MASTER

Satisfaction illuminated
study of the effects of lighting in the work environment on satisfaction

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Satisfaction Illuminated

Study of the Effects of Lighting in the Work Environment on Satisfaction

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The quest to understand the nature of light has lead curious human beings down into the innermost secrets of the atom and out to the farthest reaches of the starry universe

Ben Bova.

ABSTRACT

Companies do not desire dissatisfied employees. One of the possible reasons for a lack of satisfaction is the work environment. The Cost-effective Open-Plan Environments (COPE) project (executed by the National Research Council of Canada) was designed to discover to what extent environmental aspects influence the environmental satisfaction of employees working in cubicles, a common work environment in North America. This thesis has common grounds with the COPE project and looks at the effects of lighting on the satisfaction of employees. The first objective of this research is to determine the effect electric light and daylight have on satisfaction. The most important reason for companies to have satisfied personnel is the belief that satisfied employees are more productive. Nevertheless, this relation has never been empirically proven. It might just as well be that there is a turning point after which this initial positive link turns into a negative one. The second part of this study will therefore address this relationship. For this research the following two research questions have been postulated: "What is the contribution of light, electric and daylight, on satisfaction?" and "What is the relation between satisfaction and performance?".

In previous research lighting has been looked upon as being a quantitative phenomenon, focussing on illuminance levels - the light levels needed to make tasks and objects visible. In more recent research this point of view has been adjusted. A lighting installation ought to fulfill human needs beyond visibility, within restrictions such as economics, energy consumption, and maintenance. Research on lighting has thereby broaden its field of interest from only looking at the quantities of lighting to also include the qualities of lighting. Lighting is built out of physical characteristics such as illuminance and uniformity. The environment is built out of, among others, the characteristics texture and colour. The lit environment is the addition of these two, comprising all the characteristics. These characteristics have their effect on the psychological state of human beings, including satisfaction. Satisfaction in this research has been divided into three independent components: Overall Environmental Satisfaction[1], Job Satisfaction[2], and Satisfaction with Lighting[3].

There is a constant interaction between the lighting characteristics, the environmental circumstances and the individual's state of mind. All these factors need to be incorporated when performing research on lighting. To research the relation between lighting and each aspect of satisfaction two hypotheses have been formulated per aspect of satisfaction. The first one is "The various aspects of lighting (i.e. illuminance, uniformity, non-glare, direction, and daylight) will have a beneficial contribution on Overall Environmental Satisfaction / Job Satisfaction / Satisfaction with Lighting". The second one "The various aspects of daylight will have a bigger beneficial contribution on Overall Environmental Satisfaction / Job Satisfaction / Satisfaction with Lighting than the equivalent different aspects of electric lighting". To look at the influence of having a window, daylight, or neither a third hypothesis has been formulated "Having a window will have a bigger positive contribution towards satisfaction than only receiving daylight in your workstation. Only receiving daylight in its turn will be more beneficial than having no daylight at all".

[1] The extent to which people are satisfied with their work environment, looking at aspects such as noise, draft and lighting.
[2] The extent to which people are satisfied with their job.
[3] The extent to which people are satisfied with the lighting in their work environment.

The COPE field study comprises measurements of 779 workstations in 9 buildings. It consists of physical data combined with a satisfaction questionnaire. For this final thesis project the lighting measurements and the related satisfaction portion of the data were used. For each lighting characteristic a representative measurement was chosen from the data. Daytime lighting measurements combining electric light and daylight were available for the entire data set; for 41 workstations it was possible to separate the daylight and the electric light contributions, to test the relative importance of the two components. The final analyses consisted of regression analyses and a MANOVA.

For the hypotheses whether lighting has an effect on satisfaction the all subject set (N = 779) could be used, in regression analyses with five demographic control variables and five lighting variables. These lighting variables are illuminance, direction, uniformity, glare and daylight. The results show that these interacting variables do have a significant effect on Overall Environmental Satisfaction and Satisfaction with Lighting. None of the individual variables significantly relate with overall environmental satisfaction. The individual variables glare and uniformity have a negative relation with satisfaction with lighting; high glare and low uniformity are both unsatisfactory. Daylight is positively related to satisfaction with lighting. Neither the interacting variables, nor the individual variables show any significant effect on Job Satisfaction.

For the hypotheses that the daylight effect will have a bigger contribution, the small set of subjects had to be used (N = 41). Due to this low number the independent variables needed to be pruned to avoid an unacceptably low power. The end result is that there are 5 independent variables left: job category, illuminance, uniformity, glare, and direction. They only have an effect on Satisfaction with Lighting.

The final hypothesis, whether having a window is more beneficial than only receiving daylight or receiving no daylight, shows a remarkable result. There is no significant effect on Job Satisfaction and having a window is most beneficial for the Satisfaction with Lighting, which both is not really surprising. For the Overall Environmental Satisfaction however, it is best to only receive daylight, and not to be directly adjacent to a window.

The 15 studies that focus on the relation between satisfaction and performance have not yet been able to show a direct link between these two variables. As a matter of fact, it seems more logical to conclude that lighting, together with all the other aspects of the built environment, have a direct influence on performance instead of through an intervening variable like satisfaction. Being that the environment influences both satisfaction and performance people might easily be inclined to conclude that satisfaction influences performance.

Due to the fact that this final thesis did not include the gathering of data but used an already existing set, a lot of problems had to be overcome. The end result is that significance has been lost and there is a lack of predicting power. Still it can be said that both electric lighting as well as daylight have its influence on some forms of satisfaction. When looking at the Overall Environmental Satisfaction, which is more important than Satisfaction with Lighting, it is surprising to see that people working in second row offices (which do receive daylight but do not have windows) are most satisfied. One reason for this is the fact that a window causes bigger temperature discrepancies and draught.

PREFACE

This research is the final thesis of my Technology and Society study (TeMa[1]), programme of Human-Technology Interaction (HTI[2]) at the Eindhoven University of Technology (TU/e[3]), the Netherlands. The main question of Human-Technology Interaction is: '*how does technology affect humans and what characteristics contribute to this?*'. In light of this question I address the affects lighting has on the satisfaction and performance of human beings.

Through my supervisor at the university, Florian Kaiser, I was introduced to Jennifer Veitch. Together with colleagues she is involved in a large project on the effects of environment on satisfaction. Her part in this involves the lighting aspects of the built environment. Eventually this research will lead to a software tool for optimizing office design. My part in this life-size project is to derive the lighting variables most likely to influence satisfaction.

Besides this the objects for this thesis are expanded to also look at the differences between daylight and electric light on satisfaction and to view the relation between satisfaction and performance.

Having been able to perform my final thesis with the Institute for Research in Construction, department of the National Research Council (NRC[4]) in Ottawa, Canada has given me a chance to look at a different part of the world. There has not been a single aspect that was disappointing. The people were hospitable in all their friendliness, the country was amazing in all its extremes, and the topic of my research was interesting in all its challenges. Therefore I would like to thank Jennifer Veitch and all the staff of the IRC for giving me this great experience.

Besides Florian Kaiser, my supervisor at the university, and Jennifer, my supervisor at the IRC I was also supervised by Ariadne Tenner from Philips Lighting. I would like to thank all three of them for their contribution in the whole process that led to this end product of my final thesis. I would also like to use this opportunity to thank my family and friends for their ceaseless support. Without them it would have been impossible to go through the entire process with such a wonderful experiences and to achieve this result.

Eindhoven, November 2003

Jan Geerts,

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INTRODUCTION

Companies have a tangible interest in investing as little money as possible in work environments. If, however, the work environment does not match the needs and requirements of the people working there, a company's employees might become dissatisfied with their jobs. Eventually this will have adverse effects on the company's operations (i.e. by leading to difficulty retaining skilled employees, or by reducing their effectiveness at work).

One type of office, the open-plan office, seems at first glance to be rather cost effective. One of the reasons for this is that it allows for allocating less space to each individual. However, this office type comes with the risk of negatively affecting satisfaction (Bruce & Blackburn, 1992; Brennan, Chugh, & Kline, 2002; Veitch, Farley, & Newsham, 2002).

Debate is still going on whether satisfied people will reach a higher quantity and quality of work (Carlopio, 1996). When this relationship can be proven, maximizing job satisfaction will be mutually beneficial. On the one hand employees feel more comfortable and on the other hand the company may be more profitable.

Veitch *et al.* (2002) found a direct relationship between aspects of environmental satisfaction (e.g. satisfaction with privacy, satisfaction with lighting, satisfaction with ventilation) and overall environmental satisfaction. In addition Veitch *et al.* (2002) also found a direct relationship between overall environmental satisfaction and job satisfaction.

This study will start from this established relationship. Through the use of a bigger dataset it will be analysed how lighting variables affect satisfaction. Furthermore, this first step will be expanded with a literature study on the effects of satisfaction on performance.

To do so, the objectives and problem definition will first be explained followed by an elaborate description of the background and the literature. The theoretical and practical frameworks that are derived out of this will be conceptualized. Next, the method followed to amass and process the data will be described. The results will subsequently be presented, interpreted, and discussed. Finally, these will be formulated in conclusions and recommendations.

OBJECTIVES AND RESEARCH QUESTIONS

Objectives

The built environment is a large and complex jigsaw puzzle. Its pieces can be found in engineering, psychology, architecture, and health and contain elements such as (installed) lighting, air quality, and noise level (Newsham, 1997). To discover what effects those pieces have on satisfaction a large study is undertaken by the Institute for Research in Construction (IRC[5]). The Cost-effective Open Plan Environments project (COPE project[6]), as it is called, focused on the environment in open plan offices and the manner to make it as cost effective as possible in the long term. One task in this larger project was a field study investigating the relations between the physical conditions in open-plan offices and occupants' satisfaction with those conditions and with their jobs.

Part of the COPE field study is to look at the effects lighting has on the satisfaction of individuals. To gain insight in this matter lighting will be divided into electric lighting and daylight, since the effects of both might not be the same. Satisfaction too is a multi aspect variable and will be broken up into its different aspects, e.g. satisfaction with lighting, satisfaction with the overall environment and job satisfaction. The objective of the first part of this thesis is to determine the effect light, and daylight specifically, has on the different aspects of satisfaction.

Most laymen would argue that satisfaction and work performance are positively correlated (Fisher, 2003). For that reason a satisfied employee will generate a higher profit for the company. This relation, however, has never been indisputably proven. It might just as well be that there is a turning point after which this initial positive link turns into a negative one. The second part of this study will therefore explore this relationship in a separate literature review.

Research questions

To be able to adequately address both contemplations they will have to be put into concrete questions. This leads to the next research questions:

What is the contribution of light, electric and daylight, on satisfaction?

and

What is the relation between satisfaction and performance?

The results of the first question will be incorporated into the COPE project results. The major goal of the COPE project is to come up with a computer program that will serve as a tool for architects, designers, constructors, and students. Apart from lighting, this program also incorporates acoustics and indoor air quality (Newsham, 1997). Users of this program will be able to test trade-offs between office design choices, with the aim of maximizing the employees' satisfaction. Maximization means that the disturbing aspects of the environment, in its daily use, will move to the periphery, or even background, of an individual's perception.

Apart from this practical domain this study addresses a theoretical domain. With the results of this thesis study and the COPE project as a whole, further research on and development of materials used in office environments can be guided in the right direction. Thereby the functionality (i.e. the match between humans and technology) of the office environment will be enhanced.

By incorporating the second research question into this study and linking the two together, companies might further increase the likelihood of making a profit. Therefore the results of this study may be of interest for the above mentioned target groups but at the same time may be useful for companies that are trying to generate the highest profit possible, and which company doesn't have that goal?

LIGHTING

Research on the subject of lighting has been dominated by systematic investigations of the relationship between illuminance on the work plane and visual performance. The main focus has been to achieve the most economical lighting installations without detracting from the illuminance (i.e. lighting quantity). Recognition of the different aspects of lighting has led to new developments in research concerning lighting. Enough light to see the task at hand is no longer the sole goal. Comfort and psychological aspects now too play a role in the design of buildings (Fontoynont, 2002). "The appropriate quantity of light contributes to the achievement of good quality, but is not its sole determinant" (Veitch & Newsham, 1997). Quantity is extended to quality, i.e. a lighting installation fulfills human needs within restrictions such as economics, energy consumption, and maintenance (Newsham & Veitch, 2001). However, this is highly dependable on the context in which the lighting is installed and the targets that the installation has to achieve. According to Boyce (1998), lighting quality is a means to an end goal. It can therefore be defined by the extent to which the installation meets the objectives and the constraints set by the client (the owner of the building), the designer and ultimately the end user.

Objective Measurement of Light

All the different sources of lighting, and their combinational effects, have to conform to the same illuminated environment design issues. In other words, the illuminated environment can be broken up into different characteristics, which will all have their influence on the usability of a workstation. Rea (2000) in the IESNA lighting handbook discriminates the following important characteristics in an office environment: (1) illuminance, (2) direct glare, (3) reflected glare, (4) uniformity, (5) daylight integration and control, and (6) surface characteristics (see Picture 1). They will be defined below. In this research these characteristics are being called the objective qualities of lighting.

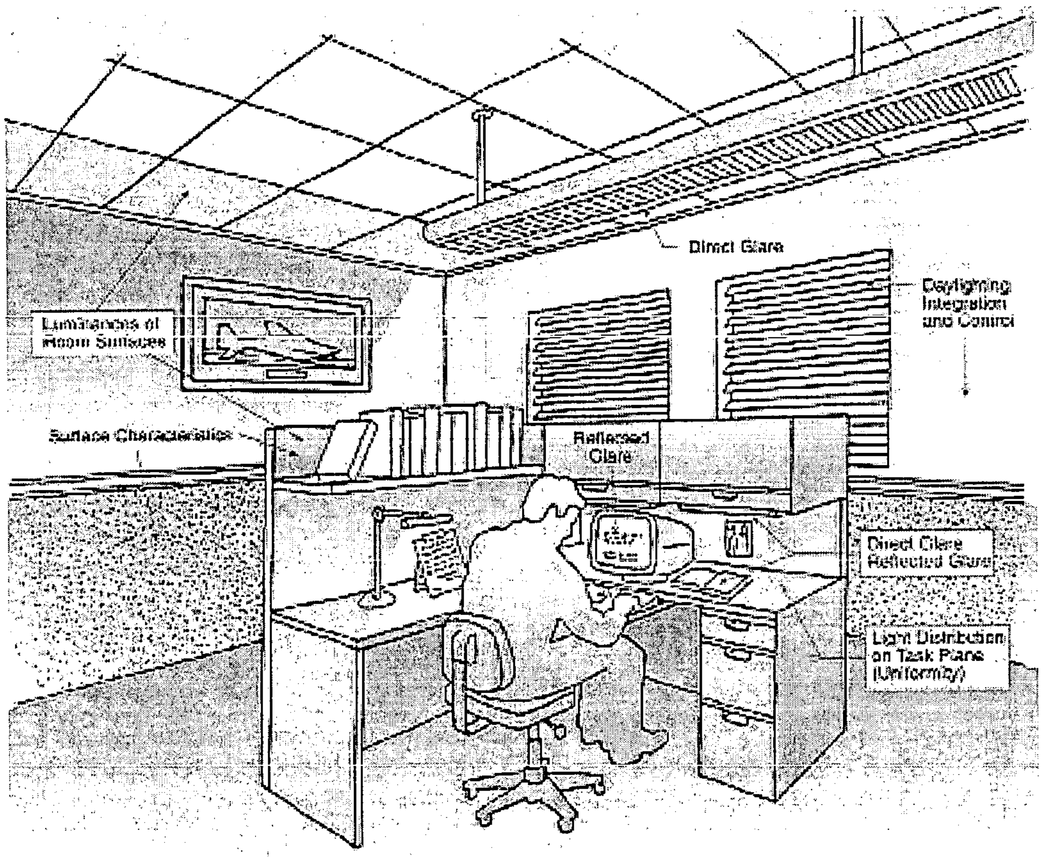
Illuminance [E] is the quantity of light, or luminous flux, falling from all directions on a unit area of a surface. The unit is lux (lx) and one lux equals one lumen per square metre.

Glare is an interference with visual perception caused by a bright light source in the field of view, too high luminance contrasts or a combination of both. Two fundamentally different types are distinguished, discomfort glare and disability glare. Discomfort glare is a sensation of annoyance or pain. It is most likely the result of frequent changes in pupil size caused by excessive brightness contrasts. Discomfort glare is annoying, but does not impair visibility. Disability glare is the result of interference in the visual process. A frequently occurring form is veiling glare, whereby light is dispersed or scattered in the optical system of the eye to such a degree that a uniform luminous veil is drawn over the retina. This reduces the contrast sensitivity and impairs visibility.

Relating to uniformity there are two different photometric quantities that are relevant: minimum-to-maximum illuminance ratios and the minimum-to-average illuminance ratios across the work surface (desk). The more equal the two compared levels of illuminance are, the more uniformly lit the task plane is.

Daylight integration can be applied in two different ways. On the one hand the available daylight can be distributed in an optimized way (architecture, screens etc.) in order to illuminate deep spaces and to prevent glare. On the other hand the electric light can be controlled with respect to the daylight penetrating the room in order to save electrical energy. For the control of the electric lighting sensors have to be installed. Control systems range from simple built-in sensors to building management systems.

Surface characteristics of the entire working area are important with respect to lighting, ranging from the computer screen to the surface of the ceiling. The way these surfaces reflect lighting have a significant influence on how the light is distributed throughout the area. Dark coloured surfaces reflect less light than bright surfaces. Smooth, reflecting surfaces reflect the light more directly while surfaces with structure scatter the light and distribute it in many directions.



Picture 1. *An office with all the important luminous characteristics (Rea, 2000). Reprinted from IESNA Lighting Handbook, 9th Edition, courtesy of the Illuminating Engineering Society of North America.*

Effects of Light

General Model of Lighting Quality

Human needs concerned with lighting consist of many facets. All these facets are dependent on, in no particular order, (1) the task at hand (Hedge, Sims, & Becker, 1995; Boyce *et al.*, 2000; Muramatsu & Nakamura, 2002; Newsham, Arsenault, & Veitch, 2002a), (2) the environment (Knez, 1995), (3) the perceived control over lighting (Roche *et al.*, 2000), and the closely interlinked variables (4) evaluator's personal preference (Roche *et al.*, 2000), and (5) evaluators personal characteristics (Knez, 1995).

Therefore, lighting quality is much more than just the absolute amount of illuminance on a specific surface. It is also more than all the interacting objective qualities together. Lighting quality is influenced by three main influences; individual well-being, economics, and architecture (Veitch, 2001b). Each of these influences can be divided into several minor subcomponents (see Figure 1). Of these three main influences, only architecture is composed of objective qualities. The other two influences are subjective qualities of lighting. Collins, Brown, & Bowman (1988) also found that an individual's general well-being is an influence in determining symptoms of visual discomfort. Parsons (2000) stated that persons do not respond to their environment (including lighting) in a consistent way related to direct measures of the physical environment. It is dependent on the intra-individual and inter-individual differences. Intra-individual differences are differences that occur in the same person over time (e.g., emotional state, fatigue) and are therefore a part of the individual well-being described by Veitch (2001b).

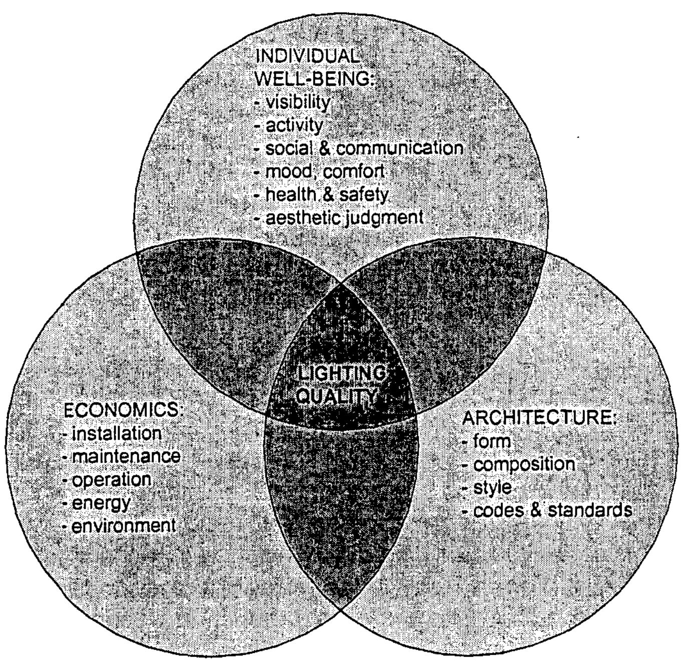


Figure 1. *Influences and subcomponents contributing to lighting quality (Veitch, 2001b).*

The inter-individual differences are differences between people and are for example gender and age (Parsons, 2000). Veitch (2001b) also made the link between these intra-individual and inter-individual differences. She states that the individual well-being variables as mentioned in Figure 1 differ depending upon individual characteristics such as age and eye sensitivity. They may do so through any of several mechanisms; perceived control, attention, environmental appraisal, and affect.

The relationship between lighting and arousal is still a matter of discussion between researchers (Veitch, 2001a). Noguchi & Sakaguchi (1999) found that a high colour temperature[4]-[8] stresses and activates the autonomic nervous system and the central nervous system. Baron, Rea, & Daniels (1992) concluded that low levels of illuminance positively affected interpersonal behaviours in that the participants rated fictitious employees better. These enhanced ratings are equal to the effects of receiving gifts. Baron *et al.* (1992) also found that exposure to warm-white light increased subjects' willingness to serve as unpaid volunteers.

Since research in most of these areas is still at an early stage it is not clear whether daylight and electric light have the same effect. The above-mentioned unique characteristics (e.g. changes over time in intensity, direction, and spectrum) of daylight might just be the cause of the above-mentioned psychological effects.

Preferred Lighting Conditions
Illuminance is well researched. Up to a certain extend (500-1000 lux), more light increases visibility. However, there is a broad range of everyday illuminances over which tasks are equally visible (Rea & Ouellette, 1991). The optimal illuminance in work environments however, is still debated over in literature. The current tendency is to emphasize individual control because there are so many differences between people. Veitch & Newsham (2000) observed that preferred desktop illuminance ranged from 83 to 725 lux in an open plan environment test facility. Boyce, Eklund, & Simpson (2000) found in a lab experiment that people use lighting control systematically to set different illuminance levels for different tasks. The way in which they did this differed from person to person. The average preferred illuminance level, derived out of a wide range of preferred illuminance levels, in a research conducted by Newsham & Veitch (2001) was 490 lux. However, a separate set of participants set the level to 400 lx to avoid glare on the VDT screen. In a research conducted by Begemann, Beld, & Tenner (1997) a desired extra amount of electric lighting on top of the daylight showed a level of 800 lux.

Glare (both direct and indirect) is thought of as being a negative quality of lighting. Glare is to light as noise is to sound. It is unwanted luminous energy and should therefore be minimised as much as possible. There are two types of glare: disability glare and discomfort glare. "Disability glare describes the effect of scattered light, from luminaries or bright surfaces, when it reduces the contrast between a viewed object and its background. Discomfort glare refers to the experience of physical symptoms associated with viewing bright sources, either in the field of view or by reflection" (Veitch & Newsham, 1996 p. 22).

Loe, Mansfield, & Rowlands (1994) related the uniformity of the lighting of an entire scene to judgements of interest. The more differences in lighting, the more interesting the environment is. The variability and interest appear to be desired, although the degree in which this should happen is yet debated over (Veitch & Newsham, 1996). In a study performed by Bernecker, Davis, Webster, and Webster (1993) the visual comfort drops with a lack of uniformity on the desktop. In a later study Veitch & Newsham (2000) have concluded the same. Interesting desktop luminance scenes (i.e. scenes with high lighting differences on the desktop) are not necessarily the most preferred office lighting conditions. 57.4 % of their participants preferred a uniform environment. The desired uniformity of an entire scene seems to be different from the desktop uniformity

[4] Relates to the colour of a completely radiating (blackbody) source at a particular temperature and of light-sources that colour-match such a body.

The characteristic 'daylight' is such a separate element in the illuminating science that this will be discussed below.

Through conjoint analysis Muramatsu & Nakamura (2002) ordered the above-mentioned characteristics. They found illuminance is most important, followed by glare, lighting distribution (uniformity) and usage of daylight.

Lighting and Satisfaction

Several recent laboratory- and field studies (Boyce *et al.*, 2000; Roche *et al.*, 2000; Newsham *et al.*, 2002a; Muramatsu & Nakamura, 2002) have found that individual lighting preferences differ from person to person. Individual control over lighting will allow people to adjust the lighting to their own preferences. Therefore successive research examines the possible beneficial role individual lighting control can have on satisfaction. Newsham & Veitch (2000), Jennings, Rubinstein, DiBartlomeo, & Blanc (2000), Roche *et al.* (2000), and Maniccia, Rutledge, Rea, & Morrow (1999) have all demonstrated that individual lighting control has an association with increased satisfaction and energy savings.

The way individual controls are being used differs greatly from individual to individual (Boyce *et al.*, 2000). This is in line with results found by Newsham & Veitch (2001) who found that people experiencing lit environments that are substantially different from their preference, show significantly lower ratings of lighting quality and overall environmental satisfaction.

This can have a positive impact on the cost effectiveness of work in several ways. First, with individual control people who desire a lower illuminance level than is generally installed can save energy on electric lighting. Second, task performance might be improved because of a better harmony between the illuminance level and the physical characteristics of the individuals' visual systems. Third, with more control, peoples' moods might be improved.

Daylight versus Electric Light

Life in modern societies differs in many ways from life before industrialization. Until the end of the 19th century most of the activities humans undertook were performed during the day. Darkness was hard to overcome with fires, torches, or candles. Therefore, little could be done during the night. The industrial revolution, and with it the development of electric lighting, overcame this problem.

Vision, provided through lighting, is an important source of information. During years of evolution, the human eye adapted to the characteristics of daylight (Li & Lam, 2001). An advantage of the present time is that through the development of technology we are now able to generate lighting that provides a high quantity of light at any time, day or night. It is sufficient to perform a staggering amount of tasks either during daytime or nighttime.

Nevertheless, electric lighting is not the same as daylight. Although it is built out of the same electromagnetic fundamentals it does not posses certain characteristics. Daylight is distinguished by its unique, ever changing spectra and distributions (Rea, 2000). Daylight is a dynamic light source (i.e. it comprises diffuse skylight, reflected light, and intense direct sunlight), changing in intensity, direction, and spectrum across the day as well as across seasons (Heerwagen & Heerwagen, 1986). Begemann *et al.* (1997) conclude that no matter what the daylight illuminance levels are, people always add 800 lux of electric lighting. Therefore, the dynamic pattern of daylight might be preferred over the static illuminance levels of electric lighting. Simultaneously the necessary windows donate extra information about the outside world (i.e. weather conditions, time of day and outdoor activities) (Fontoynont, 2002; Leslie, 2003; Reinhart, 2001). These differences in quality may contribute to a different perception and reaction to daylight than to electric light.

Additionally, the outside view often procured with receiving daylight allows an individual to relax his or her eyes by focussing on distant objects (Rea, 2000). According to Herzog, Maguire, & Nebel (2003) natural elements (which are more likely to be seen outside than inside) lead to attention restoration on all four components of the attention restoration theory (being away, extent, fascination, and compatibility).

Roche, Dewey, & Littlefair (2000) did research on the aspects of daylight and windows and found that an average daylight factor[5] between 2% and 5% is most desired. This numbers correspond to existing guidelines on the amount of daylight entering work environments. Too high a percentage they concluded causes discomfort due to overheating from the sun, glare and reflections. "Nevertheless, most people (73%) considered having a window in their work area very important".

It is found that daylight is supportive of human health and activities. A decline in the intensity, duration, or time of exposure may contribute to fatigue, mood shifts, and reduced performance. At the same time, when implemented properly, daylight can lessen energy demands through the reduction of the use of electric lighting (Athienitis & Tzempelikos, 2002; Leslie, 2003).

[5] The ratio of interior daylight illuminance at a given point on a given plane (usually the workplane) to the exterior illuminance under the same overcast sky conditions.

CONCEPTUAL FRAMEWORK

As mentioned previously, exploring lighting effects addresses many different issues. How an individual perceives lighting is dependent on even more variables. There is a constant interaction between the objective lighting quality (lighting characteristics) and the subjective lighting quality (the environmental circumstances and the individual's state of mind).

As mentioned under the heading 'Lighting', lots of research has been performed on lighting quantity, but present-day research focuses on relating many physical descriptors of lighting conditions to the many behavioural needs of people, following an integrated model of lighting quality. Lighting quality is gaining interest of more and more researchers.

The first objective of this research (i.e. 'Determining the effect the diverse aspects of lighting have on the different aspects of satisfaction') connects well to these new developments. The literature points towards the direction that the different characteristics of lighting (i.e. illuminance, uniformity, luminance, direction, spectrum and dynamics) have an influence on the different forms of satisfaction. These forms of satisfaction insofar as lighting and work environment are concerned are: Overall Environmental Satisfaction, Job Satisfaction and Satisfaction with Lighting. On top of that, there is the question whether daylight is better than electric lighting concerning satisfaction. Focussing on either one of the different satisfaction forms, the research question ('What is the contribution of light, electric and daylight, on satisfaction?') is bipartite and can therefore be divided.

Lighting and Satisfaction

The first part is concerned with the effect lighting has on the different forms of satisfaction. The following hypotheses can be derived:

1a. The various aspects of lighting (i.e. illuminance, uniformity, non-glare, direction, and daylight) will have a significant beneficial contribution on Overall Environmental Satisfaction.
1b. The various aspects of lighting (i.e. illuminance, uniformity, non-glare, direction, and daylight) will have a significant beneficial contribution on Job Satisfaction.
1c. The various aspects of lighting (i.e. illuminance, uniformity, non-glare, direction, and daylight) will have a significant beneficial contribution on Satisfaction with Lighting.

The prediction is that the different aspects of lighting will have a positive effect on all three components of satisfaction. Illuminance is the aspect that will have the main influence. The prevalent influence of these aspects will be on the Satisfaction with Lighting, followed by the Overall Environmental Satisfaction and lastly, the Job Satisfaction.

Daylight versus Electric Lighting

The second part is concerned with the possible different effects of daylight versus electric lighting. The following hypotheses can de divided:

2a. The various aspects of daylight will have a bigger beneficial contribution on Overall Environmental Satisfaction than the equivalent different aspects of electric lighting.
2b. The various aspects of daylight will have a bigger beneficial contribution on Job Satisfaction than the equivalent various aspects of electric lighting.
2c. The various aspects of daylight will have a bigger beneficial contribution on Satisfaction with Lighting than the equivalent various aspects of electric lighting.

The prediction is that the influence of daylight will have stronger effects than electric lighting on all three components of satisfaction. The prevalent influence of these aspects will be on the Satisfaction with Lighting, followed by the Overall Environmental Satisfaction and lastly, the Job Satisfaction.

Daylight versus Window

Daylight differs from electric lighting. It is interesting to see whether or not receiving daylight also increases the different kinds of satisfaction. If so, it might therefore be more beneficial than electric lighting.
Another intriguing aspect to investigate is to see which aspect is more important, receiving daylight in your work environment or having a window. The advantage of having a window as opposed to only receiving daylight is that it provides, besides daylight, an outside view. This latter aspect has been found to be beneficial. A fourth, (control) hypothesis can therefore be derived out of the first research question[6].

3. Having a window will have a bigger positive contribution towards satisfaction than only receiving daylight in your workstation. Only receiving daylight in its turn will be more beneficial than having no daylight at all.

The extra beneficial aspects of receiving daylight and having a window will most likely lead to a higher satisfaction on all three components. Therefore people with no daylight at all will be least satisfied, followed by the people receiving only daylight. People with a window, and thereby also receiving daylight, will be most satisfied. Dividing up the sample set in subjects receiving no daylight, only daylight and subjects having a window will show that this is the case.

[6] This is even more important when you consider that the work situation in North America differs from Europe. Where in most European countries daylight (and an outside view) is mandatory by law, this is not the case in North America (the USA and Canada).

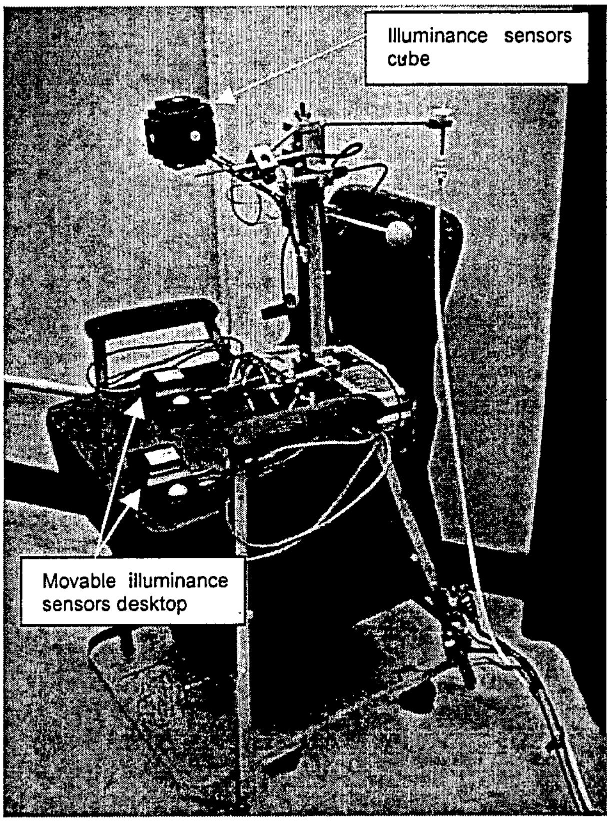
METHOD

The data of the COPE field study comprises measurements of 779 workstations in 9 buildings. The buildings are scattered over North America, geographically ranging from Quebec City, Quebec, Canada in the northeast to San Rafael, California, United States of America in the southwest. Large companies or the federal government occupied the buildings. There were various departments in each building.

The time of the measurements range from May 2000 to April 2002. Measurements have been performed in all four seasons. The data consists of physically measured data (e.g. illuminance, radiant temperature, and sound level) combined with a satisfaction questionnaire encompassing several components of satisfaction (e.g. environmental satisfaction, job satisfaction and satisfaction with lighting). The lighting and satisfaction portion of this data will be used in this final thesis.

Data Collection

A team of researchers working for the IRC collected the data. They were all instructed on the procedures of the data collection and how to use the equipment. The data was collected using a specifically developed chair (see Picture 2) and cart (Veitch *et al.*, 2002). This equipment measured the microclimate at the position occupied by an employee in an open-plan office environment.



Picture 2. *COPE-study chair with the physical data collecting equipment (illuminance sensors highlighted).*

These open-plan office environments, or cubicles, are typical work environments in North America. Cubicle sizes range from desk-size (3 m²) to an average closed office size (12 m²). Cubicle walls are mainly free-standing fabric partitions or furniture elements. They range in height from desktop height until 1.80 m.

The chair served as a platform for the indoor environment sensors. The various sensors mounted on the chair are among others: illuminance sensors, air velocity equipment, and octave band analyzers. The illuminance measurements were taken corresponding to locations defined in lighting recommended practice documents (Human Resources Development Canada, 1989;

Illuminating Engineering Society of North America, 1993). The cart, among other things, held data acquisition equipment. For a full description see Veitch *et al.* (2002).

All the 779 workstations were visited during the day (DayTime). NRC researchers returned after normal working hours to perform additional physical measurements, including illuminance measurements (NightTime). These measurements took place on a subset (around) of the workstations visited during the day. The decision whether or not a workstation would be visited during the night was not based on any general rule but merely on common knowledge and floor plans.

Satisfaction Measurements

For a workstation to be visited it had to be occupied and the employee had to be willing to participate in the experiment. Participating employees were presented with a palmtop consisting of a questionnaire addressing their workstation satisfaction and demographic and other information. They were instructed to fill out the questionnaire referring to current environmental conditions. This frame of reference was correlated with the physical data gathered with the chair and cart. Participants were able to answer or skip each question but were not able to return to a previous one (Veitch *et al.*, 2002).

The questions and their response categories are inserted in Appendix A: the satisfaction questionnaire. Nineteen questions were primarily based upon Stokols and Scharf's (1990) research on assessing employees' ratings of facility performance. One question asked the participant to rank seven elements of the work environment in order of their importance. The used software prevented more than one element with the same rank. Two questions used the same disagree/agree scale and were basically drawn from an, at that time, recent survey of job satisfaction for the Canadian Federal Public Service (Ross, 1999). One question required a rating on how the environment influenced the participant's productivity at the time of the survey relative to general prevailing conditions (Wilson & Hedge, 1987).

The answers relating to workstation satisfaction were transformed to result in more general satisfaction categories in the different fields of study incorporated in the COPE field study. The procedures used to establish this, are exploratory[9] and confirmatory factor analysis[10]. This leads to three clear factors (labelled Satisfaction with Privacy, Satisfaction with Lighting, and Satisfaction with Ventilation) with several high value loadings on each. The same has been done for Overall Environmental Satisfaction and Job Satisfaction. The way the for this thesis relevant satisfaction categories are derived out of the questionnaire can be found in Table 1. Scores on the three measures of satisfaction were averages of the responses on the contributing questions; thus, the range of possible scores was from a low of 1 (very unsatisfied) to a high of 7 (very satisfied).

Satisfaction category	Way of derivation
Overall Environmental Satisfaction	Average of 'productivity' (26)* and 'satisfaction indoor environment' (27)
Job Satisfaction	Average of 'good place to work' (24) and 'satisfaction with the job' (25)
Satisfaction with Lighting	Average of 'amount of desktop lighting' (1), 'amount of light for computer work' (10), 'amount of glare' (11), 'access to an outside view' (14), and 'quality of lighting' (16).

Table 1. *The derivation method for Overall Environmental Satisfaction, Job Satisfaction, and Satisfaction with Lighting. * The number between brackets is the number of the question in the questionnaire.*

Through the use of Structural Equation Modelling[11] the relationship between these three factors (Satisfaction with Privacy, Satisfaction with Lighting, and Satisfaction with Ventilation) and Overall Environmental Satisfaction (OES) and Job Satisfaction was examined. The final model (see Figure 2) showed a relationship between the three factors and Overall Environmental Satisfaction and a relationship between Overall Environmental Satisfaction and Job Satisfaction.

As can be seen in Figure 2, Satisfaction with Lighting is directly related to Overall Environmental Satisfaction and indirectly related to Job Satisfaction. This means that to adequately relate lighting with satisfaction, three categories of satisfaction (Overall Environmental Satisfaction, Job Satisfaction and Satisfaction with Lighting) should be incorporated in this thesis study.

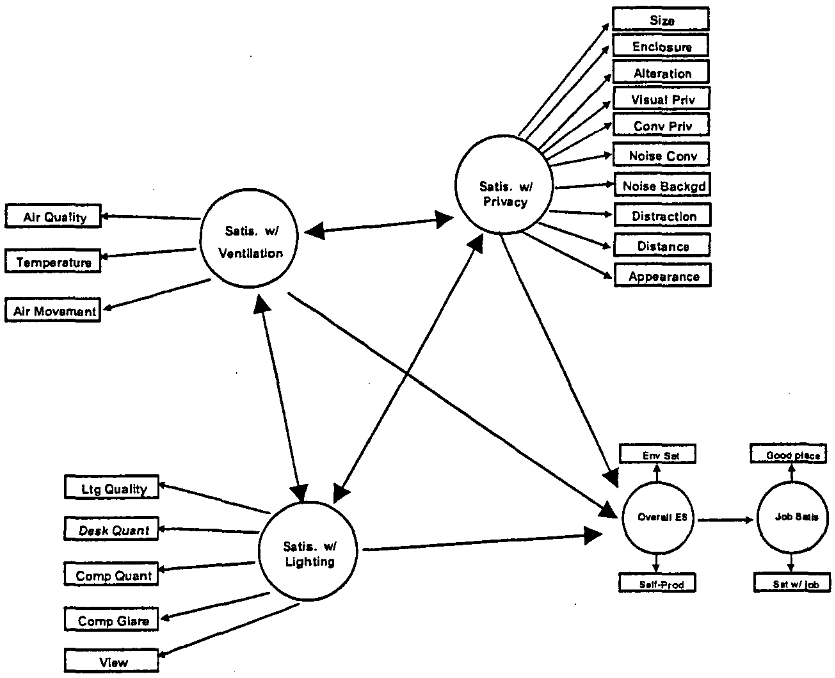


Figure 2. *Final Structural Equation Model used in the COPE-study*

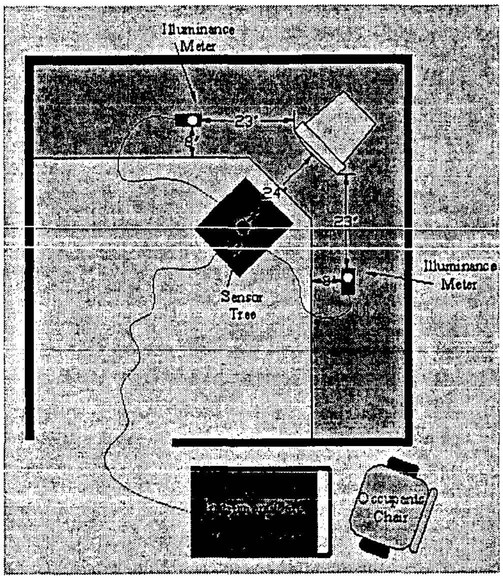
Lighting Measurements

Daytime Lighting Measurements

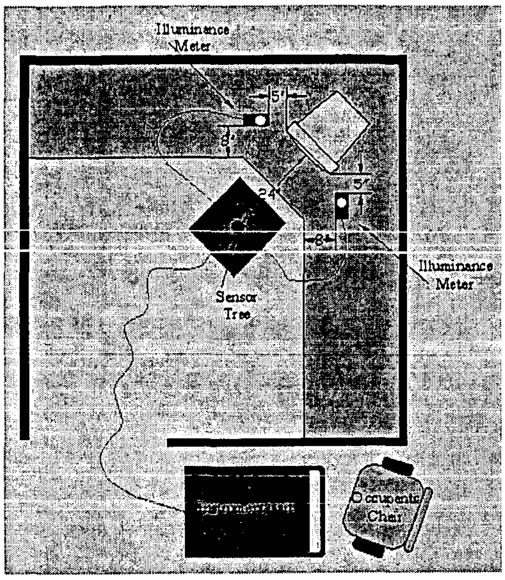
During the COPE field study data collection, there were a number of illuminance measurements performed concerning the amount of light on specific places. Multiple locations on the six sides of a cube, called cubic illuminances (developed by C. Cuttle (1997), see picture 2), and on both sides of the visual display terminal, called the desktop illuminances (see pictures 3 and 4), were where these measurements took place. These measurements resulted in the lighting variables used in this thesis; illuminance, uniformity, direction, glare, and daylight.

Illuminance (on the cube)

The illuminance levels were derived from the cubic illuminance measurements. For this study, it was applied using a cube with sensors on six sides, measuring illuminance at the location of a human's head when a person is working on a computer. By doing so, variations in the level of illuminance at the eye caused by movement of the head can be taken into account. The average of the six illuminance levels has been used in this research.



Picture 3. *Location of the first two of four desktop illuminance measurements; recorded during day and night.*



Picture 4. *Location of the second two of four desktop illuminance measurements; recorded during day and night.*

Uniformity

The uniformity variable was derived from the desktop illuminance levels. The minimum measured value of the four desktop illuminance levels was subtracted from the maximum measured value. This result was divided by the maximum of the four desktop illuminance levels [$(E_{max} - E_{min})/E_{max}$]. This gave a number between '0' and '1' in which a number approaching one stands for a big difference between the maximum and minimum measurements. A number approaching zero indicates a small difference between the maximum and the minimum, thereby indicating a more uniform desktop luminance. A cubicle for which the general levels of illuminance are lower can be as uniform as a cubicle with in general higher levels of illuminance. By including the second step in the calculations (dividing through the maximum), the level of illuminance is cancelled out from the analyses. Thereby the uniformity is the sole determinant in this variable.

Direction
The direction variable takes the angle of incidence of the light into account. The average horizontal value of the cubic illuminances was divided by the average vertical cubic illuminances. A value close to one indicates the light coming from the horizontal and vertical planes is almost equal. The farther away from 1, the more difference there is between the horizontal and vertical plane illuminances.

Glare
The glare variable is a discrete variable caused by reflections of the electric lighting in the computer screen and consists of three levels. These three levels are a low, medium and high amount of glare on the visual display terminal. A low glare rating represents a black screen or a screen with dull glare. If the glare on the screen is neither dull nor bright it has been given a medium rating. This has also been applied for screens with a bright section, which cover less than 1/16 of the screen. A high glare rating represents a screen with a bright section bigger than 1/16 of the screen. These values were derived from the pictures taken of the screens at the time of the field data collection.

Daylight
For the daylight variable a distinction has been made between workstations having a window and an outside view, workstations being less than 5 meters from a window but not having an outside view, and workstation being farther away than 5 meters from a window. This distinction has been made due to the fact that daylight penetrates a building for a maximum of 5 meters. The literature also points towards a different appraisal between on the one hand receiving daylight and having an outside view and on the other hand only receiving daylight.

A limited set of workstations was also visited at night to obtain lighting measurements without the influence of daylight.

Deriving Daylight Contributions
Since there is a distinction between daylight and electric lighting it is important to find out what the amount of daylight in the workstations has been. However, there are no direct daylight measurements performed by the COPE field study team. The daylight contributions[12] therefore have to be derived by subtracting the night-time measurements from the daytime measurements, since the contribution of daylight during the night is zero. Electric light from outside is assumed to be low. The majority of the workstations are located on higher levels so streetlights have no effects. Reflective light from neighbouring buildings are minimum since the distance between the researched building and their neighbours are large enough.

Approximately one third of the workstations (N = 262 out of a total of 779) were measured both during the day and the night. The remaining workstations (N = 517) were only measured during the day and can therefore not be used directly to derive the daylight contributions. For the results to be as reliable as possible and suitable for statistical calculations it is necessary to use as many workstations as possible. Therefore workstation with no NightTime measurements (N = 517) ought to be compared with workstations on which NightTime measurements have been performed (N = 262). If they are similar on all respects the NightTime measurements can be generalized, or copied, to the workstation without NightTime measurements.

To do so, several steps need to be taken. The first one is to check the difference between the DayTime and the NightTime measurements of the 262 workstations. Workstations with low discrepancies can be used further on in the research. It was impossible to include the workstations with windows. The reason for this is that they could not give any assurance whether or not the measurements were accurate due to the influence of daylight entering the workstations. It was not clear whether the differences between DayTime and NightTime measurements of these workstations only came from the daylight or also from flaws in the measurement.

When these 262 workstations have small differences it can be assumed they do not receive any daylight. This will be checked in the *error-testing process*. The second step is to check for the closeness of these workstations to each other (*scattering check*). A second check to make certain that there is absolutely no daylight entering into the derived workstations has to be performed (reliability check). The final step contains generalization of the workstations that were measured during the night on those workstations not measured during the night (generalization process).

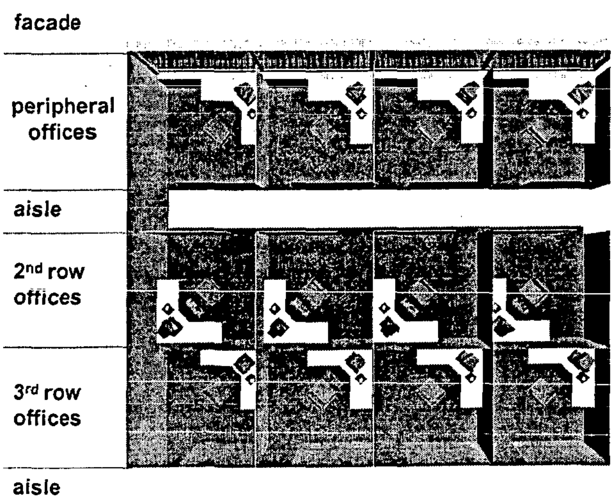
Error-testing Process

The difference between the DayTime and the NightTime measurements is dependent on two main factors:

- Daylight entering the workstation;
- Measurement errors owing to the fact that (1) different lights can be turned on during the night than during the day (e.g. one building had a dimming function on its luminaires and it was decided that the luminaires would be fully turned on during the night; task lights might be turned off during the day but on during the night), (2) objects in the vicinity of the measurement equipment might be replaced between the two measurements causing or removing shadows, (3) there might be a slight difference between the location of two corresponding measurements.

Method

It is common knowledge that daylight penetrates a building for a maximum of 5 meters when there are no obstacles in the path of the light beams, see picture 5. By use of the floor plans it is determined whether a workstation is farther or closer than 5 m from a window. The exact amount of daylight however cannot be deduced this way. Further more, the same article showed that 2nd row workstations[7] receive some daylight but by far not enough to allow working without electric lighting for any considerable part of the



Picture 5. *Daylight will penetrate a building in general up to the second row offices; which is comparable to 5 meter. (Reinhart. 2001)*

[7] A 2nd row workstation is defined as an office, which directly borders a peripheral office or an aisle adjacent to a peripheral office.

working year. These conclusions were drawn after performing simulations on some of the workstations visited in the early stages of the COPE field study.

The workstations that apply to these two criteria (measured during the night and farther than 5 m from a window) have theoretically a contribution of zero lux of daylight. Still, the difference between DayTime and NightTime measurements might be quit large. To find out whether or not there is a matter of measurement error there are two criteria set up. First, the subtraction of the NightTime measurements from the daytime measurements may not drop below 0 lux. Daylight, after all, cannot contribute in a negative way to the daytime measurements. Also, a difference of more than 50 lux between the values of the DayTime measurements and the NightTime measurements strongly indicate that the measurement difference is far greater than would be caused by the daylight contribution. A discrepancy of 50 lux is generally allowed however because lighting measurements are subjected to inaccuracies that can lead to up to a 20% difference between two output results of the same constant light source.

To check for the accuracy of the measurements, one by one the cube measurements will be considered. There was less possibility of error in positioning the chair, and fewer possible obstacles changing the locations of the measurements devices for the cube measurements than for the desktop measurements.

Result

Of the 779 workstations that were visited by the COPE-team there are 115 workstations that meet the two criteria of having NightTime measurements performed on them and being farther than 5 m away from a window. Of these 115 workstations there are 81 workstations that have a value below zero on either one of the six sides of the cube. This means that there are 115 – 81 = 34 workstations (29.6 %) that might have a difference between the DayTime and NightTime measurements due to a daylight contribution.

To check for this, the six cubic illuminance measurements of all 34 workstations have been compared to reflect on a 50 lux maximum difference. There are 13 cubicles for which minimal one of its six derived values is above 50 lux. This leaves 34 – 13 = 21 workstations (18.3 % of 115) that might be used to determine daylight contributions.

The main reason for this discrepancy between DayTime and NightTime measurements (21 out of 115) lies in the amount of artificial light turned on during the night. Some of the luminaires in the buildings could be manually adjusted, thereby changing the amount of electric light reaching the desk and the luminance measurement equipment. Upon returning for the NightTime measurements the COPE-team decided to turn on all the luminaires at their maximum output when there was any questioning on the DayTime situation. This holds for both the ceiling based luminaires as for the task lighting. The reason for this decision is that they could estimate the effect of the entire installation.

The 21 workstations with small enough discrepancies are scattered over 6 buildings. All of them are rechecked on errors by use of the pictures and floor plans. All things considered it can be concluded that workstations exceeding the 5 m criteria do not receive any daylight whatsoever. To get an answer on the first research question: "*What is the exact contribution of daylight on the overall environmental satisfaction and job satisfaction?*" it is important to mirror as many of these 21 NightTime measured peripheral workstations as possible to there corresponding non NightTime measured peripheral workstations.

Scattering Check
There are now 21 workstations left. These are the workstations with NightTime measurements, are more than 5 meters away from a window, and have small discrepancies between DayTime and NightTime measurements (i.e. where we can be confident that the differences are caused by relatively small measurement errors). The next step is to see whether or not these workstations are geographically near to each other or are scattered over all the floors and buildings.

The reason for this is that when they are geographically located in a small uni-characteristic section[8] of a floor it might be able to statistically prove that the total population has accurately been measured. Therefore all the NightTime measured workstations can be safely copied to their corresponding non NightTime measured workstations.

Method
As mentioned previously the 21 workstations are distributed over 6 different buildings. The exact distribution is as follows:

Building / floor	F_{floor} / X_{floor}	Y_{build} / X_{build}
Building 1		
First floor	0 / 1	
Second floor	0 / 6	
Total		0 / 7
Building 2		
First floor	0 / 1	
Second floor	0 / 5	
Third floor	0 / 2	
Total		0 / 8
Building 3		
Total		1 / 5
Building 4		
Total		4 / 12
Building 5		
Sixth floor	0 / 2	
Seventh floor	1 / 5	
Ninth floor	2 / 6	
Tenth floor	1 / 12	
Total		4 / 25
Building 6		
Second floor	1 / 3	
Third floor	7 / 8	
Fifth floor	0 / 2	
Eleventh floor	2 / 3	
Total		10 / 16
Building 7		
Tenth floor	0 / 15	
Eleventh floor	0 / 8	
Twelfth floor	1 / 7	
Total		1 / 30

[8] A section of a floor in which all the environmental conditions are the same for every work station (i.e. same partition height, same location of the luminaires, same size, same relative position of the computer screen to the luminaires)

Building / floor	F_{floor} / X_{floor}	Y_{build} / X_{build}
Building 8		
Total		1 / 6
Building 9		
First floor	0 / 0	
Second floor	0 / 3	
Third floor	0 / 3	
Total		0 / 6
Overall total		**21 / 115**

Table 2. *Number of workstations with small discrepancies between DayTime and NightTime measurements compared to the total amount of workstations; divided into buildings and floors. Y = the number of workstations with small measurement errors. X = total number of workstations with DayTime and NightTime measurements.*

From this table it can be deduced that there is just one single building (number 6) that is likely to have accurate measurements. These categorical variables can be tested with the use of a binominal test[9] (Agresti & Finlay, 1999, p. 188). The results (P(X = 16) = 0.895) show that less than 95 % can be accounted for. Therefore the in-between measurements have too big of a discrepancy and the workstations cannot be mirrored over the entire building.

Result

The third floor of the same building is the only floor for which the measurements are accurate enough (P(X = 8) = 0.996). This means that there are 7 workstations, which can be mirrored over equivalent workstations on the same floor. These are therefore the only workstations that can be used to answer the research question. (For a complete list of the results refer to appendix B.)

Reliability Check

The LightSwitch Wizard is a tool with which the annual amount of daylight entering an office can be calculated (Reinhart, 2001). The space design variables that this wizard takes into account are the workstation size, partition height, floor to ceiling height, aisle width, ceiling reflectance, partition reflectance, floor reflectance, façade orientation, shading device, $\tau_{visible}$ of windows (clear or tinted glass), and climates centres. With this wizard a reliability check will be performed to make sure there is absolutely no daylight entering the seven non-error workstations of the third floor of the 6th building (3FB6).

Method

To do so these 3FB6 workstations will be compared to calculations performed on resembling workstations with the use of the LightSwitch Wizard. Positive results will confirm that there is no daylight entering the 3FB6 workstations and therefore the measurement errors are small enough (e.g. difference between daytime and night-time between 0 and 50 lux).

Reinhart (2001) has performed calculations with different combinations on the above mentioned space design variables. For all of the seven 3FB6 workstations a representing LightSwitch workstation has to be distilled out of those calculations. Results of the calculations on these LightSwitch workstations will show whether or not there is a significantly small amount of daylight in every 3FB6 workstation. In Table 3 all the variables for the different 3FB6 workstations can be found.

[9] "A process in which only one of two outcomes can eventuate, is called a Bernoulli trial" (Hays, 1988, p. 121). "An experiment carried out in such a way that *N* independent trials are made from a stationary Bernoulli process is known as binomial sampling" (Hays, 1988, p. 130).

WS ID	Variable WS size [m (ft)]	Partition height [m (in)]	Ceiling height [m (ft)]	Aisle width [m (ft)]
3FB6WS1	2.8 x 3.0 (9.2 x 9.8)	1.72 (68)[1]	2.5 (8.3)	2.0 (6.4)
3FB6WS2	3.3 x 3.0 (10.8 x 9.8)	1.72 (68)	2.5 (8.3)	2.0 (6.4)
3FB6WS3	3.0 x 3.0 (9.8 x 9.8)	1.72 (68)	2.5 (8.3)	2.0 (6.4)
3FB6WS4	2.2 x 3.1 (7.2 x 10.2)	1.72 (68)	2.5 (8.3)	2.0 (6.4)
3FB6WS5	3.2 x 3.0 (10.5 x 9.8)	1.72 (68)	2.5 (8.3)	2.0 (6.4)
3FB6WS6	3.2 x 3.0 (10.5 x 9.8)	1.72 (68)[1]	2.5 (8.3)	2.0 (6.4)
3FB6WS7	2.8 x 2.8 (9.2 x 9.2)	1.72 (68)	2.5 (8.3)	2.0 (6.4)

WS ID	Variable Ceiling reflectance[2]	Partition reflectance[2]	Floor reflectance[2]	Façade orientation
3FB6WS1	80 %	50 %	20 %	North
3FB6WS2	80 %	50 %	20 %	North
3FB6WS3	80 %	50 %	20 %	South
3FB6WS4	80 %	50 %	20 %	South
3FB6WS5	80 %	50 %	20 %	South
3FB6WS6	80 %	50 %	20 %	South
3FB6WS7	80 %	50 %	20 %	South

WS ID	Variable Shading device	$T_{visible}$ of windows	Climate centre	Row
3FB6WS1	Manual	Clear	Winnipeg, MB	3rd
3FB6WS2	Manual	Clear	Winnipeg, MB	2nd
3FB6WS3	Manual	Clear	Winnipeg, MB	2nd
3FB6WS4	Manual	Clear	Winnipeg, MB	3rd
3FB6WS5	Manual	Clear	Winnipeg, MB	2nd
3FB6WS6	Manual	Clear	Winnipeg, MB	2nd
3FB6WS7	Manual	Clear	Winnipeg, MB	2nd

***Table 3 a,b,c.** Variable of the 7 3FB6 workstations. [1] Although not all partitions are 1.72 m high, the one facing the window is. [2] There were no reflectance measurements performed. Values are assumed according to the pictures and correspond to the most common reflection values for offices.*

Result

Reinhart made calculations for 16 different types of workstations. The seven 3FB6 workstations can be compared to two of those 16 LightSwitch workstations, since most of the seven 3FB6 workstations are quite similar. In Table 4 you can find the clustering of the seven 3FB6 workstations and their representing LightSwitch workstation with its slightly incongruous characteristics. Some of the variables cause a bit more daylight while others block it more. Overall, they can be regarded as to be averaging out so the two representing LightSwitch workstations are adequate.

LightSwitch	Building 6	Variables different from the 7 3FB6 workstations WS size	Partition height	Ceiling height
LS_WS1	3FB6WS1 3FB6WS2 3FB6WS3 3FB6WS5 3FB6WS6 3FB6WS7	10 x 10	72	8
LS_WS2	3FB6WS4	8 x 8	64	9

***Table 4.** Values of the incongruous characteristics between the LightSwitch workstations and the 3FB6 workstations.*

LightSw WS	Climate centre	Façade orientation	Shading type	Glazing type	Daylight autonomy[A] (> 450 lux)		Daylight appearance[A] (> 150 lux)		Desktop illuminance[A] ∈ [300 lux, 600 lux]		Desktop illuminance uniformity[A]		Mean VDT illuminances[A] >550 lux	
					R 2	R 3	R 2	R 3	R 2	R 3	R 2	R 3	R 2	R 3
1	Win	North	Manual	Clear	1 %	1 %	1 %	1 %	0 %	0 %	2 %	4 %	1 %	1 %
	Win	South	Manual	Clear	1 %	-	1 %	-	0 %	-	6 %	-	1 %	-
2	Win	South	Manual	Clear	-	1 %	-	1 %	-	0 %	-	0 %	-	1 %

***Table 5.** Calculated values for the LightSwitch workstations.* [A] *For definitions see chapter 'Glossary'.*

Although second row workstations can receive a fair amount of daylight, depending on the type of glazing, façade direction and shading type, the LightSwitch workstations used in this comparison study hardly receive any daylight. Except for the 'desktop illuminance uniformity' there isn't a single variable for the representing LightSwitch workstations that exceeds the 1% level (see table 5).

In this case the 'desktop illuminance uniformity' is not relevant because it does not provide information about the amount of illuminance existing in the workstation. Therefore it can be concluded that the illuminance on all the measured points in the LightSwitch workstations consist of 0 or 1 percent of daylight on an annual bases. This means that the 3FB6 workstations don't receive any substantial amount of daylight and it is safe to say that the measurements were within the limits set out for them.

Generalization Process

Because the missing data is not randomly missing, see 'Reliability', there is no statistical method that is applicable for filling in the missing data. Moreover, the offices are so different from each other that when you would divide them into groups you are left with just one or two NightTime measured workstation(s) per group. This means that statistical methods like 'multiple imputation' will transfer the measurements from one workstation with NightTime measurements to one workstation with no NightTime measurements (Figure 3a). They will not base the new values on iterative processes. Hence, it is best to manually go through all the workstations and decide on the level of the NightTime measurements via common knowledge on an individual basis.

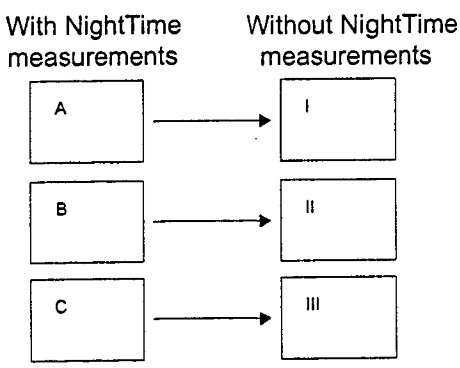


***Figure 3a**. Generalization with a statistical program (measurements from A are transposed to I; measurements from B are transposed to II, ...).*

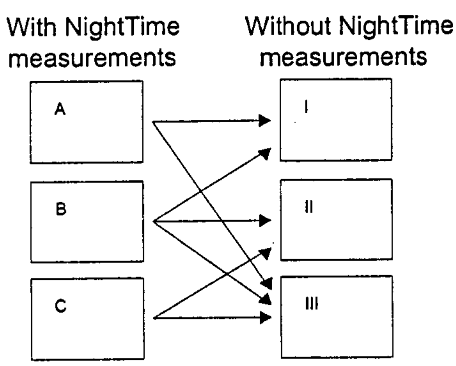


***Figure 3b**. Generalization by hand (measurements from A, B, and C are transposed to a multiple number of workstations).*

Method
Since all the NightTime measurements are located roughly at the same vertical height, all the measured points of one workstation were influenced by the same light sources (i.e. daylight and luminaires). So all measurements in one workstation were reflected on all the corresponding measurements of a similar workstation. In some cases the average of multiple workstations made up the amount of artificial light (Figure 3b).

To determine which workstations resemble each other a few guidelines were developed to guarantee a uniform process.

Guidelines
The team that collected the data took two pictures of every cubicle, one of the visual display terminal and one overview picture of the workstation. Going by these pictures the location and direction of the visual display terminal was determined and drawn into the floor plans.

Using the overview pictures of each cubicle and some overview pictures of the office floors, the location of the luminaires was determined. Whenever this was not possible due to a lack of pictures or a randomization of the luminaires, the lighting plans were requested from the contact person.

The size and shape of each cubicle were determined according to the floor plans and the pictures. The pictures, together with certain variables in the data-file, contain information on the partition height of each partition wall. Low partitions cause a wider distribution of the luminances from the ceiling luminaires and daylight. High partitions allow fewer luminances from light sources outside the workstation to contribute to the total amount of illuminance in a workstation.

For the peripheral workstations (workstations with a '0' on the DayL15 variable) it was also necessary to determine on which façade the workstation was situated. The reason for this is that the daylight entering a north facing workstation cannot be compared to the daylight illuminating a façade facing south. These two directions of daylight have different proportions of sunlight, reflections from ground and adjacent objects, and light from the sky. Therefore, they enter the building at different angles and at different quantities depending on the time of day.

Result
Taking all the guidelines into account, the generalization of the third floor of building six could occur. The 7 workstations of the third floor of building 6 that were measured during DayTime as well as NightTime were generalized to a total of 34 workstations. In total this means that the subject size has drastically been reduced (from 780 to 41). It was nonetheless enough to perform statistical calculations on them and interpret their results. In Table 6 you can find the number of remaining workstations for each step of the process.

Description	Number of workstations
- Total number of workstations	779
- Number of workstations with NightTime measurements	262
- Number of workstations with NightTime measurements and farther than 5 meter from a window	115
- Number of workstations with NightTime measurements, farther away than 5 meter from a window, and low discrepancies between DayTime and NightTime measurements	21
- Number of workstations with NightTime measurements, farther away than 5 meter from a window, low discrepancies between DayTime and NightTime measurements, and geographically near each other.	7
- Number of workstations usable for statistical analyses	41

Table 6. *The numbers of remaining workstations in each step of the process.*

Data Analysis Procedure

For each subject the data has been collected on a single occasion. This has been divided into two parts (A and B). Part 'A' consists of a questionnaire containing questions about satisfaction. The participants complete it. Part 'B' entails a physical measurement of the environmental characteristics. All as described previously under the heading 'Data Collection'.

Lighting and Satisfaction

The hypotheses 1a through 1c all lay a link between lighting and satisfaction in that the various aspects of lighting will have a beneficial contribution on the three categories of satisfaction studied in this research (Overall Environmental Satisfaction, Job Satisfaction, and Satisfaction with Lighting). For these three hypotheses a linear design has been used (see figure 4). After controlling for possible confounds (age, gender, job category) the characteristics of lighting have been inserted as independent variables. The dependent variables have been the three different components of satisfaction.

The hypotheses can be tested with a multiple regression analysis for each component of satisfaction, resulting in three different regression analyses. These analyses use the all subjects set.

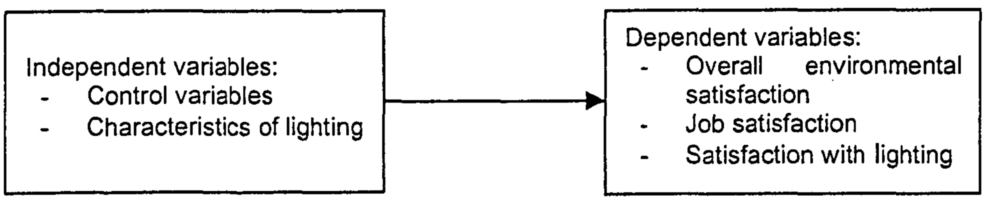


Figure 4. *Schematic representation of hypotheses 1a, b, and c.*

Daylight versus Electric Lighting

The three hypotheses 2a through 2c all make a distinction between daylight and electric lighting in that daylight will have a bigger beneficial contribution on the three categories of satisfaction (Overall Environmental Satisfaction, Job Satisfaction, and Satisfaction with Lighting) than electric lighting. For these three hypotheses two linear designs have been used (see figure 5). After controlling for possible confounds the independent variables have been inserted. These independent variables have been the characteristics of lighting. The dependent variables have been the three different components of satisfaction. This analysis has been performed twice. First the analyses on the DayLight measurements have been performed, followed by the analyses on the DayTime measurements.

The hypotheses can be tested with a multiple regression analysis for each category of satisfaction. This results in six different regression analyses. For all these analyses the 41 workstations set has been used.

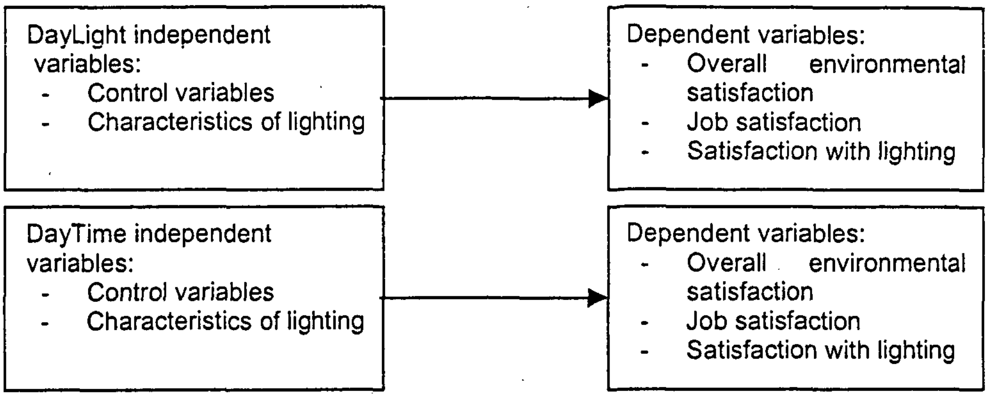


Figure 5. *Schematic representation of the hypotheses 2a, b, c.*

Daylight versus Window

The final hypothesis (*Having a window will have a bigger positive contribution towards satisfaction than only receiving daylight in your workstation. Only receiving daylight in its turn will be more beneficial than having no daylight at all*) has been tested with a linear design (see figure 6). The between subjects independent variables have been 'having a window', 'receiving only daylight' or 'none of both'. The dependent variables have been the three different components of satisfaction. There has also been some control variables added to the analysis.

The hypotheses has been tested with a Multiple ANalysis of CO-VAriance (MANCOVA[18]). For this analysis the all subjects set has been used.

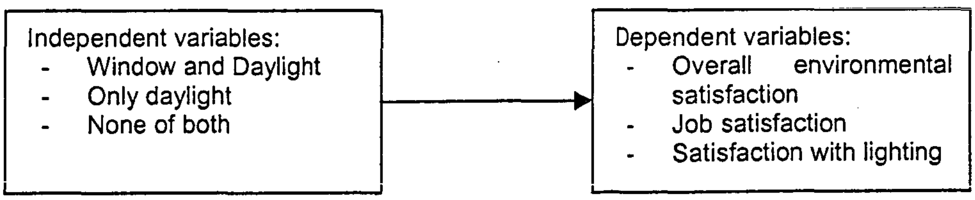


Figure 6. *Schematic representation of hypothesis 3.*

RESULTS

Descriptive Statistics

Selecting Predictors

The collected data for the COPE field study consist of a vast amount of independent and dependent variables. Put together they will create an unmanageable analysis. In addition the derived variables will interact, causing predictability to degrade. Through a stepwise reduction based upon statistical correlations and theoretical backgrounds the number of independent variables will be reduced. By applying careful thought to this, none of the reliability and validity will be lost.

Correlation analyses give insight into which variables are correlated. These correlated variables will negatively influence the results of the regression analysis and all except one of them will therefore have to be excluded. Not surprisingly, high correlations can be found between variables appertaining to the same characteristic of lighting (daylight, illuminance, uniformity, glare, and direction). The variable that best represents these researched characteristics of lighting has been used in further analyses. Besides the control variables 'age', 'Gender', 'Administration', 'Manager', and 'Professional', the independent variables are 'Daylight', 'Illuminance', Uniformity', 'Glare', and 'Direction'. The names of these independent variables correspond with the lighting characteristic they represent. The resulting correlation matrixes can be found in Appendix C: 'Correlation Matrixes'.

Normality Check

The nominal variables of these remaining variables ought to be checked for normality. This has to be done for the all subjects set as well as the 41 workstations set. This check has been performed by use of normal distribution plots (see Appendix D: 'Plots' for the most important ones) and the skewness and kurtosis results (see Tables 7 and 8).

	N	Skewness	SE Skewness	Kurtosis	SE Kurtosis
OES*	745	-0.17	0.09	-0.69	0.18
Job Satisfaction	767	-0.82	0.09	1.48	0.18
Satisfaction with Lighting	776	-0.49	0.09	-0.34	0.18
Illuminance	779	7.24	0.09	81.87	0.18
Uniformity	779	0.34	0.09	-0.42	0.18
Direction	779	1.84	0.09	16.15	0.18

Table 7. *The Skewness and Kurtosis results for all the nominal variables of the all subjects set. * Overall Environmental Satisfaction.*

	N	Skewness	SE Skewness	Kurtosis	SE Kurtosis
OES*	37	-0.24	0.39	-0.22	0.76
Job Satisfaction	41	-0.50	0.37	-0.00	0.72
Satisfaction with Lighting	39	-0.56	0.38	0.94	0.74
Illuminance DayTime	41	1.12	0.37	0.05	0.72
Uniformity DayTime	41	0.30	0.37	-1.11	0.72
Direction DayTime	41	0.08	0.37	-1.50	0.72
Illuminance DayLight	40	1.04	0.37	-0.06	0.73
Uniformity DayLight	40	1.12	0.37	5.94	0.73
Direction DayLight	40	-4.65	0.37	26.13	0.73

Table 8. *The Skewness and Kurtosis results for all the nominal variables of the 41 workstations set. * Overall Environmental Satisfaction.*

Both the values of skewness and kurtosis have to be as close to 0 as possible for the distribution to be considered normal. The rule of thumb is that the limit for skewness is –3 or 3. Below or above this, a distribution is considered not to be normal. For kurtosis these limits are –8 and 8.

For the all subjects set, shown in Table 7, there are two variables (illuminance and direction) that do not have a normal distribution. For the 41 workstations set, shown in Table 8, there is one variable (direction DayLight) that does not have a normal distribution. This is not surprising since daylight normally comes from one side, causing the direction variable to divert from a normal distribution.

Tabachnick and Fidell (2001) propose a way of testing the significance of skewness and kurtosis. This form of testing however does not hold well for small sample sizes. When it is calculated for the above results none of the distributions would be normal. In this case this test is not really applicable because of its small sample size.

It was decided that the non-normal distributed variables would not be transformed to make them normal. The reason for this is that outliers are the main cause for the distributions not to be normal anymore (see Appendix 'Plots'). Simultaneously, a transformation will make the variables more difficult to interpret. Therefore comparability between the characteristics of lighting will be lost.

Determining Outliers

To determine the univariate outliers the standardized z-scores were used. Case values on nominal distributed variables with z-scores higher than three, were excluded. A value of three corresponds with the probability falling three standard deviations away from the mean of a normal distribution, generally accepted as being a criterion for outliers.

The multivariate outliers in each analysis were identified by use of the Mahalanobis distance, d-sq. Very large values indicate that a case is an extreme outlier and probably is having an undue effect on the outcome. This statistical procedure is distributed as a chi-square and is tested against the degrees of freedom, the number of predictor variables in the model. A conservative alpha of $p<.001$ is used in this study.

Descriptive Outcomes

Now that the correct predictors have been selected, the normality check has been performed, and the outliers have been determined and excluded the sample sizes, means, standard deviations, and median of all the variables are as follows. For the all subjects set see Table 9. For the 41 workstations set see Table 10.

	N	Mean	SD	Median
OES*	722	4.07	1.30	4.00
Job Satisfaction	743	5.13	0.98	5.00
Satisfaction with Lighting	752	4.76	1.20	5.00
Age**	742	2.62	0.95	3.00
Gender**	748	1.51	0.50	2.00
Administration**	747	0.27	0.45	0.00
Manager**	747	0.09	0.28	0.00
Professional **	747	0.39	0.49	0.00
Illuminance	755	243.37	149.79	201.90
Uniformity	755	0.44	0.20	0.41
Direction	755	1.92	2.00	0.88
Daylight**	755	0.98	0.91	1.00
Glare**	749	2.32	0.82	2.26

Table 9. *Sample size, mean, standard deviation, and median for all the variables of the all subjects set. * OES = Overall Environmental satisfaction; ** age: 1 = from age 18 till age 30, 2 = from age 30 till age 40, 3 = from age 40 till age 50, 4 = from age 50 till age 65; Gender: 1 = female, 2 = male; Administration: 0 = not belonging to the group, 1 = belonging to the group; Manager: 0 = not belonging to the group, 1 = belonging to the group; Professional: 0 = not belonging to the group, 1 = belonging to the group; Daylight: 0 = receiving no daylight, 1 = receiving daylight but not having a window, 2 = receiving daylight and having a window; Glare: 1 = a completely black screen or dull glare, 2 = the glare is neither dull nor bright or the bright section does not cover more than 1/16 of the screen, 3 = the bright section covers more then 1/16 of the screen.*

	N	Mean	SD	Median
OES*	36	4.53	1.11	4.75
Job Satisfaction	37	5.24	0.83	5.00
Satisfaction with Lighting	39	5.13	0.94	5.20
Age**	37	2.54	0.90	3.00
Gender**	39	1.44	0.50	1.00
Administration**	39	0.38	0.49	0.00
Manager**	39	0.18	0.39	0.00
Professional**	39	0.36	0.49	0.00
Illuminance daytime	39	322.70	233.28	194.60
Uniformity daytime	39	0.52	0.51	0.17
Direction daytime	39	2.20	2.16	0.78
Glare**	39	2.08	0.87	2.00
Illuminance Daylight	38	221.74	235.65	116.75
Uniformity Daylight	38	0.98	0.77	0.77
Direction Daylight	38	0.97	1.40	1.10

Table 10. *Sample size, mean, standard deviation, and median for all the variables of the 41 workstations set. * OES = Overall Environmental satisfaction; ** age: 1 = from age 18 till age 30, 2 = from age 30 till age 40, 3 = from age 40 till age 50, 4 = from age 50 till age 65; Gender: 1 = female, 2 = male; Administration: 0 = not belonging to the group, 1 = belonging to the group; Manager: 0 = not belonging to the group, 1 = belonging to the group; Professional: 0 = not belonging to the group, 1 = belonging to the group; Daylight: 0 = receiving no daylight, 1 = receiving daylight but not having a window, 2 = receiving daylight and having a window; Glare: 1 = a completely black screen or dull glare, 2 = the glare is neither dull nor bright or the bright section does not cover more than 1/16 of the screen, 3 = the bright section covers more then 1/16 of the screen.*

Daytime or Daylight Measurements

The measurements of the all subjects set were performed during the day, resulting in the daytime measurements. The set consisted of all the subjects except for the univariate and multivariate outliers. The values of the 41 workstations set variables were derived from subtracting the nighttime measurements from the daytime measurements. This resulted in the daylight values of the lighting characteristics.

This subject set only consisted of the workstations that were farther away than 5 meter from a window, had low discrepancies between DayTime and NightTime measurements, and were geographically near each other. These were supplemented with the workstations that were similar to them and in close proximity, resulting in 41 workstations.

Daytime Tests Model
For the daytime tests the all subjects set can be used. The control variables used in these analyses are age, gender, administration, manager, and professional. The independent variables are illuminance, uniformity, direction, and glare. The dependent variables are Overall Environmental Satisfaction, Job Satisfaction, and Satisfaction with Lighting. With these variables the regression analyses will be performed.

Daylight Contribution Tests: Pruning
When using the 41 workstations set the number of variables is relatively large. When the four remaining independent variables (illuminance, uniformity, glare, and direction) and five control variables (3 job categories, age, and gender) are included in the regression analysis there are still 9 variables left. "... Because of the width of the errors of estimating correlation with small samples, power may be unacceptably low no matter what the cases-to-independent variables ratio if you have fewer than 100 cases. However, a bare minimum requirement is to have at least 5 times more cases than independent variables ..." (Tabachnick & Fidell; 1989). This means it is more likely predicting power will be lost if the cases-to-independent variables ratio drops below 5, which is the case with 9 independent variables and 41 subjects (cases).

To make certain no errors have been made in the preceding calculations, and thereby excluding too many subjects, a check on all these previously performed calculations on daylight entering the workstations (see heading 'Deriving Daylight Contributions') have been performed. This check revealed no flaws and therefore there are only 41 subjects that can be used in the following steps.

The result of this is that the predictors will have to be pruned to 5 or 6 variables. Reduction of the independent variables nevertheless means that a direct comparison between the results of these regression analyses and the ones performed on the entire data-set will be impossible. Up to now the exact same list of variables is being used. An indirect comparison, barring in mind the differences between the lists of independent variables, is still possible.

The three dummy coded job categories are being combined into one new dichotomous variable. To do so 'administrative' and 'technical' will be given a '0' and 'professional' and 'managerial' a 1. The combined professions are somewhat similar and the new groups are almost equal in size.

Second is to look at the age category. Most of the respondents (N = 34; 82.9 %) are above the age of 40. A subdivision at the age of 40 has been made because generally speaking, peoples' vision declines rapidly after the age of 40. This skewed distribution will lack explanatory power and can be eliminated.

The variable gender might be excluded since, up to this point, there is no sound theoretical basis to assume any difference between females and males, nor any empirical evidence (Veitch & Newsham, 2000). The distribution is equal with 22 females and 18 males.

When all the above-mentioned actions are implemented there are five independent variables left,

- Job category; divided into administrative and technical on the one hand and professional and managerial on the other hand;
- Illuminance; average of all the six sides of the cube;
- Uniformity; maximum minus minimum desktop value divided by the maximum desktop value;
- Glare; derived from pictures of the computer screens, divided in 'black screen', 'bright section less than 1/16 of the screen area', and 'bright section above 1/16 of the screen area';
- Direction; the average of the horizontal values of the cube divided by the average of the vertical values.

The correlation tables of these independent variables, combined with the dependent variables, can be found in Appendix D: 'Correlation plots pruned list of variables'. With this five variables the statistical analyses for the daylight contribution will be performed.

Analyses and Results

For this research a number of regression analyses have been performed for each aspect of satisfaction. These have been performed on:

1. the all subjects set with daytime measurements;
2. the 41 workstations set (floor 3 of building 6) with DayLight measurements;
3. the 41 workstations set (floor 3 of building 6) with electric light measurements.

With these regression analyses the hypotheses 1 and 2 ('the contribution of lighting on satisfaction' and 'the advantage of daylight over electric lighting') can be answered. All the regression results can be found in Appendix F: 'Results of the Regression analyses'. To test hypothesis 3 ('the advantages of a window are higher than only receiving daylight') a MANCOVA has been performed. The results of the MANCOVA can be found subsequent to the results of the regression analyses.

Lighting and Satisfaction

The first hypothesis is divided into three sub-hypotheses. These three hypotheses are:

1a. The various aspects of lighting (i.e. illuminance, uniformity, non-glare, direction, and daylight) will have a significant beneficial contribution on Overall Environmental Satisfaction.
1b. The various aspects of lighting (i.e. illuminance, uniformity, non-glare, direction, and daylight) will have a significant beneficial contribution on Job Satisfaction.
1c. The various aspects of lighting (i.e. illuminance, uniformity, non-glare, direction, and daylight) will have a significant beneficial contribution on Satisfaction with Lighting.

Lighting and Overall Environmental Satisfaction

Hypothesis 1a can be answered with the use of the regression analysis on the all subjects set, looking at Overall Environmental Satisfaction.

Daytime measurements and Overall Environmental Satisfaction						
Step	β	β	β	β	β	β
1. Age	-.038	-.038	-.042	-.038	-.039	-.041
Gender	.069	.069	.064	.063	.066	.066
Administration	.068	.068	.060	.066	.069	.068
Manager	-.046	-.046	-.051	-.051	-.053	-.054
Professional	-.082	-.082	-.089	-.089	-.088	-.088
2. Glare		.002	.008	.002	-.001	-.002
3. Illuminance			.066	.063	.050	.045
4. Uniformity				-.050	-.062	-.062
5. Direction					-.036	-.032
6. Daylight						.014
Change in R^2	.020*	.000	.004	.002	.001	.000
Total R^2	.020*	.020*	.024*	.026*	.027*	.027*

Table 11. *The results of the regression analysis over the all subjects set regarding Overall Environmental Satisfaction, N = 709. * p≤.05, **p≤.01, ***p≤.001*

The overall result is significant (R^2 (709) = 0.027, p < .05; see table 11), meaning that the various aspects combined do have a positive influence on the Overall Environmental Satisfaction. Being a multiple regression analysis, the various aspects are inserted one after another. This shows that none of the variables on its own has a significant influence on the Overall Environmental Satisfaction.

Lighting and Job Satisfaction
Hypothesis 1b can be answered with the use of the regression analysis on the total population, looking at job satisfaction.

Daytime measurements and Job Satisfaction						
Step	β	β	β	β	β	β
1. Age	-.125***	-.125***	-.127***	-.128***	-.131***	-.132***
Gender	-.003	-.003	-.006	-.006	-.001	-.001
Administration	-.061	-.061	-.065	-.067	-.061	-.062
Manager	-.008	-.008	-.011	-.011	-.017	-.017
Professional	-.034	-.034	-.039	-.039	-.036	-.036
2. Glare		-.017	-.013	-.011	-.016	-.017
3. Illuminance			.041	.042	.017	.013
4. Uniformity				.016	-.005	-.005
5. Direction					-.065	-.062
6. Daylight						.011
Change in R^2	.020*	.000	.002	.000	.003	.000
Total R^2	.020*	.020*	.022*	.022*	.025*	.025

Table 12. *Results of the regression analysis over all the subjects regarding Job Satisfaction, N = 724. * p≤.05, **p≤.01, ***p≤.001*

The overall result when looking at the regression analysis for Job Satisfaction regarding the total sample (Table 12) is not significant. Excluding the final step (daylight) will lead to a significant result (R^2 (724) = 0.025, p < .05). Except for the first variable, being age, none of the variables has a significant influence in any of the six steps. Interestingly, the results show that the older people are, the less satisfied they are with their job.

Lighting and Satisfaction with Lighting
With the use of the regression analysis on the all subjects set, looking at Satisfaction with Lighting, hypothesis 1c can be answered (Table 13).

	Daytime measurements and Satisfaction with Lighting					
Step	β	β	β	β	β	β
1. Age	.025	.026	.019	.025	.022	-.007
Gender	.055	.054	.044	.041	.049	.045
Administration	.094	.094	.078	.088	.097*	.091
Manager	.044	.044	.032	.033	.025	.010
Professional	-.004	-.004	-.020	-.021	-.016	-.019
2. Glare		-.081*	-.067	-.080*	-.088*	-.099**
3. Illuminance			.145***	.141***	.100*	-.005
4. Uniformity				-.090*	-.126**	-.124***
5. Direction					-.107*	-.035
6. Daylight						.278***
Change in R^2	.010	.007*	.021***	.008*	.008*	.053***
Total R^2	.010	.017	.037***	.045***	.054***	.107***

Table 13. *Results of the regression analysis over all the subjects regarding Satisfaction with Lighting, N = 732. * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$*

The individual steps 2 through 6 of the total model are all significant. This means that each characteristic of lighting has a significant influence on the Satisfaction with Lighting. Most of these characteristics also show significance in subsequent steps. In the final step (the total model) only daylight, uniformity, and glare are significant. With increasing daylight and uniformity the Satisfaction with Lighting will go up. For glare the opposite is true. The more glare, the less satisfied people are with the lighting.

The total model is also significantly positive (R^2 (732) = 0.107, $p < .001$), meaning that all the independent variables (control variables and characteristics of lighting) together, have a positive relation with Satisfaction with Lighting.

Daylight versus Electric Lighting
Like the first hypothesis, the second hypothesis is also divided in three sub hypotheses. These are:

2a. The various aspects of daylight will have a bigger beneficial contribution on Overall Environmental Satisfaction than the equivalent different aspects of electric lighting.
2b. The various aspects of daylight will have a bigger beneficial contribution on Job Satisfaction than the equivalent various aspects of electric lighting.
2c. The various aspects of daylight will have a bigger beneficial contribution on Satisfaction with Lighting than the equivalent various aspects of electric lighting.

For these hypotheses it is no longer possible to use the all subjects set. They will have to be answered with the use of the 41 workstations set.

Overall Environmental Satisfaction
For hypothesis 2a it is clear that there is a difference between receiving daylight or not (tables 14a and 14b). Job category and illuminance are significant in the final step when looking at daylight but not when looking at electric lighting measurements. This difference is not present in the total model.

Daylight measurements and Overall Environmental Satisfaction					
Step	β	β	β	β	β
1. Job Category	-.293	-.296	-.312	-.329*	-.332*
2. Glare		.201	.259	.344	.342
3. Illuminance			.274	.433*	.431*
4. Uniformity				.320	.349
5. Direction					.059
Change in R^2	.086	.040	.072	.076	.003
Total R^2	.086	.126	.198	.273*	.276

Table 14a. *The results of the regression analysis over the 41 workstations set regarding Daylight and Overall Environmental Satisfaction, N = 34. *p≤.05, **p≤.01, ***p≤.001*

Electric lighting measurements and Overall Environmental Satisfaction					
Step	β	β	β	β	β
1. Job Category	-.289	-.294	-.327*	-.296	-.297
2. Glare		.195	.252	.282	.286
3. Illuminance			.283	.265	.280
4. Uniformity				.156	.156
5. Direction					.017
Change in R^2	.083	.038	.076	.022	.000
Total R^2	.083	.121	.197	.219	.219

Table 14b. *The results of the regression analysis over the 41 workstations set regarding electric lighting and Overall Environmental Satisfaction, N = 37. * p≤.05, **p≤.01, ***p≤.001*

Job Satisfaction

The results in Table 15a and 15b show that neither two regression analysis have any significance. Hypothesis 2b is therefore not significant and has to be rejected.

Daylight measurements and Job Satisfaction					
Step	β	β	β	β	β
1. Job Category	-.128	-.128	-.157	-.144	-.151
2. Glare		.045	.083	.146	.157
3. Illuminance			.234	.329	.361
4. Uniformity				.199	.149
5. Direction					-.226
Change in R^2	.017	.002	.053	.028	.046
Total R^2	.017	.019	.071	.100	.146

Table 15a. *The results of the regression analysis over the building 6 subjects regarding daylight and Job Satisfaction, N = 35. *p≤.05, **p≤.01, ***p≤.001*

Electric lighting measurements and Job Satisfaction					
Step	β	β	β	β	β
1. Job Category	-.200	-.199	-.227	-.170	-.174
2. Glare		-.023	-.001	.055	.029
3. Illuminance			.151	.127	.034
4. Uniformity				.280	.281
5. Direction					-.117
Change in R^2	.040	.001	.022	.071	.005
Total R^2	.040	.040	.062	.133	.138

Table 15b. *The results of the regression analysis over the building 6 subjects regarding electric light and Job Satisfaction, N = 39. * p≤.05, **p≤.01, ***p≤.001*

Satisfaction with Lighting

Looking at the differences between daylight and electric light (tables 16a and 16b), it can be seen that both the total models are not significant. The only remaining significant characteristic with the daylight measurements is illuminance. This means that the Satisfaction with Lighting increases as the illuminance from daylight increases. As for the electric light regression results, there is no significance left.

Daylight measurements and Satisfaction with Lighting					
Step	β	β	β	β	β
1. Job Category	-.138	-.138	-.162	-.139	-.139
2. Glare		.021	.078	.169	.168
3. Illuminance			.314	.444*	.440*
4. Uniformity				.277	.283
5. Direction					.025
Change in R^2	.019	.000	.095	.055	.001
Total R^2	.019	.019	.114	.169	.170

Table 16a. *The results of the regression analysis over the building 6 subjects regarding daylight and Satisfaction with Lighting, N = 37. * p≤.05, **p≤.01, ***p≤.001*

Electric lighting measurements and Satisfaction with Lighting					
Step	β	B	β	β	β
1. Job Category	-.122	-.124	-.168	-.146	-.143
2. Glare		.035	.082	.114	.068
3. Illuminance			.296	.290	.105
4. Uniformity				.143	.152
5. Direction					-.227
Change in R^2	.015	.001	.084	.019	.018
Total R^2	.015	.016	.100	.119	.137

Table 16b. *The results of the regression analysis over the building 6 subjects regarding electric light and Satisfaction with Lighting, N = 41. * p≤.05, **p≤.01, ***p≤.001*

Daylight versus Window

The third hypothesis (having a window will have a bigger positive contribution towards satisfaction than only receiving daylight in your workstation. Only receiving daylight in its turn will be more beneficial than having no daylight at all) can be tested with a MANCOVA.

The first part of the analysis tests the first half of the hypothesis. As can be seen, in general people are more satisfied when receiving daylight then when working under

100% electric lighting (*F* (3, 720) = .976, p = .001), see Table 17a. When looking at the three individual characteristics of satisfaction however, it appears that receiving daylight does not have a significant effect on job satisfaction (see Table 17b). However, it does have a significant effect on overall environmental satisfaction and satisfaction with lighting (respectively: *F* (1, 722) = 13.425, p < .001 and *F* (1, 722) = 12.113, p = .001).

	Neither daylight or window compared to only daylight			
Test	Model df	Error df	F	P
Wilks	3	720	5.818	.001***

Table 17a. *Multivariate Wilks test for the total model, comparing 'no daylight' to 'only daylight'. Factor loadings for daylight: NO = -1, DL = 1, Wi = 0.*

	Neither daylight or window compared to only daylight			
Variable	Model df	Error df	F	P
OES	1	722	13.425	.000***
JobSatis	1	722	2.923	.088
Sat_Light	1	722	12.113	.001***

Table 17b. *Univariate F-test for the variables 'Overall environmental satisfaction' (OES), 'Job satisfaction' (JobSatis) and 'Satisfaction with lighting' (Sat_Light), comparing 'no daylight' to 'only daylight'. Factor loadings for daylight: NO = -1, DL = 1, Wi = 0.*

The second half of the fourth thesis can be answered with the second part of the MANCOVA. As can be seen in Table 18a, in general people are more satisfied when they have an outside view as opposed to only receiving daylight *F* (3, 720) = 8.604, p < .001). As for the three individual characteristics of satisfaction (see Table 18b), the same patterns can be observed here as in the previous one. Overall Environmental Satisfaction and Satisfaction with Lighting tends to be significantly different for people with a window than for people receiving only daylight (respectively: *F* (1, 722) = 6.765, p = .009 and *F* (1, 722) = 6.409, p = .012). See Table 19.

	Only daylight compared to daylight and window			
Test	Model df	Error df	F	P
Wilks	3	720	8.604	.001***

Table 18a. *Multivariate Wilks test for the total model, comparing 'only daylight' to 'daylight and window'. Factor loadings for daylight: NO = -1, DL = 1, Wi = 0.*

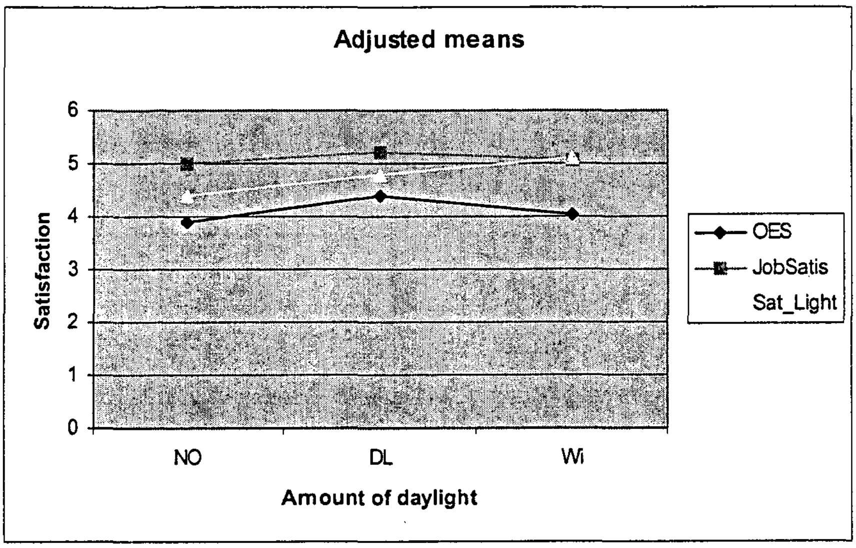
	Only daylight compared to daylight and window			
Variable	Model df	Error df	F	P
OES	1	722	6.765	.009**
JobSatis	1	722	0.274	.601
Sat_Light	1	722	6.409	.012*

Table 18b. *Univariate F-test for the variables 'Overall environmental satisfaction' (OES), 'Job satisfaction' (JobSatis) and 'Satisfaction with lighting' (Sat_Light), comparing 'only daylight' to 'daylight and window'. Factor loadings for daylight: NO = -1, DL = 1, Wi = 0.*

Although the differences regarding Overall Environmental Satisfaction and Satisfaction with Lighting are significant for both steps in the MANCOVA, the direction of these changes is somewhat surprising. Table 19 and Graph 1 show that the Satisfaction with Lighting goes up for each step people receive more daylight. The Overall Environmental Satisfaction however, is highest for people whom only receive daylight. Their Overall Environmental Satisfaction is higher than for people having a window.

	OES	Job Satisfaction	Satisfaction with Lighting
NO	3.906	5.007	4.376
DL	4.409	5.214	4.802
Wi	4.046	5.088	5.118
Total	4.196	4.959	4.751

Table 19. *The adjusted means for the three dependent variables for all three groups of respondents. NO = no daylight or window; DL = only daylight; Wi = daylight and window) and the total; OES = Overall Environmental Satisfaction.*



Graph 1. *The adjusted means for the three dependent variables for all three groups of respondents. NO = no daylight or window; DL = daylight; Wi = daylight and window; OES = Overall Environmental Satisfaction; JobSatis = Job Satisfaction; Sat_Light = Satisfaction with Lighting*

DISCUSSION

Lighting and Satisfaction

This research once again shows that lighting has a significant influence on satisfaction. Namely, the all subjects set does show a significant positive relation between the interacting various aspects of lighting on the one hand and the Overall Environmental Satisfaction on the other hand. With increasing illuminance (on the cube), uniformity, and daylight levels, and with decreasing glare and direction levels, the Overall Environmental Satisfaction increases. However, none of the individual characteristics of lighting has a significant influence on the Overall Environmental Satisfaction. Therefore it has again been shown that lighting is a multi attribute phenomenon in which it is hardly possible to just look at one characteristic of lighting.

The influence of lighting on the three different aspects of satisfaction is very different for each form of satisfaction. There is no relation between lighting and Job Satisfaction. Reviewing the two questions postulated to address this hypothesis it is not really surprising there is no relation between Lighting and Job Satisfaction. With the questions being 'My department is a good place to work' and 'I am satisfied with my job' the relation can be expected to be low. With only age being significantly negative related to Job Satisfaction it could be concluded that the older people get, the less satisfied they are with their jobs. Excluding the variable 'Daylight' out of the regression analysis does lead to a significant model in which the remaining lighting variables do have a significant influence on job satisfaction. The daylight variable nevertheless is an essential part of light and cannot simply be excluded.

Besides the influence of lighting on the Overall Environmental Satisfaction it also has an influence on the Satisfaction with Lighting. Every added variable has a significant influence on the Satisfaction with Lighting. The variables glare, uniformity, and direction are negatively related while the other two (illuminance and daylight) are positively related. This means that when the characteristics illuminance, daylight, and uniformity increase, the Satisfaction with Lighting also goes up. (The variable uniformity goes up when the characteristic uniformity goes down, and vice versa.) In this regression analyses glare and direction also have a negative contribution to Satisfaction with Lighting. Since direction and uniformity are more or less counterparts, the results sustain each other. With increasing direction, uniformity will go down and vice versa. This is in line with Bernecker *et al.* (1993) whom found that uniformity plays a vital role in what they call perception of visual comfort. The variables 'glare', 'uniformity', and 'daylight' are the only variables that, on their own, have a significant relation with Satisfaction with Lighting.

Therefore it can be concluded that the hypotheses 1a and 1c are supported. Every lighting characteristic plays an important roll in whether or not the lit environment leads to Overall Environmental Satisfaction and Satisfaction with Lighting. Hypothesis 1b has to be rejected. With a more elaborate questionnaire appertaining job satisfaction a relation between lighting and Job Satisfaction might have been proven.

Daylight versus Electric Lighting

The two models (Daylight and electric lighting) on the 41 workstations set do not have any significant influence on the Overall Environmental Satisfaction. However, the daylight measurement model, without the last characteristic 'direction' included, is significant. This might mean that the fact that daylight most of the times comes from a certain side is a negative site-effect of daylight.
The major effect can be found in the characteristic 'illuminance'. In the daylight regression analysis this characteristic has a significant relation with Overall Environmental Satisfaction in the final step. This means people feel more satisfied when working under daylight illuminance than when working under electric lighting illuminance.

With the loss of power due to the smaller sample with the 41 subjects set it is not surprising there are not any significant results for daylight or electric lighting and Job Satisfaction.

For Satisfaction with Lighting none of the two total models are significant. The only characteristic that is, is illuminance in the daylight analysis. It once again suggests that people are differently sensitive to electric lighting or daylight. Increasing illuminance using electric light might not have the desired effect of more satisfied personal.

Daylight versus Window

Interestingly, Overall Environmental Satisfaction is highest for people who only receive daylight, without a window view (see Table 11 and graph 1). It is significantly less for people receiving no daylight at all, which is not really surprising when looking at the theoretical basis. It is however, also significantly less for people having an outside view.

A reason for this might be that other environmental aspects go down when you are positioned next to a window. The temperature differences for example are generally a lot higher close to windows then in the centre core of a building, with heat gains in summer and heat losses in winter. These thermal differences can also be a cause for more draft close to a window. High levels of daylight can also cause sun and sky glare. Aspects like this may be a reason for the Overall Environmental Satisfaction to go down while the Satisfaction with Lighting still goes up. This is in accordance with the results form Roche *et al.* (2000). They included factors like overheating and draft in their research. These were, together with an increase in glare, the main causes for a decline in the preference of a window seat.

SATISFACTION AND PERFORMANCE

Satisfaction with the Work Environment

Many theories of behaviour at work fail to adequately consider the effects of the physical environment on employees' behaviour and attitudes. Whether they focus mainly on the job characteristics (e.g., Hackman & Oldham, 1980), on the behavioural aspects of jobs (e.g. van de Ven & Ferry, 1980), or try to explain a wider range of variables (e.g. Seashore, Lawler, Mirvis, & Camman, 1983), they tend to overlook the physical work environment. Through the intervening variable 'satisfaction' the environment might have an indirect influence on performance.

Therefore Stokols & Scharf (1990) developed the Ratings of Environmental Features (REF). Privacy, air quality and lighting are the main pillars in this questionnaire. Carlopio (1996) has developed the Physical Work Environment Satisfaction Questionnaire (PWESQ). In this questionnaire five dimensions are addressed, namely: environmental design, facilities, work organisation, equipment and tools, and health and safety.

More recently, a preliminary study on the COPE field study data has shown there is a relationship between degrading aspects of the work place and negative effects. Charles and Veitch (2002) concluded that reduced space allocation risks creating an unpleasant working environment. Hygge & Knez (2001) looked at the interactions between noise, heat and illuminance. They found that it depends on the amount of all three variables and the task at hand whether they have a positive or negative influence on performance. The main result for attention was a trade off between speed and accuracy.

Not just lighting but also the entire area of work environmental aspects have their influence on satisfaction.

Visual Performance

Visual performance can be defined as the extend to which a viewed object can be differentiated from other stimuli in the observer's field of view (Oborne, 1982; McCormick & Sanders, 1982). The visual performance is dependent on very personal characteristics. It is dependent on how the eye receives and conditions light and on the interpretation of what is seen by the person (Parsons, 2000). Extending this point of view Megaw & Bellamy (1983) stated that lighting is of little effect on performance. The performance is more dependent on personal aspects and on the quality of the task features such as contrast and size of detail. Baron *et al.* (1992) found that positive effects induced by lower levels of illuminance (150 lux compared to 1500 lux) and warmer white light (3000 K compared to 5000 K), is a mechanism to influence behaviour. They defined behaviour as word categorization and expected ability to perform clerical tasks but also evaluations of a fictitious employee, preference for resolving interpersonal behaviour, and willingness to offer help to others.

It appears that lighting can influence performance in several ways besides the processing of visual information. The fact that a lot of research has been performed on light quantity has led to an adequate amount of illuminance in the general office and work environment. Giving more consideration to the quality of lighting can be more beneficial for the performance of people.

Satisfaction and Performance

Most people (e.g. employees, managers) would argue that there is a direct positive relation between satisfaction and performance (v. Yperen & d. Jong, 1997). Decades of research in this field of study have shown that this relation is modest in magnitude. Fisher (2002) has summarized the findings of the major studies of the relation job satisfaction – job performance. The average observed relationship is positive but weak.

v. Yperen & d. Jong (1997) state that this relation is weak because of external influences like the definition of work performance, the matter in which the work is organized (e.g. assembly line), the dependency on other people, and / or the lack of technical equipment. They assume the way work performance is measured relates too much to the job the employees actually have to perform. This way they are inclined to answer more positive than is the actual case. Therefore v. Yperen & d. Jong (1997) used the Organizational Citizenship Behaviour questionnaire, which tests performance on a more general level. They found a stronger relationship between satisfaction and performance although the satisfaction was dependable on supervising, payment, and promotion opportunities.

The present day literature points towards the direction that intra personal lighting preferences differ a lot. Elaborating on this topic Boyce *et al.* (2000) did research on the effect of individual lighting control on performance. They concluded that different subjects used the control system in different ways, pointing again in the direction of personal differences. The subjects with control over their lighting did perceive themselves to have performed better but in fact did not significantly perform better. One reason for this discrepancy might be that the research was performed over a short period of time. A longer time track might reveal differences in performances between people who have and who do not have individual lighting control. Individual lighting control has also been shown to affect satisfaction.

Veitch & Gifford (1996) concluded that there is a difference between 'feeling more energetic because of bright light' (32.7%) and 'accomplishing more under bright light' (14.8%). In this study participants filled in several questionnaires at their desks.

Taking the different results together it looks like there is no direct link between satisfaction and performance. However, there is a link between lighting and satisfaction on the one hand and lighting and performance on the other hand. A good quality of lighting might have mutual beneficial influences without their being a direct relation between satisfaction and performance.

CONCLUSION AND RECOMMENDATIONS

It can be concluded that lighting does have its influence on certain forms of satisfaction. The interacting aspects of lighting influence the Overall Environmental Satisfaction and the Satisfaction with Lighting. Although it is hard to look at just one aspect of lighting, the aspects 'glare', 'uniformity', and 'daylight' have the strongest influence on the satisfaction. It can be concluded that every lighting characteristic plays an important roll in whether or not the lit environment leads to Overall Environmental Satisfaction and Satisfaction with Lighting. This is a confirmation that lighting cannot be looked upon as being uni-characteristic, with only illuminance being of importance.

Simultaneously, the effects of daylight seem to be more positive than electric light. The Satisfaction with Lighting is highest for people having an outside view, followed by people who only receive daylight. However, being situated too close to a window is cause for more negative side effects. After all, the Overall Environmental Satisfaction is lower for people situated next to a window than for people receiving daylight but not having a window. This is probably due to environmental effects related to a window. Windows are cause for colder areas. Due to these temperature changes drafts might originate. Due to both aspects, colder areas and draft, the Overall Environmental Satisfaction might have gone down.

It seems like there is no direct link between satisfaction and performance. Interestingly, there seems to be a link between lighting and satisfaction and between lighting and performance. Therefore, a good lighting environment might still have benefits for satisfaction as well as for performance.

Future research ought to keep focussing on lighting quality. Once again it has been proven that it there is not a single factor of the illuminated environment that is the most important one. The effects of lighting consist of a continuous interaction between the different aspects of lighting: Daylight, Illuminance, Direction, Uniformity, and Glare.

The link between lighting and Job Satisfaction ought to be researched more thoroughly. Two question of the applied questionnaire were eventually used in the analyses. With the questions formulated in a different way, consisting of more factors, relations might be found.

JUSTIFICATION

Most final thesis studies in this field of study include the steps of setting up questionnaires and the actual gathering of data. This thesis is an exception to the rule, given that part of the data gathered for the COPE field study was used in this study. One drawback to using such archival data is that it is not necessary to perform these two mentioned steps. The positive counterpart is that the data set is many times more numerous than the average data set. This brings along the possibility to perform more rigorous statistical analysis and to possibly draw more firm conclusions out of them. It can also be said that a large set of subjects generates too much significance. With the characteristics of lighting not being significant related to Job Satisfaction it could be concluded that the data set was not too big to only return significant results.

Although the data were not gathered specifically for this project it was necessary to derive some new variables out of the already existing ones. Therefore it was essential to gain an in depth knowledge of the existing data. These new variables are based on the findings of preceding literature, cover the characteristics of lighting and can be used in the statistical analysis.

Since it was necessary to derive a daylight variable, including position of the workplace in the building, the majority of the subjects had to be dropped out of the analysis. The reason for this was that at the time of the data collection it was not known this final thesis would be performed with the use of this data. The COPE project does not differentiate between daylight and electric light and therefore this characteristic was not included during the collection of the data.

This was cause for a lot of problems, it was time consuming and there was a drop in statistical power. Nevertheless, the idea of the chair with all the measurement equipment combined with a satisfaction questionnaire seems to be a good way to yield sound results regarding lighting and satisfaction. With a data collection purposively for a research like this the results will be more conclusive.

Keeping the list of included variables for the COPE project and this thesis as simultaneous as possible it was still possible to compare the results between these two sets of variables.

Although the results end up being less conclusive than desired they can still be of relevance for the target groups. Partly incorporated in the COPE study they will be used in a computer program that will serve as a tool for architects, designers, constructors, and students (http://irc.nrc-cnrc.gc.ca/ie/cope/index.html). There is a more clear direction towards future research and of how materials ought to be developed to generate such an environment that people are more satisfied.

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GLOSSARY

1. TeMa (Technology and Society): Study at the Technical University of Eindhoven focussing on the interdisciplinary field of Technology and Society.
2. HTI (Human-Technology Interaction): One of the three possible branches of study within TeMa. Emphasize is on how people interact with technology on the individual level.
3. TU/e (Technical University of Eindhoven): Academic institution providing, among others, engineering courses on an academic level.
4. NRC (National Research Council of Canada): The Government of Canada's premier organization for research and development.
5. IRC (Institute for Research in Construction): Part of the National Research Council of Canada. It conducts research on technology and innovation for the Canadian construction industry.
6. COPE project (Cost-effective Open Plan Environments project): 4-year project conducted by the IRC. The goal of the study is to find out how open-plan offices can be remodelled to achieve corporate goals.
7. Illuminance: the quantity of light, or luminous flux, falling from all directions on a unit area of a surface.
8. Colour temperature: the absolute temperature of a blackbody (completely radiating) radiator having a colour equal to that of the light source.
9. Exploratory Factor Analysis: Statistical technique used to identify a smaller set of variables (factors) given a collection of continuous variables. These factors explain the majority of variation among the original set of variables (Grim & Yarnold, 1996, p. 13).
10. Confirmatory Factor Analysis: A statistical analysis that can be used to identify which of two or more models provides the best explanation, of fit, of the data (Grim & Yarnold, 1996, p. 13).
11. Structural Equation Modeling: A statistical method to test a researcher's theory about the causal relationships among a set of variables (Grim & Yarnold, 1996, p. 67).
12. DayLight contribution: That part of the DayTime measurements that is yielded by the daylight (DayLight = DayTime – NightTime).
13. Daylight autonomy: The annual percentage of occupied hours when the desktop illuminance at a workplace lies above 450 lx, i.e. when an occupant could principally work by daylight alone. (10% rise = one hour of working time per day for each occupant that is affected.) (Reinhart, 2001).
14. Daylight appearance: The annual percentage of occupied hours when the desktop illuminance at a workplace lies above 150 lx. Although such an illuminance might not be sufficient for reading or writing it does have a positive influence on satisfaction (Roche *et al.* 2000 in Reinhart, 2001).
15. Desktop illuminance: the percentage of the working year when the average of the desktop sensor points lies between 300 lx and 600 lx (Reinhart, 2001).
16. Desktop illuminance uniformity: the temporal and spatial average of desktop sensor points that lies below 80 % of the spatial mean desktop illuminance for

all occupied hours of the working year. Based on CIBSE LG7 (1993) in Reinhart (2001).

17. Mean VDT illuminance: the average desktop illuminance that exceeds 500 lx, taking into account a 10 % tolerance due to photometric errors. (Reinhart, 2001).
18. MANCOVA: Statistical measure to compare vectors of means which have been adjusted with the use of covariates. (Grimm & Yarnold, 1996).

ABREVIATIONS

3FB6	3rd floor of building 6 in the COPE-study
COPE	Cost-effective Open Plan Environments
HTI	Human-Technology Interaction
IRC	Institute for Research in Construction
MANCOVA	Multiple ANalyses of CO-VAriance
OES	Overall Environmental Satisfaction
NRC	National Research Council of Canada
TeMa	Technology and Society
TU/e	Eindhoven University of Technology

LIST OF APPENDIX

Appendix A: Satisfaction Questionnaire

1. Amount of lighting on the desktop

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory

2. Overall air quality in your work area

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory

3. Temperature in your work area

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory

4. Aesthetic appearance of your office

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory

5. Level of privacy for conversations in your office

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory

6. Level of visual privacy within your office

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory

7. Amount of noise from other people's conversations while you are at your workstation

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory

8. Size of your personal workspace to accommodate your work, materials, and visitors

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory

9. Amount of background noise (i.e. not speech) you hear at your workstation

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory

10. Amount of light for computer work

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory

11. Amount of reflected light or glare in the computer screen

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory

12. Air movement in your work area

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory

13. Your ability to alter physical conditions in your work area

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory

14. Your access to a view of outside from where you sit

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory

15. Distance between you and other people you work with

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory

16. Quality of lighting in your work area

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory

17. Frequency of distractions from other people

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory

18. Degree of enclosure of your work area by walls, screens or furniture

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory

19. Rank order importance of:

noise levels, temperature, privacy, air quality / ventilation, size of work space, window access, lighting

20. How old are you?

18-29	30-39	40-49	50-59	60-69	70+

21. What is your sex?

Female	Male

22. Job category?

Administrative	Technical	Professional	Managerial

23. Highest education level?

High school	Community college	Some university	Bachelor degree	Graduate degree

24. My department / agency is a good place to work

Very strongly disagree	Stronlgy disagree	disagree	Neither agree nor disagree	agree	Strongly agree	Very strongly agree

25. I am satisfeid with my job

Very strongly disagree	Stronlgy disagree	disagree	Neither agree nor disagree	agree	Strongly agree	Very strongly agree

26. Effect of environmental conditions on personal productivity

- 30 %	- 20 %	- 10%	0 %	+ 10%	+ 20 %	+ 30 %

27. Indoor environment in your workstation, as a whole

Very Unsatisfactory	Unsatisfactory	Somewhat Unsatisfactory	Neutral	Somewhat Satisfactory	Satisfactory	Very Satisfactory

Appendix B: Discrepancies in the Measurements

	Floors		Buildings	
Building / floor	**Y / X**	**binomial-test**	**Y / X**	**binomial-test**
Building 1				
Total			0 / 7	0.008
Building 2				
Total			0 / 8	0.004
Building 3				
Total			1 / 5	0.188
Building 4				
Total			4 / 12	0.194
Building 5				
Total			4 / 25	0.000
Building 6				
Second floor	1 / 3	0.500		
Third floor	7 / 8	0.996*		
Fifth floor	0 / 2	0.250		
Eleventh floor	2 / 3	0.875		
Total			10 / 16	0.895
Building 7				
Total			1 / 30	0.000
Building 8				
Total			1 / 6	0.109
Building 9				
Total			0 / 6	0.016
Overall total			21 / 115	0.000

Table 1. *Number of workstations with small discrepancies between daytime and night-time measurements compared to the total amount of workstations; divided for buildings and some floors. Binomial test for each building and some floors. Y = the number of workstations with small measurement errors. X = total number of workstations with daytime and night-time measurements.*

Appendix C: Correlation Matrixes

All subjects set

	OES	Sat w/ Lighting	Job Satisfaction	Age	Gender	Administration	Manager
OES	1.00						
Sat w/ Lighting	.47	1.00					
Job Satisfaction	.25	.24	1.00				
Age	-.04	.03	-.10	1.00			
Gender	.02	.03	-.00	.02	1.00		
Administration	.09	.05	-.06	.04	-.37	1.00	
Manager	-.03	.03	.02	.02	.10	-.19	1.00
Professional	-.10	-.03	-.01	.09	.07	-.49	-.25
Daylight	.04	.28	.03	.17	.02	.02	.10
Illuminance	.06	.08	.00	.09	.04	.03	.02
Uniformity	-.02	-.07	.01	.07	-.07	.13	-.01
Glare	-.01	-.09	-.03	.02	.01	.00	-.00
Direction	-.03	-.10	-.04	-.08	.05	-.02	-.11

	Professional	Daylight	Illuminance	Uniformity	Glare	Direction
Professional	1.00					
Daylight	.01	1.00				
Illuminance	.06	.37	1.00			
Uniformity	-.06	.08	.06	1.00		
Glare	.00	-.00	-.04	-.14	1.00	
Direction	.04	-.37	-.13	-.28	.00	1.00

** r .50, ** r .60, *** r .70. OES = Overall Environmental Satisfaction; Sat w/ Lighting = Satisfaction with Lighting.*

41 Workstations set - DayLight variables

	OES	Sat w/ Lighting	Job Satisfaction	Age	Gender	Administration	Manager
OES	1.00						
Sat w/ Lighting	.58*	1.00					
Job Satisfaction	.35	.24	1.00				
Age	.09	.23	-.21	1.00			
Gender	.02	.16	.02	.30	1.00		
Administration	.28	.30	.08	-.06	-.12	1.00	
Manager	.09	.05	.01	.36	.51*	-.38	1.00
Professional	-.37	-.18	-.22	-.05	-.14	-.60**	-.34
Daylight	.16	.39	.01	.30	.14	-.15	.34

Illuminance	.18	.27	.12	.11	-.09	-.09	.12
Uniformity	-.01	-.03	.18	-.22	.30	.16	-.05
Glare	.19	.03	-.04	.10	-.09	-.08	.14
Direction	-.06	-.09	-.03	-.16	.17	-.05	.08

	Professional	Daylight	Illuminance	Uniformity	Glare	Direction
Professional	1.00					
Daylight	-.01	1.00				
Illuminance	.05	.62**	1.00			
Uniformity	-.11	-.32	-.27	1.00		
Glare	-.02	.21	-.11	-.31	1.00	
Direction	.05	.24	.17	-.53*	-.03	1.00

** r .50, ** r .60, *** r .70*

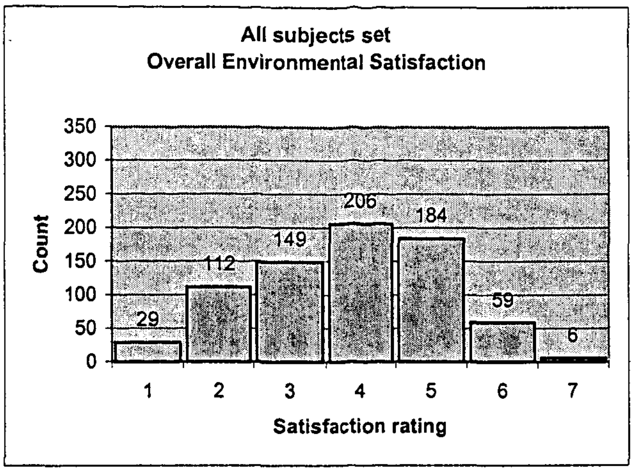
41 Workstations - DayTime variables

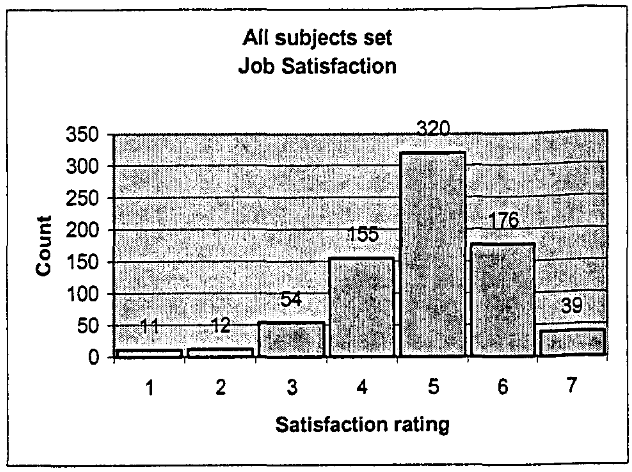
	OES	Sat w/ Lighting	Job Satisfaction	Age	Gender	Administration	Manager
OES	1.00						
Sat w/ Lighting	.51*	1.00					
Job Satisfaction	.30	.21	1.00				
Age	.17	.25	-.09	1.00			
Gender	.07	.19	-.05	.35	1.00		
Administration	.34	.35	.03	-.07	-.33	1.00	
Manager	.06	-.02	.03	.37	.57*	-.40	1.00
Professional	-.40	-.11	-.14	-.14	-.04	-.58*	-.38
Daylight	-.01	.22	.07	.27	.21	-.13	.28
Illuminance	.16	.18	.17	.04	-.11	-.04	.03
Uniformity	.09	.28	.23	.21	.02	.21	-.02
Glare	.23	.03	.10	.05	.01	.02	.13
Direction	-.13	-.11	-.26	.05	.09	-.03	-.07

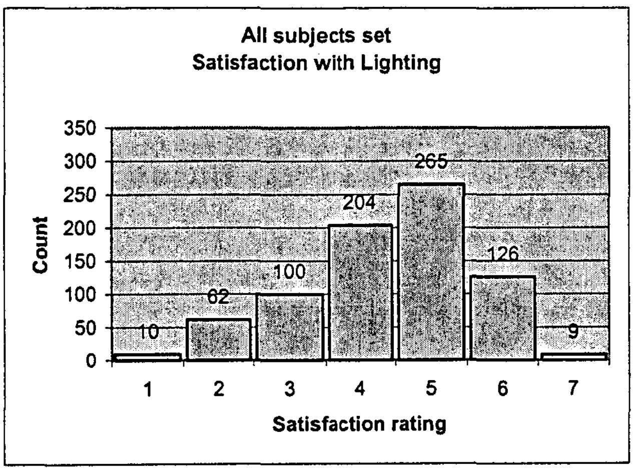
	Professional	Daylight	Illuminance	Uniformity	Glare	Direction
Professional	1.00					
Daylight	-.03	1.00				
Illuminance	.05	.48	1.00			
Uniformity	-.11	.03	.19	1.00		
Glare	-.12	.20	-.18	-.29	1.00	
Direction	.09	-.67**	-.77***	-.20	-.09	1.00

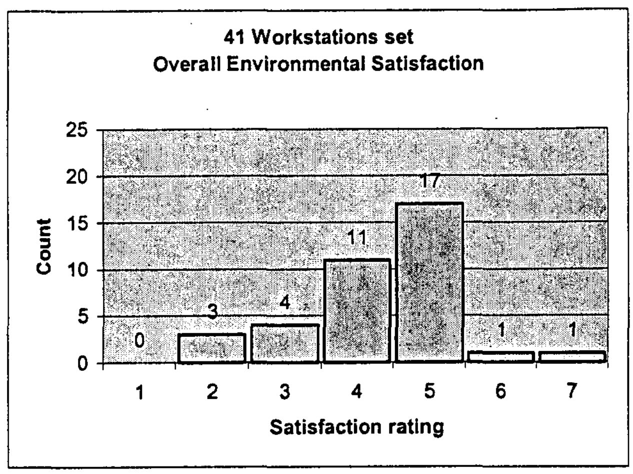
** r .50, ** r .60, *** r .70*

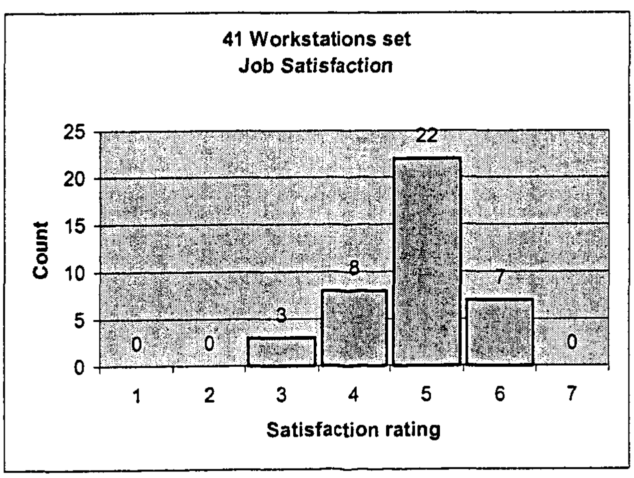
Appendix D: Plots

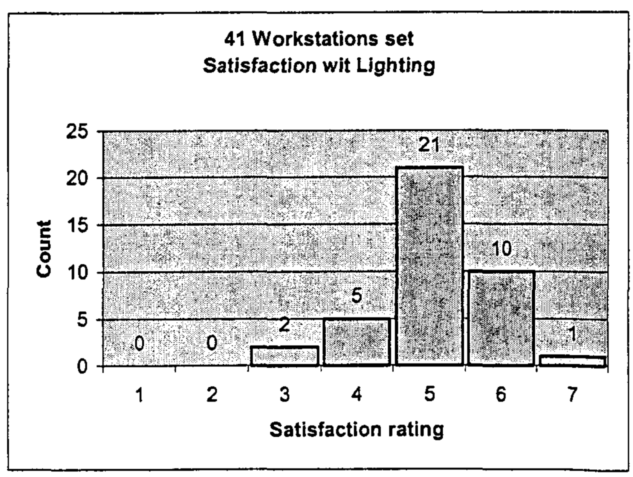


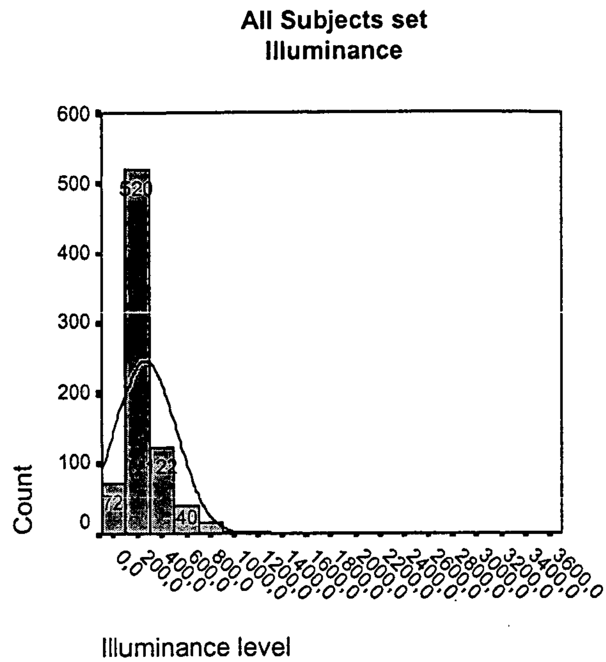




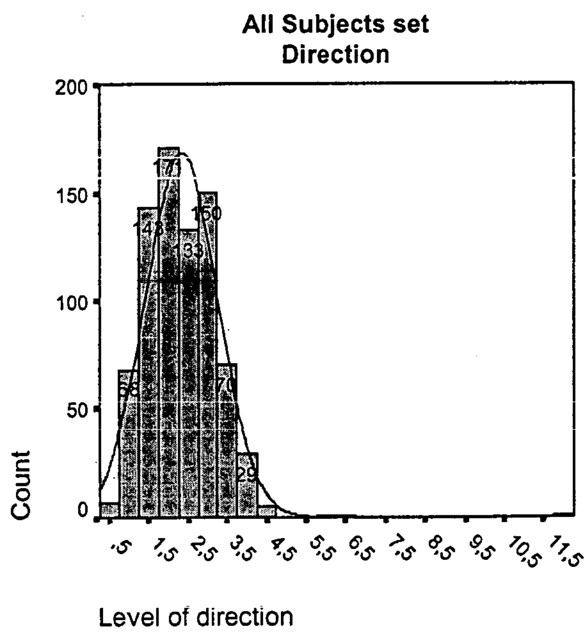




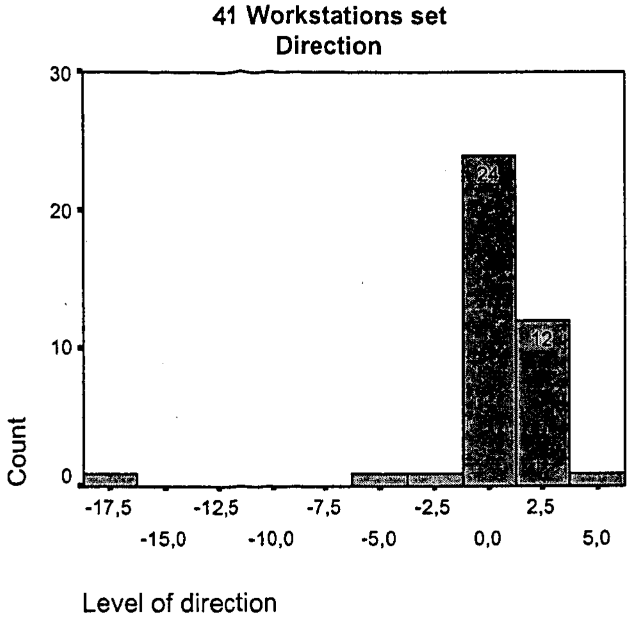




All Subjects set
Illuminance
Count
Illuminance level



All Subjects set
Direction
Count
Level of direction


41 Workstations set
Direction
30
20
10
0
Count
24
12
-17,5
-12,5
-7,5
-2,5
2,5
-15,0
-10,0
-5,0
0,0
5,0
Level of direction

Appendix E: Correlation Matrixes Pruned Variables

41 Workstations set - Pruned DayLight variables

	OES	Sat Lighting	Job Satisfaction	Job Category	Illuminance	Uniformity	Glare	Direction
OES	1.00							
Sat w/ Lighting	.58*	1.00						
Job Satisfaction	.35	.24	1.00					
Job Category	-.29	-.13	-.20	1.00				
Illuminance	.18	.27	.12	.14	1.00			
Uniformity	-.01	-.03	.18	-.15	-.27	1.00		
Glare	.19	.03	-.04	.09	-.11	-.31	1.00	
Direction	-.06	-.09	-.03	.11	.17	.53*	-.03	1.00

** r .50, ** r .60, *** r .70*

41 Workstations set - Pruned DayTime variables

	OES	Sat w/ Lighting	Job Satisfaction	Job Category	Illuminance	Uniformity	Glare	Direction
OES	1.00							
Sat w/ Lighting	.58*	1.00						
Job Satisfaction	.35	.24	1.00					
Job Category	-.29	-.12	-.20	1.00				
Illuminance	.20	.26	.11	.14	1.00			
Uniformity	.19	.16	.31	-.16	.06	1.00		
Glare	.19	.03	-.03	.06	-.15	-.24	1.00	
Direction	-.21	-.29	-.11	-.12	-.78***	.04	-.09	1.00

** r .50, ** r .60, *** r .70*

Appendix F: Results of the Regression Analyses

All subjects set – Overall Environmental Satisfaction

Step	Overall Environmental Satisfaction (N = 709)					
	β	β	β	β	β	β
1. Age	-.038	-.038	-.042	-.038	-.039	-.041
Gender	.069	.069	.064	.063	.066	.066
Administrative	.068	.068	.060	.066	.069	.068
Manager	-.046	-.046	-.051	-.051	-.053	-.054
Professional	-.082	-.082	-.089	-.089	-.088	-.088
2. Glare		.002	.008	.002	-.001	-.002
3. Illuminance			.066	.063	.050	.045
4. Uniformity				-.050	-.062	-.062
5. Direction					-.036	-.032
6. Daylight						.014
Change in R^2	.020*	.000	.004	.002	.001	.000
Total R^2	.020*	.020*	.024*	.026*	.027*	.027*

* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

All subjects set – Job Satisfaction

Step	*Job Satisfaction* (N = 724)					
	β	β	β	β	β	β
1. Age	-.125***	-.125***	-.127***	-.128***	-.131***	-.132***
Gender	-.003	-.003	-.006	-.006	-.001	-.001
Administrative	-.061	-.061	-.065	-.067	-.061	-.062
Manager	-.008	-.008	-.011	-.011	-.017	-.017
Professional	-.034	-.034	-.039	-.039	-.036	-.036
2. Glare		-.017	-.013	-.011	-.016	-.017
3. Illuminance			.041	.042	.017	.013
4. Uniformity				.016	-.005	-.005
5. Direction					-.065	-.062
6. Daylight						.011
Change in R^2	.020*	.000	.002	.000	.003	.000
Total R^2	.020*	.020*	.022*	.022*	.025*	.025

* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

All subjects set – Satisfaction with Lighting

Step	Satisfaction w/ Lighting (N = 732)					
	β	β	β	β	β	β
1. Age	.025	.026	.019	.025	.022	-.007
Gender	.055	.054	.044	.041	.049	.045
Administrative	.094	.094	.078	.088	.097*	.091
Manager	.044	.044	.032	.033	.025	.010
Professional	-.004	-.004	-.020	-.021	-.016	-.019
2. Glare		-.081*	-.067	-.080*	-.088*	-.099**
3. Illuminance			.145***	.141***	.100*	-.005
4. Uniformity				-.090*	-.126**	-.124***
5. Direction					-.107*	-.035
6. Daylight						.278***
Change in R^2	.010	.007*	.021***	.008*	.008*	.053***
Total R^2	.010	.017	.037***	.045***	.054***	.107***

* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

41 Workstations set - DayLight variables
Overall Environmental Satisfaction

Step	Overall Environmental Satisfaction (N = 34)					
	β	β	β	β	β	β
1. Age	.103	.089	.035	.085	.110	.097
Gender	-.049	-.009	.114	.020	-.009	-.020
Administrative	-.319	-.327	-.438	-.426	-.347	-.352
Manager	.121	.110	.023	.002	.120	.112
Professional	-.006	-.072	-.227	-.225	-.145	-.159
2. Glare		.198	.302	.376	.378	.366
3. Illuminance			.348	.439*	.462*	.423
4. Uniformity				.250	.301	.321
5. Direction					-.167	-.176
6. Daylight						.084
Change in R^2	.165	.036	.100	.037	.021	.003
Total R^2	.165	.201	.301	.337	.358	.361

* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

41 Workstations set - DayLight variables
Job Satisfaction

Step	Job Satisfaction (N = 35)					
	β	β	β	β	β	β
1. Age	-.255	-.257	-.323	-.262	-.265	-.318
Gender	.064	.068	.185	.116	.117	.103
Administrative	-.212	-.212	-.277	-.360	-.374	-.406
Manager	-.135	-.141	-.288	-.319	-.328	-.385
Professional	-.395	-.394	-.508	-.520	-.529	-.568
2. Glare		-.030	-.108	.230	.229	.180
3. Illuminance			.343	.490*	.487*	.374
4. Uniformity				.354	.349	.422
5. Direction					.020	-.011
6. Daylight						.271
Change in R^2	.130	.001	.097	.076	.000	.031
Total R^2	.130	.131	.228	.304	.304	.335

* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

41 Workstations set - DayLight variables
Satisfaction with Lighting

Step	Satisfaction w/ Lighting (N = 36)					
	β	β	β	β	β	β
1. Age	.162	.157	.105	.121	.168	.104
Gender	.016	.024	.120	.101	.069	.022
Administrative	.678*	.680*	.623	.599	.839*	.793*
Manager	.369	.359	.229	.220	.374	.299
Professional	.425	.425	.334	.330	.487	.456
2. Glare		.051	.132	.167	.177	.116
3. Illuminance			.310	.351	.398*	.207
4. Uniformity				.098	.180	.290
5. Direction					-.345	-.387*
6. Daylight						.418
Change in R^2	.194	.003	.081	.006	.091	.079
Total R^2	.194	.197	.278	.284	.374	.453

* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

41 Workstations set - DayTime variables
Overall Environmental Satisfaction

Step	Overall Environmental Satisfaction (*N* = 31)					
	β	β	β	β	β	β
1. Age	.134	.144	.135	.136	.076	.142
Gender	.118	.139	.223	.223	.232	.257
Administrative	.118	.097	.043	.046	.008	.058
Manager	-.172	-.248	-.363	-.362	-.426	-.349
Professional	-.390	-.390	-.471	-.470	-.547	-.474
2. Glare		.230	.325	.323	.452*	.435
3. Illuminance			.333	.335	.650	.591
4. Uniformity				-.008	.066	.019
5. Direction					.385	.169
6. Daylight						-.225
Change in R^2	.229	.049	.098	.000	.041	.020
Total R^2	.229	.278	.376	.376	.418	.437

* *p≤.05,* ***p≤.01,* ****p≤.001*

41 Workstations set - DayTime variables
Job Satisfaction

Step	Job Satisfaction (*N* = 32)					
	β	β	β	β	β	β
1. Age	-.094	-.090	-.114	-.187	-.172	-.150
Gender	-.037	-.037	.040	.045	.045	.049
Administrative	-.219	-.221	-.248	-.365	-.353	-.340
Manager	-.159	-.178	-.273	-.312	-.306	-.288
Professional	-.362	-.351	-.429	-.480	-.463	-.440
2. Glare		.123	.182	.252	.216	.223
3. Illuminance			.287	.242	.146	.141
4. Uniformity				.303	.286	.274
5. Direction					-.118	-.168
6. Daylight						-.068
Change in R^2	.054	.014	.074	.073	.004	.002
Total R^2	.054	.068	.142	.215	.219	.221

* *p≤.05,* ***p≤.01,* ****p≤.001*

41 Workstations set - DayTime variables
Satisfaction with Lighting

Step	Satisfaction w/ Lighting (*N* = 33)					
	β	β	β	β	β	β
1. Age	.183	.182	.168	.147	.128	.077
Gender	.213	.217	.276	.274	.279	.257
Administrative	1.018**	1.017**	.993**	.957**	.943*	.910*
Manager	.456	.446	.364	.353	.344	.302
Professional	.684*	.686	.626	.614	.589	.539
2. Glare		.053	.117	.141	.175	.167
3. Illuminance			.260	.245	.346	.369
4. Uniformity				.094	.114	.144
5. Direction					.124	.276
6. Daylight						.186
Change in R^2	.371*	.003	.061	.007	.005	.013
Total R^2	.371*	.373*	.434*	.441*	.446	.459

* *p≤.05,* ***p≤.01,* ****p≤.001*

41 Workstations set - Pruned DayLight variables
Overall Environmental Satisfaction

Step	Overall Environmental Satisfaction (N = 34)				
	β	β	β	β	β
1. Job Category	-.293	-.296	-.312	-.329*	-.332*
2. Glare		.201	.259	.344	.342
3. Illuminance			.274	.433*	.431*
4. Uniformity				.320	.349
5. Direction					.059
Change in R^2	.086	.040	.072	.076	.003
Total R^2	.086	.126	.198	.273*	.276

* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

41 Workstations set - Pruned DayLight variables
Job Satisfaction

Step	Job Satisfaction (N = 35)				
	β	β	β	β	β
1. Job Category	-.128	-.128	-.157	-.144	-.151
2. Glare		.045	.083	.146	.157
3. Illuminance			.234	.329	.361
4. Uniformity				.199	.149
5. Direction					-.226
Change in R^2	.017	.002	.053	.028	.046
Total R^2	.017	.019	.071	.100	.146

* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

41 Workstations set - Pruned DayLight variables
Satisfaction with Lighting

Step	Satisfaction w/ Lighting (N = 37)				
	β	β	β	β	β
1. Job Category	-.138	-.138	-.162	-.139	-.139
2. Glare		.021	.078	.169	.168
3. Illuminance			.314	.444*	.440*
4. Uniformity				.277	.283
5. Direction					.025
Change in R^2	.019	.000	.095	.055	.001
Total R^2	.019	.019	.114	.169	.170

* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

41 Workstations set - Pruned DayTime variables
Overall Environmental Satisfaction

Step	Overall Environmental Satisfaction (N = 37)				
	β	β	β	β	β
1. Job Category	-.289	-.294	-.327*	-.296	-.297
2. Glare		.195	.252	.282	.286
3. Illuminance			.283	.265	.280
4. Uniformity				.156	.156
5. Direction					.017
Change in R^2	.083	.038	.076	.022	.000
Total R^2	.083	.121	.197	.219	.219

* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

41 Workstations set - Pruned DayTime variables
Job Satisfaction

Step	Job Satisfaction (N = 39)				
	β	β	β	β	β
1. Job Category	-.200	-.199	-.227	-.170	-.174
2. Glare		-.023	-.001	.055	.029
3. Illuminance			.151	.127	.034
4. Uniformity				.280	.281
5. Direction					-.117
Change in R^2	.040	.001	.022	.071	.005
Total R^2	.040	.040	.062	.133	.138

* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

41 Workstations set - Pruned DayTime variables
Satisfaction with Lighting

Step	Satisfaction w/ Lighting (N = 41)				
	β	β	β	β	β
1. Job Category	-.122	-.124	-.168	-.146	-.143
2. Glare		.035	.082	.114	.068
3. Illuminance			.296	.290	.105
4. Uniformity				.143	.152
5. Direction					-.227
Change in R^2	.015	.001	.084	.019	.018
Total R^2	.015	.016	.100	.119	.137

* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$