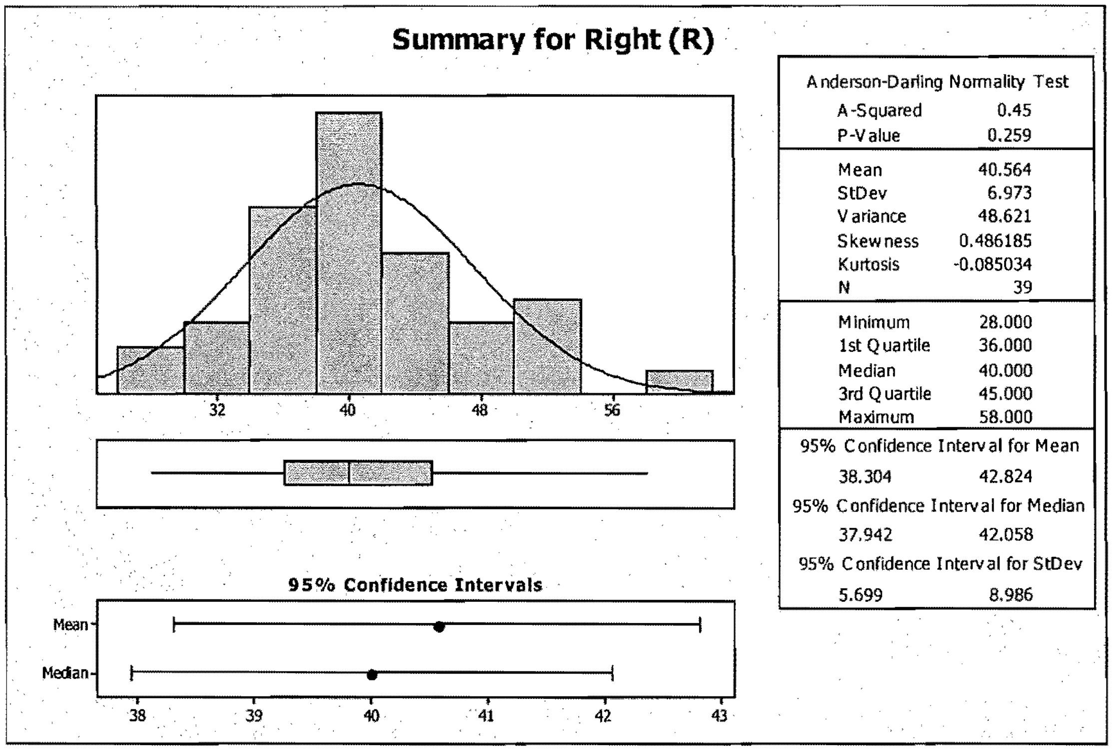


Figure 9: Eye level seated work surface illumination levels

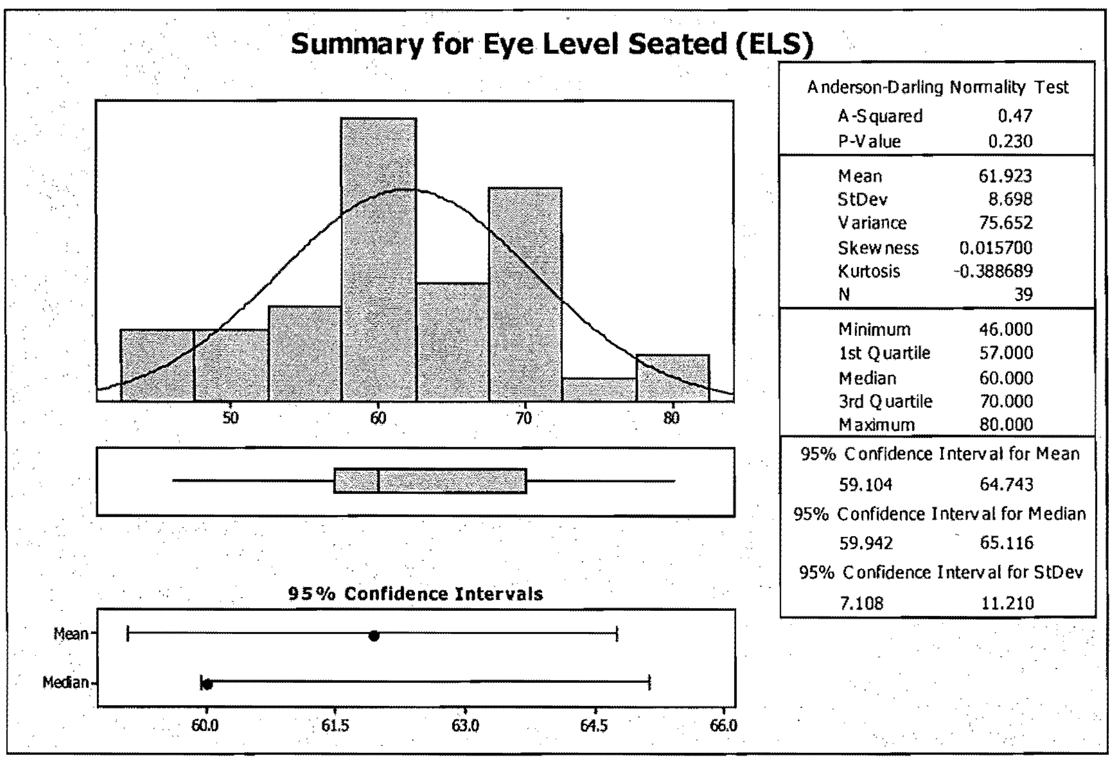
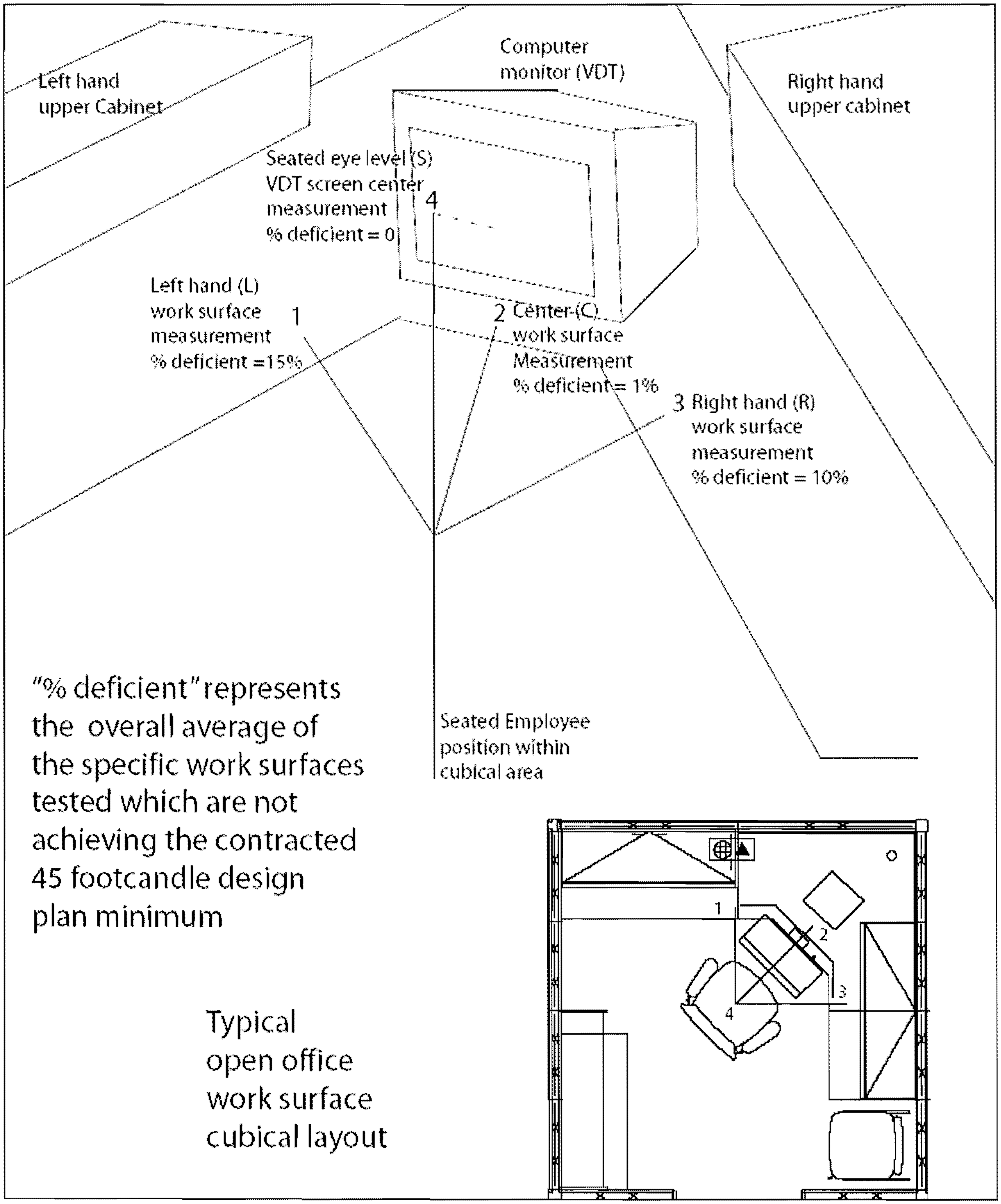


Figure 10: Areas deficient in achieving the 45 fc design plan



Discussion

The average left and right hand work surface measurements appear to be lower than the anticipated Xcel Energy lighting design plan level of 45 footcandles. The center and seated points in front of the visual display terminal (VDT) appear to meet or exceed the lighting design plan. Three out of the four areas measured at the desktop work surface, left, center and right, appear to fall below the recommended Minnesota State Rule, 50 fc illumination levels, while the eye level positions (S) meet or exceed this. Shadowing from cubical walls and overhead cabinets is causing a significant reduction in light levels on the left and right hand work surfaces resulting in the 45 fc Xcel Energy design plan and MNOSHA 50 fc minimum not being achieved by the semi-ambient light system. Employees viewing paper documents adjacent to their visual display terminals are not receiving adequate illumination levels from the semi-ambient, overhead lighting system within the Orville L. Freeman Office Building. The lack of adequate work surface illumination levels on the areas adjacent to the visual display terminal may be the cause of employee eyestrain and complaints.

Summary

The data obtained from sampling in the Freeman Building open office cubicles statistically indicates an illumination deficiency with the Xcel Energy lighting design plan, strategy objective 16 (App. D, p. 50-51), and the State of Minnesota statutory minimums. Further sampling of open office illumination levels was halted and estimated to hold true for remaining open office areas within the Freeman Building due to the repetition within the 39 measurement samples. The measurement data obtained provides the necessary information to form a conclusion and make recommendations.

Chapter V: Conclusions and Recommendations

Introduction

The purpose of this study was to analyze employee work surface illumination levels while viewing paper documents or using visual display screens (VDT's) in an open office environment. Illumination standards, ergonomics and the types of lighting systems available were reviewed to provide a reference for comparison to existing conditions within the Freeman State Office Building. The methods used provided illumination data for the primary areas an employee typically will interface while at work rather than non-essential or unoccupied space. The data obtained from measurement sampling in the Freeman Building open office cubicles supports an illumination deficiency when compared to the building design plan, ANSI standards and the State of Minnesota statutory minimums. The conclusions and recommendations that follow are intended to help achieve the illumination levels recommended by the national and local standards previously identified in this study.

Conclusions

- The Xcel Energy verification report under "Strategy Objective," (App. D, p. 50-51) appears only concerned with overall watts per square foot of floor space rather than illumination levels at the work surface area as indicated by the objective of strategy 16.
- The methods used to design open office illumination levels and whether or not the employee's dynamic interaction within a cubicle was taken into consideration is unclear.
- Shadowing from cubical walls and overhead cabinets is causing a significant reduction in light levels on the left and right hand work surfaces resulting in the 45 fc Xcel Energy design plan and MNOSHA 50 fc minimum not being achieved by the semi-ambient light system.

- The results of this study are estimated to hold true for the remainder of the Freeman Building's open office areas.

<u>*Recommended potential solutions*</u>

Short term:

1. Require the building contractors to install or reconfigure light fixtures in a manner which will meet or exceed the levels specified in the Xcel Energy Strategy Objectives.
2. Install two task lights for each cube within the entire building. This requires installation by present Facilities staff or it could be performed through existing furniture installers who are presently working on-site.
3. Add task lighting in the following order for; 1) Medical conditions 2) As required by the plan or State Rule and 3) As requested depending upon the task itself, its size, its importance, the duration of time it needs to be performed (Herman Miller, 2001)
4. Open office cubical areas throughout the Freeman Building should be tested individually and task lights added depending upon the level necessary to meet the 45 fc design plan or the 50 fc MN. State Rule.

Long term:

1. Add alternative desktop task lighting which will allows greater user versatility in positioning the fixture over the task performed and in adjusting lumination levels.
2. Determine a standard task, work surface illumination policy for the Freeman Building's lighting system incorporating recognized standards, federal and state regulations.
3. Alter semi-ambient light levels to compensate for increased task light energy consumption. Energy reduction can be accomplished by replacing the current fluorescent

Areas of Further Research

- Specific task lighting options which offer the user more versatility in both physical and output adjustment depending upon work place demands.
- Fluorescent luminaire output and wavelength in relation to the potential effect on worker eyestrain.
- The degree lighting can be absorbed and reflected by wall colors, material types and work surface reflectance.

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Appendix A

Job safety agreement between:

The Minnesota State Employees Union AFSCME, Council No. 5, AFL-CIO and

The State of Minnesota, July 1, 2005 through June 30, 2007

Source: Minnnesota Department of Employee Relations (DOER)

Retrieved from the Internet on May 10th, 2006, from:

http://www.doer.state.mn.us/lab-rel/pdfs/0507/AFSCME.pdf

- Article 11 - Job Safety
- Section 7. Policy on VDT Ergonomics.
- Appendix L - Policy on VDT Ergonomics

Appendix A

Agreement between:
Minnesota State Employees Union AFSCME, Council No. 5, AFL-CIO
and the
State of Minnesota
July 1, 2005 through June 30, 2007

ARTICLE 11 - JOB SAFETY

Section 7. Policy on VDT Ergonomics. The VDT Ergonomics Policy adopted by the Statewide Safety Committee is contained in Appendix L. This policy is not subject to the grievance and arbitration provisions contained in Article 17 of this Agreement.

APPENDIX L - POLICY ON VDT ERGONOMICS

Prepared Jointly by AFSCME, Council 5 and the
Department of Employee Relations Through
A Joint Labor-Management Committee

Purpose and Scope

This policy is intended to provide guidelines to state agencies and employees addressing ergonomic considerations associated with the operation of Video Display Terminals (VDTs). Specifically, this policy provides agencies with options they should explore to enhance the general working conditions of those employees who operate a VDT and encourages discussion with employees who will be operating new VDT hardware and/or software being purchased. This policy is not subject to the grievance and arbitration provisions contained in Article 17 of this Agreement.

Policy

It is the policy of the State Executive Branch to provide employees who work with VDT's on a continuing and substantial basis with a consistent reference in regard to recognized workplace hazards and workstation comfort which would enable state employees to perform productively.

Policy Guidelines

A. Illumination: Effective illumination in the space housing VDTs/CRTs (Cathode Ray Tube) is an important part of insuring health and user comfort. Lighting levels for VDT/CRT work should be substantially lower than for tasks using printed materials or in traditional office work. Illumination is measured in units called lux, or footcandles. While the lighting in offices is usually 750 lux (75 footcandles) and higher, the lighting level where VDTs are used should be in a lower range (200-500 lux or 20-50 footcandles).

Lower lighting can be accomplished by simply removing bulbs or reaching an agreement with the building lessor to make arrangements for more suitable lighting conditions. Task lighting may be necessary in areas where illumination levels are particularly low. The Safety and Workers' Compensation Director's Office or your Department Safety Officer are able to provide assistance in determining appropriate lighting levels.

Appendix B

State of Minnesota Employee Computer Workstation Setup Recommendations

Source: Minnesota Department of Employee Relations (DOER)
Retrieved from the Internet on May 10th, 2006, from:
http://www.doer.state.mn.us/ei%2Dsafih/ergon/statnsup.htm

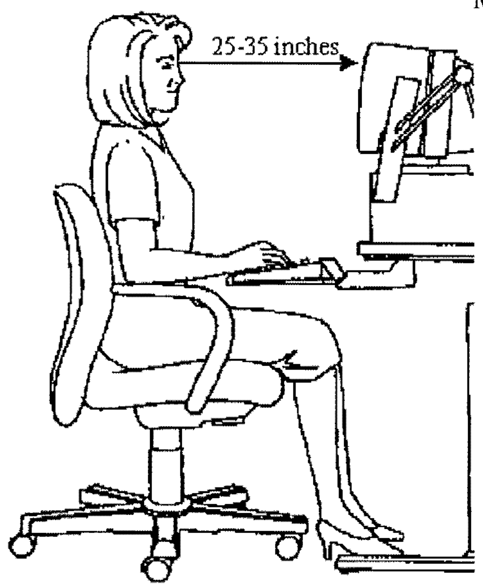
- Lighting
- Computer office environments should have between 20-50 footcandles of light
- Use window treatments to eliminate or reduce bright light
- Use additional task lighting only while performing non computer related task

Appendix B

DOER Computer workstation setup

Lighting

- computer office environments should have between 20-50 footcandles of light
- use window treatments to eliminate or reduce bright light
- use additional task lighting only while performing non computer related tasks



Monitor/VDT

- position the top 1/4 of the monitor at or slightly lower than eye level
- align monitor and keyboard/mouse
- position monitor to avoid glare from outside light sources or overhead lighting
- set refresh rate between 70-80 Hz to limit flicker
- use dark characters on light backgrounds
- clean screen at least 1 time per week

Seating

- position hips slightly higher than knees
- place feet firmly on the floor
- position lumbar support slightly below waist line
- allow 1-3 inches between the edge of the seat and the back of your knees

Document Holder

- position adjacent or directly in front of the monitor

Employee Responsibilities

- learn and use adjustment features for all equipment
- change position/posture at least 1x/hr
- arrange work area to reduce reaching
- incorporate stretching into daily work routine without interrupting work flow
- consult your eye doctor a minimum of once every two years

Input Devices (keyboard/mouse)

- position input devices at or slightly lower than elbow height
- keep wrists comfortably straight
- relax shoulders

Appendix C

Minnesota Rules, Table of Chapters

Table of contents for Chapter 5205

5205.0120 MINIMUM LEVELS OF ILLUMINATION

STAT AUTH: MS s 182.657

Current as of 06/21/05

Appendix C

Minnesota Rules, Table of Chapters

Table of contents for Chapter 5205

5205.0120 MINIMUM LEVELS OF ILLUMINATION.

Subpart 1. **For traversed spaces.** Illumination by daylight or artificial light shall be supplied for traversed spaces, such as hallways, roadways, etc., during working hours, and for work when attended by operators. Minimum levels of illumination, as listed in the following table, are required in all places of employment in Minnesota. Values greater than these minima shall be used when ordered by the Occupational Safety and Health Division.

Minimum	Recommended Footcandles
Illumination on Traversed Spaces:	
Roadways, yard thoroughfares	2-1
Storage spaces, aisles and passageways in workrooms, excepting exits and passageways leading thereto	3-2
Spaces such as stairways, hallways, exits and passages leading thereto	5-3
Spaces such as locker rooms, wash rooms, toilet rooms, and passageways where there are exposed moving machines, hot pipes, or live electric parts	6-4

Subp. 2. **At the working place.**

Illumination at the Work:

Where discrimination of detail is not essential:	
Work such as handling material of a coarse nature, grinding clay products, rough sorting, coal and ash handling, foundry charging	5-3
Where slight discrimination of detail is essential:	
Work such as rough machining, rough assembling, rough bench work, rough forging, grain milling	10-5
Where moderate discrimination of detail is essential:	
Work such as machining, assembly work, bench work, fine core making in foundries	30

Where close discrimination of detail is essential: Work such as fine lathe work, pattern making, tool making, weaving or sewing light-colored silk or woolen textiles, office work, accounting, typewriting	50
Where discrimination of minute detail is essential: Work such as drafting, weaving or sewing dark colored material, very fine inspection or inspection of very dark goods	100-25

The preceding table gives the range of minimum illumination values that are considered desirable for different classes of work. These values are based upon practice established through years of experience. Elderly persons or persons with defective eyesight require more light than do those having perfect vision. A range of footcandle values is given for each group of operations. In modern practice it will usually be found desirable to select values in or even beyond the upper portion of the range.

It is recognized that any specific process when carried on in different factories is performed with different degrees of fineness and with other variations, so that one factory may need more illumination than another for the same class of work. In the table, ranges of footcandle values are given to correspond to the variations actually existing in practice. Attention is called to the fact that the values in the table are operating values, that is, they apply to measurements of the lighting system in ordinary use, not simply when the lamps and reflectors are new and clean.

STAT AUTH: MS s 182.657
Current as of 06/21/05

Appendix D

Verification Report

Energy Design Assistance – Custom Consulting

MDA/MDH (Office Building)

Xcel Energy

7116.37 10/25/2005

Herzog/Wheeler & Associates

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Lighting Design Alternatives

Selected Strategies
Strategy 16, L04OO – Open Office Direct /Indirect System at 45 fc w/hi performance T8
Strategy 17, L07PO - Private Office Recessed Direct System at 50 fc w/hi performance T8
Strategy 18, L04CN – Conference Direct/Indirect System at 45 fc w/hi-Reflective Ceiling, hi performance T8
Strategy 19, L08CG – Large Conference Direct/Indirect System at 45 fc w/hi-Reflective Ceiling, hi performance T8 S
Strategy 20, L01CI - Corridor and Other Spaces (Storage, Restroom etc.) w/hi performance T8

Strategy Objectives To reduce lighting energy consumption by reducing the power density requirements (in watts per square foot) of the lighting system as compared to the prescriptive State Energy Code.

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Post-Construction Findings The verified lighting power densities achieve the following percentages of modeled lighting power density reductions:

Strategy #, Space Type	% of Goal Achieved
16, Open Office	52%
17, Private Office	91%
18, Conference Room	100%
19, Large Conference Room	0%
20, Corridor/Storage/Restrooms	0%