Daylight and View

The Influence of Windows on the Visual Quality of Indoor Spaces

Hester Hellinga

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The Influence of Windows on the Visual Quality of Indoor Spaces

Proefschrift

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“Ik ga met schilderijen om, zoals ik met de dingen omga,
ik schilder een raam zoals ik door een raam naar buiten kijk.
Als een raam in het schilderij er niet goed uitziet,
doe ik het dicht en ik sluit de gordijnen,
precies zoals ik het zou doen in mijn eigen kamer.”

(Pablo Picasso, 1881 – 1973)

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Preface

It was 2006 when I started my PhD research, a new adventure in a familiar environment. It seems ages ago, but it is “only” seven years later that I am writing this preface. A period characterized by many changes and new experiences, many setbacks, but also a period during which I met a lot of nice and inspiring people. Finishing my PhD would not have been possible without the support of colleagues, family, and friends. Some of them helped with good advice, some just gave me an enjoyable time. In either way, they have been very important to me.

First I would like to thank my promoter prof. Hans Cauberg for the fruitful conversations we had. Many thanks also go to my copromotor Truus Hordijk who was a very dedicated supervisor. I am very grateful for her support. Many thanks also go to Sylvia Jansen, for her advice concerning the development of the questionnaires for my research and statistical analysis of the results.

Throughout my PhD research, many people gave me advice about scientific research in general and questionnaire research in particular. I would like to thank all of them, colleagues from the Netherlands and abroad. Many thanks go to prof. Marc Fontoynont, prof. Werner Osterhaus, prof. Evert van Loenen and prof. Andy van den Dobbelsteen for their participation in my review committee.

I also would like to thank all colleagues from the Faculty of Architecture who supported me one way or another, especially from the department Building Technology. A special thanks goes to Shohre, Yayi, Martin, Yulia and other (former) fellow PhD candidates for their friendship and support. I also would like to thank Vincent Uso, with whom I worked on the scale model research described in this thesis. It was a pleasure to work together.

My research involved two questionnaire studies, in which many people participated. I would like to thank all participants in the questionnaire study in office buildings: employees of ABT, Cauberg-Huygen Raadgevende Ingenieurs, Delft University of Technology, DSM, Royal Haskoning, Hunter Douglas, and TNO. Furthermore, I would like to thank the students and employees of the Delft University of Technology who participated in the scale model research.

In 2011 I left Delft and moved to Zwolle to work at Cauberg-Huygen Raadgevende Ingenieurs. Thanks to all my colleagues from CHRI for providing me with such a nice work environment.

I am most grateful to my parents Jan en Griet Hellinga, because they have always supported me in many ways. We talked a lot about my experiences as a PhD candidate, and my father helped me to build the scale model for the scale model research. Many thanks also go to my brother Durk (paranymph), who is the computer geek of the family and helped me to build my own website.

Finally, I would like thank my friends, especially Hester, Katharina, Saskia (paranymph), Mariëlle, Marie and all salseros and salseras who have become dear friends on and outside the dance floor.

I would like to end this preface with a Frisian saying:

"Wèr`t wy op de wrâld ek binne, oeral skynt deselde sinne".[1]

Hester Hellinga

Zwolle, September 2013

[1] Wherever at the world we are, the same sun shines everywhere.

Summary

Windows are important for a comfortable and healthy indoor environment. In this PhD thesis the influence of windows on perceived visual comfort is investigated. Two variables play an important role: daylight and outside view. To be able to improve the visual quality of indoor spaces, one needs to have insight in how daylight and view affect the perception of an indoor space and how both variables are related.

During the first phase of the research, the influence of different features of daylight and outside view on the perceived visual quality of indoor spaces is explored. This is done by means of a literature research and a questionnaire research in office buildings. The results are used to develop a method for the analysis of the daylight and view quality of windows, the D&V analysis method. It can be used by designers to optimize the design of daylight openings, and by researchers to study the influence of daylight and view on the visual quality of indoor spaces.

The results of the questionnaire research give new insight into the statistical relationship between different variables influencing the visual quality of indoor spaces. By Principle Component Analysis (PCA) light and view factors are derived from the research data, which measure the perceived visual quality of a workplace. Furthermore, correlations are calculated to study the relationship between the questionnaire variables. The results show that items which are related to the daylight access and/or artificial lighting in the offices are statistically significantly correlated and that they could be combined in one factor for light quality. The results also show that daylight and view variables are correlated, which means that if someone is satisfied with the amount of daylight, there is a bigger chance that someone is also satisfied with the outside view.

In order to study the influence of visual comfort on the overall perception of a workplace, subsequently, a factor is constructed that measures workplace quality. This factor includes the results of items which are related to three different topics: general impression of the workplace, possibility to concentrate, and assessment of the thermal indoor climate. The perceived light quality appeared to have a statistically significant effect on the perceived workplace quality. The perceived view quality, on the other hand, only had a small effect on perceived workplace quality. It does not necessarily mean that the view quality is not important. Another reason could be that the correlation between the daylight and view variables is that strong, that much of the variation in the outcome of the workplace factor can already be explained by the daylight variables solely.

During the second phase of the research the D&V analysis method is developed. With this method a visual representation can be made of the daylight access and view through a window. Because in the literature no methods were found for the assessment of outside view, the D&V analysis method integrates existing methods for the

assessment of daylight quality with a new method for the assessment of view quality. Starting point is a basic theory of how the view and daylight access through a window can be recorded or measured objectively. In three different ways a projection can be made: by a hand drawing, a computer simulation or with a camera with a fisheye lens.

Many methods already exist for the assessment of daylight quality, but they consist of very different procedures. Therefore, the decision is made to transform existing daylight diagrams, in order to make them applicable to the D&V analysis method. In this way it has become possible to examine the access of daylight through a window in multiple ways with the new analysis method, without the need to construct a new model for each assessment method. The accuracy of the daylight diagrams is explored by comparing results obtained with the diagrams to computer calculations. The conclusion is drawn that the accuracy of the diagrams is acceptable and that results to not deviate more from the results of light simulation programs than the results of the different light simulation programs amongst each other.

Based on the results of the literature and questionnaire research, a new method is developed for the assessment of view quality. After making a projection of the window and view through the window by following the procedure of the D&V analysis method, a series of multiple choice questions is answered. By adding the results, subsequently, a view quality score is calculated that shows if the view quality is low, medium or high.

The applicability of the D&V analysis method is explored by an experiment with a scale model of an office with seven different window configurations. The results indicate that sky component, which is calculated in accordance with the new analysis method, could be a good predictor of the vertical illuminance inside the scale model. The sky component was also statistically significantly correlated with the assessment of the amount of daylight in the scale model by the participants in the research. To what extent participants in the experiment perceived glare was not related to the perceived and measured amount of daylight in the scale model, or to the different window configurations which were shown to the participants. For this reason, the amount of glare could not be predicted with the dot and sunpath diagrams. Finally, the new assessment method for view quality was found to give a good indication of the effect of different window designs on the quality of the outside view from the scale model.

Samenvatting

Ramen zijn belangrijk voor een comfortabel en gezond binnenmilieu. In dit proefschrift wordt de invloed van ramen op de beleving van visueel comfort onderzocht. Twee variabelen spelen een belangrijke rol: daglicht en uitzicht. Om de visuele kwaliteit van binnenruimten te kunnen verbeteren, moet men inzicht hebben in hoe daglicht en uitzicht de waarneming van een ruimte beïnvloeden en hoe beide variabelen met elkaar samenhangen.

Gedurende het eerste deel van het onderzoek is de invloed van verschillende eigenschappen van daglicht en uitzicht op de waargenomen visuele kwaliteit van binnenruimten onderzocht. Dit is gedaan door middel van een literatuuronderzoek en een vragenlijstonderzoek in kantoorgebouwen. De resultaten zijn gebruikt om een methode te ontwikkelen voor de analyse van de daglicht en uitzichtkwaliteit van ramen, de D&V analysemethode. Het kan door architecten worden gebruikt om het ontwerp van daglichtopeningen te optimaliseren en door onderzoekers om de invloed van daglicht en uitzicht op het visueel comfort te onderzoeken.

De resultaten van het vragenlijstonderzoek geven nieuwe inzichten in de statistische relatie tussen verschillende variabelen die van invloed zijn op de visuele kwaliteit van binnenruimten. Door middel van Principle Component Analyses (PCA) zijn licht- en uitzichtfactoren samengesteld uit de onderzoeksdata, die de waargenomen visuele kwaliteit van de werkplek meten. Verder zijn correlaties berekend om de relatie tussen de vragenlijstvariabelen te onderzoeken. De resultaten laten zien dat items die gerelateerd zijn aan de daglichttoetreding en/of kunstverlichting in de kantoren statistisch significant met elkaar correleren en dat ze samengevoegd kunnen worden in één factor voor lichtkwaliteit. De resultaten laten ook zien dat daglicht en uitzicht variabelen met elkaar correleren, wat betekent dat als men tevreden is met de hoeveelheid daglicht, de kans groter is dat men ook tevreden is met het uitzicht.

Om de invloed van het visueel comfort op de totale beleving van de werkplek te onderzoeken, is vervolgens een factor geconstrueerd die de werkplekkwaliteit meet. Deze factor bevat de resultaten van items die gerelateerd zijn aan drie verschillende onderwerpen: algemene indruk van de werkplek, concentratiemogelijkheid en beoordeling van het thermisch binnenklimaat. De waargenomen lichtkwaliteit bleek een statistisch significante invloed te hebben op de waargenomen werkplekkwaliteit. De waargenomen uitzichtkwaliteit, daarentegen, had een klein effect op de waargenomen werkplekkwaliteit. Het betekent niet perse dat de uitzichtkwaliteit niet belangrijk is. Een andere reden kan zijn dat de correlatie tussen de daglicht en uitzichtvariabelen zo sterk is, dat veel van de variatie in de uitkomst van de factor werkplekkwaliteit alleen al aan de hand van de daglichtvariabelen kan worden verklaard.

Tijdens de tweede fase van het onderzoek is de D&V analysemethode ontwikkeld. Met de methode kan de daglichttoetreding en het uitzicht door een raam visueel inzichtelijk worden gemaakt. Omdat er in de literatuur geen methoden werden gevonden voor de beoordeling van uitzicht, is er een analysemethode ontwikkeld die bestaande methoden voor de beoordeling van daglichtkwaliteit integreert met een nieuwe methode voor de beoordeling van uitzichtkwaliteit. Startpunt is een basistheorie van hoe het uitzicht en de daglichttoetreding door een raam kan worden vastgelegd of gemeten op een objectieve manier. Er kan op drie verschillende manieren een projectie worden gemaakt: door middel van een handgetekende afbeelding, een computersimulatie of met een camera met fisheye lens.

Er bestaan veel methoden voor de beoordeling van daglichtkwaliteit, maar deze bestaan uit erg verschillende procedures. Er is daarom besloten om bestaande daglichtdiagrammen te transformeren met als doel ze geschikt te maken voor de D&V analysemethode. Op deze manier wordt het mogelijk om met behulp van de nieuwe analysemethode de daglichttoetreding door een raam op verschillende manieren te bestuderen, zonder voor iedere beoordelingsmethode een nieuw model te hoeven construeren. De nauwkeurigheid van de daglichtdiagrammen is onderzocht door resultaten verkregen met de diagrammen te vergelijken met computerberekeningen. Er is geconcludeerd dat de nauwkeurigheid van de diagrammen acceptabel is en dat resultaten niet meer afwijken van de resultaten van de lichtsimulatieprogramma’s dan de resultaten van verschillende lichtsimulatieprogramma’s onderling.

Gebaseerd op de resultaten van het literatuur- en vragenlijstonderzoek is een nieuwe methode ontwikkeld voor de beoordeling van uitzichtkwaliteit. Na het maken van een projectie van het raam en het uitzicht volgens de procedure van de D&V analysemethode, wordt een serie multiplechoicevragen beantwoord. Door de resultaten op te tellen wordt vervolgens een score voor de uitzichtkwaliteit berekend die laat zien of een afbeelding een lage, gemiddelde of hoge uitzichtkwaliteit heeft.

De toepasbaarheid van de D&V analysemethode is onderzocht door middel van een experiment met een schaalmodel van een kantoor met zeven verschillende raamconfiguraties. De resultaten laten zien dat de hemelcomponent, die berekend is volgens de nieuwe analysemethode, een goede voorspeller kan zijn van de verticale verlichtingssterkte in het schaalmodel. De hemelcomponent was ook statistisch significant gecorreleerd met de beoordeling van de hoeveelheid daglicht in het schaalmodel door de deelnemers aan het onderzoek. In welke mate deelnemers aan het onderzoek verblinding hebben ervaren was niet gerelateerd aan de ervaren en gemeten hoeveelheid daglicht in het schaalmodel of aan de verschillende raamconfiguraties die de deelnemers te zien kregen. Om die reden kon de hoeveelheid verblinding niet worden voorspeld met behulp van de stippen- en zonnebaandiagrammen. Tenslotte bleek de nieuwe beoordelingsmethode voor uitzichtkwaliteit een goede indicatie te geven van het effect van verschillende raamontwerpen op de kwaliteit van het uitzicht vanuit het schaalmodel.

Symbols

Symbols used in statistical tests

Roman symbols

b	regression coefficient
b_n	regression coefficient of the n^{th} predictor
df	degrees of freedom
F	test statistic used in ANOVA
M	mean
n	sample size
p	significance
R^2	coefficient of determination (i.e. the proportion of data explained by the model)
r	Pearson's correlation coefficient
SD	standard deviation
t	test statistic for Student's t-test
U	test statistic for the Mann-Whitney test
X_n	n^{th} predictor of the regression coefficient
Y_i	outcome variable multiple regression analysis
Z	z-score (number of standard deviations of an observation above the mean)

Greek symbols

ε_i	difference between the predicted and the observed value of Y for the i^{th} participant
χ^2	chi-square test statistic

Symbols used in remainder of the thesis

Roman symbols and abbreviations

a	solar azimuth (bearing angle) [°]
C	constant
C_g	glazing factor
C_{GMT+i}	difference between the local time zone and the Greenwhich Mean Time
DF	daylight factor
dS_H	surface element of the sky dome
E_{hor}	horizontal illuminance [lux]

$E_{hor(ff)}$	horizontal illuminance in the free field (unobstructed horizontal illuminance) [lux]
E_{inside}	vertical illuminance inside the scale model [lux]
$E_{outside}$	vertical illuminance outside de scale model [lux]
ERC	external reflection component
E_{ver}	vertical illuminance [lux]
$E_{vert(ff)}$	vertical illuminance in the free field (unobstructed vertical illuminance) [lux]
E_{vs}	illuminance of the visible part of the sky [lux]
F	position of an object in the view
F'	projection of F on a vertical plane
H	hour angle of the sun from solar noon [°]
h	solar altitude (angle of elevation) [°]
IRC	internal reflection component
L	luminance of a surface element of the sky dome [cd/m^2]
L_0	luminance of the uniform sky dome [cd/m^2]
L_z	luminance at the zenith [cd/m^2]
LT	current local time
LO	longitude of the location in degrees east (negative) or west (positive) of the meridian [°]
MF	maintenance factor
P	view point
r_{eq}	distance between P and the projection of F in the diagrams of the equidistant projection [mm]
r_{LMK}	distance between P and the projection of F in the diagrams of the LMK mobile advanced [pixel/1000]
SC	sky component
SF	sky factor
ST	mean solar time
t	time in hours according to the true solar time

Greek symbols

α	angle of elevation [°]
α	angle between the line through P and dS_H [°]
β	angle between the viewing direction and the projection of the line through P and dS_H or F in the horizontal plane [°]
γ	angle between the viewing direction and the projection of the line through P and F in the vertical plane parallel to the viewing direction [°]
δ	solar declination [°]
λ	latitude of the locality [°]

π	pi (3.14159)
σ	angle between the line through P and F and the viewing direction [°]
τ	angle between the vertical axis and the projection of object F in the vertical plane perpendicular to the viewing direction [°]

Chapter 1

Introduction

1.1. Background

Windows have an important function in creating a comfortable and healthy indoor environment. In order to improve the performance of facades with regard to the visual quality of indoor spaces, it is necessary to expand the current knowledge about the influence of windows on visual quality, and to make this knowledge accessible for designers and engineers.

The two most important functions of windows are the provision of daylight access and a view to the outside (e.g. Boyce et al., 2003). Daylight is being experienced as more comfortable and attractive than artificial lighting, and the view through a window is appreciated for giving information about the outside world (e.g. Bodart & Deneyer, 2004; Dietrich, 2006). Moreover, daylight has the potential to reduce the energy demand of buildings, by minimizing the use of electricity for artificial lighting.

Daylight and a view are not only pleasant, but also important for the health of building occupants. Scientific research shows that direct sunlight and views through windows affect the well-being and stress levels of building occupants (e.g. Edwards & Torcellini, 2002; Galaciu & Veitch, 2006; Leather et al., 1998; Veitch, 2004). A big advantage of daylight is its dynamics. The luminosity and color temperature of daylight vary during the day and year, and give information about the time and weather. Our body is adjusted to this dynamic light and it influences our circadian rhythm. Rooms lit by daylight have a more natural appearance, than rooms lit by artificial light alone. A disadvantage of daylight is that it can cause glare, for example by reflections in a computer screen. It is difficult to predict when glare problems will occur, because the human eye is able to adapt to different light levels and glare perception differs between people. Moreover, the chance that people perceive glare from windows appears to be affected by the quality of the outside view (Chauval et al., 1982; Kim et al., 2011; Tuaycharoen & Tregenza, 2007).

With respect to outside views, it are mainly views of nature which have a positive effect on the health of building occupants. Environmental psychologists found that natural green has stress-reducing effects (e.g. Kaplan 1993, 2001). A literature research of Farley and Veitch (2001) shows that access to a view of nature has a positive influence on the well-being of people, the satisfaction of office employees with their jobs and the recovery of surgery patients. A high view quality is also economically interesting. Owners of hotels, dwellings and office buildings consider the view when they determine the rental or cost price (Kim & Wineman, 2005).

Very few researchers have studied the influence of both daylight and view on visual comfort. There might be several reasons why researchers and designers do not examine both daylight and view simultaneously. First of all, research on daylight quality and view quality originally belong to different research disciplines, i.e. building physics and environmental psychology. Furthermore, researchers try to limit the number of variables in each experiment, because it is more difficult to detect cause and affect relationships between many different variables. The amount of time that architects and engineers spend on window or daylight design is often very limited. Respondents on a questionnaire of Galaciu & Reinhart (2008) mentioned budged constraints and lack of client's interest as the two most important reasons. In most countries building regulations on windows and daylight are very limited (Boubekri, 2008, Tiimus, 2007).

Nevertheless, there are still many architects who have a special interest in daylight design, because it can have an important aesthetic quality (Galaciu & Reinhart, 2008). Le Corbusier is the most often mentioned architect with respect to daylight in architecture (e.g. Velds, 1999; Baker & Steemers, 2002; Boubekri, 2008). Another famous architect who had a fascination for daylighting is Louis Kahn. An interesting example of architecture where the view through windows is carefully constructed is the traditional Japanese tea house (Beita, 2010). In the Netherland architects who are connected to Stichting Living Daylights promote the use of daylight in the build environment. Once every two years an award is given to the project with the best daylight concept.

Nowadays, many existing methods and software packages are available for the analysis of daylight access (Hellinga, 2006; Bhavani & Khan, 2011), but these are sometimes too complicated and too difficult to understand for a non-experienced user (Reinhart & Wienold, 2010). Furthermore, no objective method exists yet for the analysis of view quality. A method that combines the analysis of daylight and view quality could be very helpful for designers to optimize their architectural or urban design, and for researchers to study the relation between assessment of daylight and view quality.

1.2. Objective and Research Questions

Aim of the PhD research is to develop a method for the analysis of the daylight and view quality of windows. In order to make it possible to develop this method, the influence of multiple variables on perceived daylight and view quality in office buildings is investigated. The main research question is:

How can an outside view and the access of daylight into a room be measured and visualized in an objective and comprehensible way and to what extent is it possible to predict perceived daylight and view quality?

The key questions are:

- What are the benefits of windows and people's preferences regarding windows?

- What variables influence the daylight quality in indoor spaces?
- What variables influence the view quality in indoor spaces?
- How are perceived light and view quality related?
- To what extent do perceived light and view quality influence perceived workplace quality?
- How can the outside view and the access of daylight into a room be measured, visualized and assessed in an objective and comprehensible way?
- To what extent can the access of daylight be measured with dot and sunpath diagrams?
- To what extent is it possible to predict the effect of different window configurations on perceived daylight and view quality?

1.3. Approach

The visual perception of an indoor space depends on many different variables, which is illustrated by figure 1.1. This PhD research specifically investigates the influence of windows on the perceived visual quality of indoor spaces and combines knowledge from two scientific fields, i.e. Building Physics and Environmental Psychology.

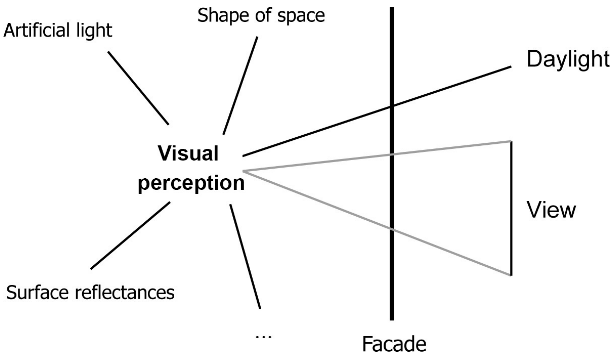


Figure 1.1: Factors influencing visual quality

The research starts with exploring what features of windows, daylight and view influence visual quality. This is done by a literature research in Part 1. The literature shows what past research revealed about the benefits and preferences of windows, daylight and outside views. Furthermore, in this part is explored what variables influence daylight and view quality and what computation or analysis methods are available.

The literature research is followed by a questionnaire research in part 2. This research is done in order to explore to what extent different variables influence satisfaction with lighting and outside view in real office environments. The survey research also studies the influence of daylight and view on the general perception and overall satisfaction with the workplace and the relationship between the assessment of light, view, and workplace quality.

The results of parts 1 and 2 are used to develop a new method for the analysis of the daylight and view quality of windows, the D&V analysis method, which is explained and validated in Part 3. It combines several existing methods for the analysis of daylight quality with a new assessment method for view quality. The accuracy and applicability of the method is explored by computer simulations and a scale model research.

1.4. Definition of Visual Quality

Visual quality is a term which can be interpreted in multiple ways. It could be described as the probability that someone finds a space visually comfortable. In an office environment visual comfort is a condition in which:

- the task a person performs is well visible;
- the person's observation is relaxed;
- and the person is satisfied with the visual conditions.

Visual comfort is to a certain extent a personal experience, since environmental preferences differ per person. In this thesis visual quality is mainly defined by the level of satisfaction of building occupants with the visual conditions. The same counts for (day)light and view quality.

1.5. Thesis Structure

The outline of the thesis is displayed in figure 1.2. As described in paragraph 1.3, the introduction is followed by three parts which each describe a separate part of the research.

Part 1 is a literature study on windows, daylight and view quality. It is divided in three chapters:

Chapter 2: Windows: Benefits and Preferences

This chapter discusses literature on the benefits of windows and people's preferences regarding windows. Furthermore, it gives an overview of legislation on windows regarding daylight and outside view.

Chapter 3: Daylight Quality

In this chapter a literature review is given on light quality in order to explore what quantitative and qualitative variables influence perceived daylight quality. Furthermore, an overview is given of the available daylight computation and assessment methods.

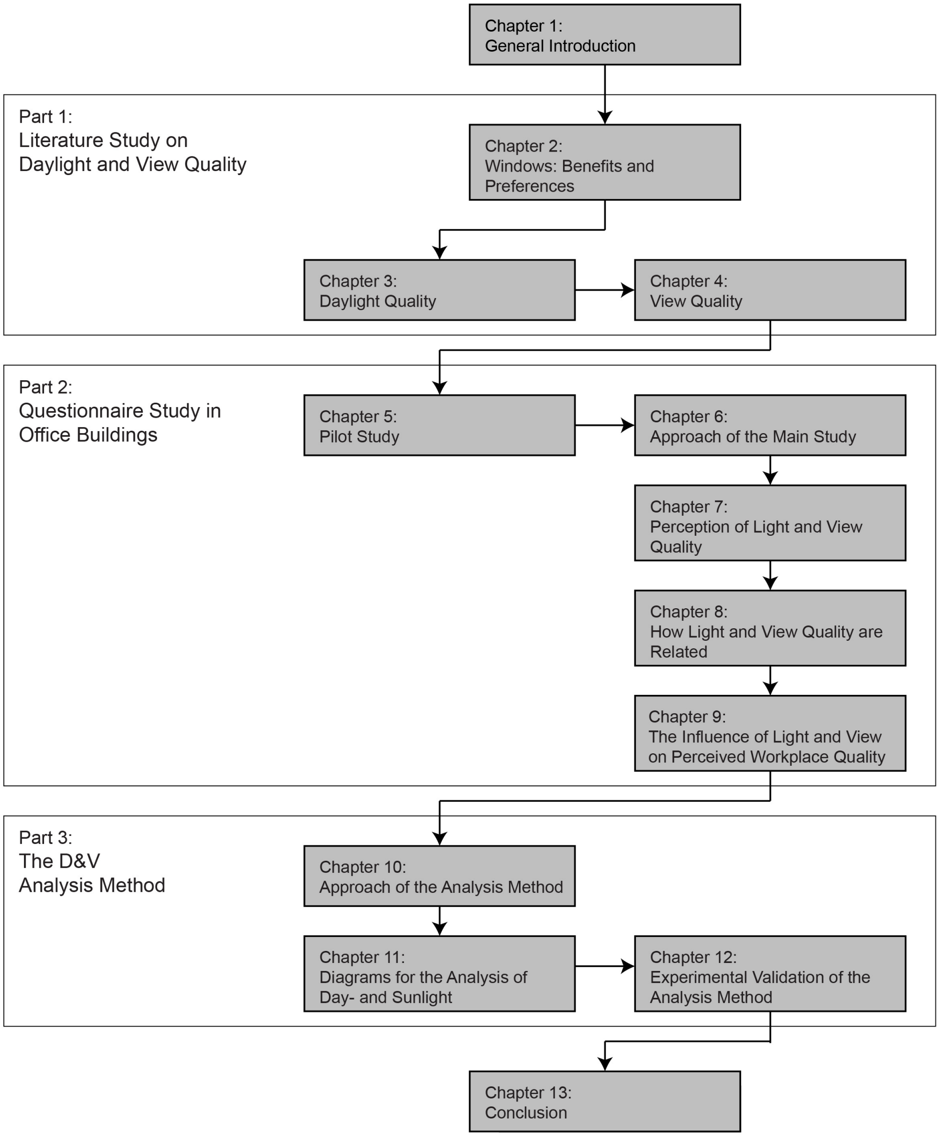


Figure 1.2: Thesis outline

Chapter 4: View Quality

In chapter 4 a literature review is given on view quality in order to explore what quantitative and qualitative variables influence perceived view quality. Furthermore, an overview is given of landscape assessment methods, in order to study if they can be used for the new analysis method.

Part 2 is a questionnaire study in office buildings. It consists of the following chapters:

Chapter 5: Pilot Study

Chapter 5 explores how office employees assess their visual environment and what according to them are important quality aspects of windows, daylight and outside view. It describes a questionnaire research which was conducted in the faculty of Architecture at the Delft University of Technology. The results give insight in how different aspects of the environment in the offices are assessed by the respondents. The findings are used as input for a more extensive questionnaire research.

Chapter 6: Main Study

The pilot study is followed by an extensive questionnaire research in eight office buildings. The approach of this main study is described in chapter 6. It explains how the questionnaire of the pilot study is improved, when the main study took place and which methods are chosen for the statistical analysis of the results. Furthermore, it describes the characteristics of the buildings which are surveyed and the number and characteristics of the respondents.

Chapter 7: Perception of Light and View Quality

Chapter 7 explores how office employees assess their workplace environment, with a focus on aspects that are related to the visual conditions. The results from the questionnaire are described and differences are examined between the results obtained from the different buildings and different groups in the main study. After studying the results of the questions separately, the impact of the outside view variables on the perceived quality of the outside view is explored and the view quality rating of pictures is examined which represent different view types. This is done in order to investigate if the preferences of the respondent can be explained by the view variables from the literature and if there are any other significant variables that play a role.

Chapter 8: How Light and View Quality are Related

In this chapter the relationship is studied between light and view variables, because the literature indicates that outside views affect the perception of glare. A factor is constructed that measures light quality and a factor that measures view quality. These factors are subjected to several statistical tests.

Chapter 9: The Influence of Light and View on Perceived Workplace Quality

The last chapter of the main study investigates to what extent daylight and view quality influence perceived workplace quality. A factor is constructed that measures workplace quality. Subsequently, the impact of light and view quality on workplace quality is explored by statistical analysis.

Part 3 is about the development and validation of the new analysis method for daylight and view quality, the D&V analysis method. It consists of three chapters:

Chapter 10: Approach of the Analysis Method

In chapter 10 the approach of the new analysis method described. It is a basic theory of how the view and daylight access through a window can be recorded or measured in an objective way. Existing methods for the analysis of daylight which are described in chapter 3 are implemented in the new method, which makes it possible to examine the access of daylight through a window in multiple ways. Furthermore, a new method for the analysis of view quality is developed based on the results of chapter 4, 5 and 7.

Chapter 11: Diagrams for the Analysis of Day- and Sunlight

In this chapter the construction of daylight diagrams is explained which are part of the D&V analysis method described in chapter 10. In order to examine to what extent the access of daylight can be measured with the dot and sunpath diagrams, results obtained with the diagrams are compared to results of computer calculations.

Chapter 12: Experimental Validation of the Analysis Method

Chapter 12 explores the applicability of the D&V analysis method by an experiment with a scale model. A comparison is made between subjective perception of the daylight access into and view from the scale model and results of the D&V analysis method, in order to investigate to what extent it is possible to predict the effect of different window configurations on perceived daylight and view quality.

Chapter 13: Conclusion

The thesis ends with an overview of the results of the research in chapter 13. In this chapter the key questions will be answered. The limitations of the research are discussed and suggestions are given for further research.

1.6. References

Baker, N.V., Steemers, K., Daylight design of buildings, London: James & James, 2002

Beita, E., Ambiguous boundaries: A Japanese way of designing with nature, p. 15-26 in Hernandez, S., Brebbia, C.A., De Wilde, W.P., ECO-Architecture III: Harmonisation between architecture and nature, Southhampton: With Press, 2010

Bhavani, R.G., Khan, M.A., Advanced lighting simulation tools for daylighting purpose: powerful features and related issues, Trends in Applied Sciences Research, Vol. 6, No. 4, 2011, p. 345-363

Bodart, M., Deneyer, A., Analyse of the survey on the office workers' interest in windows, IEA 31, Subtask A, working document, 2004

Boubekri, M., Daylight, Architecture and Health: Building Design Strategies, Oxford: Architectural Press, 2008

Boyce, P., Hunter, C., Howlett, O., The benefits of daylight through windows, New York: Lighting Research Center, Daylight Dividend Program, 2003

Chauvel, P., Collins, J.B., Dogniaux, R., Longmore, J., Glare from windows: current views of the problem, Lighting Research and Technology, Vol. 14, No. 1, 1982, p. 31-46

Dietrich, U., Daylight - Characteristics and Basic Design Principles, Lighting Design: Principles, Implementation, Case Studies, 2006, p. 16-41

Edwards, L., Torcellini, P., A literature review of the effects of natural light on building occupants, National Renewable Energy Laboratory, 2002

Farley, K.M.J., Veitch, J.A., A room with a view; a review of the effects of windows on work and well-being, Research Report, Institute for Research in Construction, NRC-CNRC, 2001

Galaciu, A.D., Reinhart, C.F., Current daylighting design practice: A survey, Building Research & Information, Vol. 36, No.2, 2008, p. 159-174

Galasiu, A.D., Veitch, J.A., Occupant preferences and satisfaction with the luminous environment and control systems in daylit offices: a literature review, Energy and Buildings, Vol. 38, No. 7, 2006, p. 728-742

Hellinga, H.IJ., Daglichtsimulatie met Desktop Radiance en DIAlux, Bouwfysica, Vol. 19, No.4, 2006, p. 21-27

Kaplan, R, The nature of the view from home: Psychological benefits, Environment and Behavior, Vol. 33, No. 4, 2001, p. 507 – 542

Kaplan, R., The role of nature in the context of the workplace, Landscape and Urban Planning, Vol. 26, No. 1-4, 1993, p. 193-201

Kim, J.T., Shin, J.Y., Yun, G.Y., Prediction of discomfort glare from windows: Influence of the subjective evaluation of window views, Indoor and Built Environment, Vol. 21, No. 1, 2011, p. 92-97

Kim, J.J., Wineman, J., Are windows and views really better? A Quantitative Analysis of the Economic and Psychological Value of Views, Rensselaer Polytechnic Institute, Lighting Research Center, New York: Daylight Dividend Program, 2005

Leather, P., Pyrgas, M., Beale, D., Lawrence, C., Windows in the workplace: sunlight, view and occupational stress, Environment and behavior, Vol. 30, No. 6, 1998, p. 739-762

Ne'eman, E., Sweitzer, G., Vine, E., Office worker response to lighting and daylighting issues in workspace environments; a pilot study, Energy and Buildings, No. 6, 1984, p. 159–171

Reinhart, C.F., Wienold, J., The daylight dashboard – A simulation-based design analysis for daylit spaces, Building and Environment, Vol. 46, No. 2, 2011, p. 386-396

Tiimus, P., Daylighting standardisation in northern Europe, MSc report, University College London, The Barlett School of Graduate Studies, 2007

Tuaycharoen, N., Tregenza, P.R., View and discomfort glare from windows, Lighting Research and Technology, Vol. 39, No. 2, 2007, p. 185-200

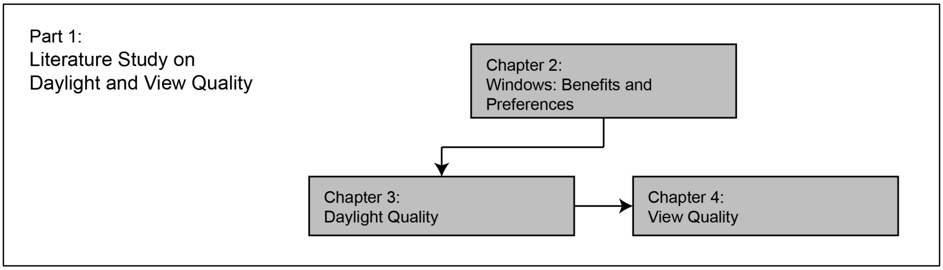
Veitch, J.A., What's new in lighting research? The broad view, International Symposium on Workplace Lighting, Dublin, 2004, p. 1-4

Velds, M., Assessment of lighting quality in office rooms with daylighting systems, Delft: Technical University of Delft, Faculty of Architecture, 1999

Part 1

Literature Study on Daylight and View Quality

Part 1 is a literature study on windows, daylight and view quality. It describes what past research revealed about the benefits and preferences of windows, daylight and outside views. Furthermore, it explores what variables influence the perception of daylight and view quality and what computation or analysis methods are available. Part 1 is divided in three chapters, chapters 2, 3 and 4.



The research questions of chapter 2 are:

- What are the benefits of windows and people's preferences regarding windows?
- What are the optimal window configurations with regard to the access of daylight and outside view?
- What requirements for windows are prescribed by the building standards?

The research questions of chapter 3 are:

- What are the benefits of daylight?
- Which characteristics of daylight influence the assessment of daylight quality?
- What computation and assessment methods exist to study daylight quality?

The research questions of chapter 4 are:

- What are the benefits of a view to the outside?
- Which features of a view affect the assessment of view quality?
- What assessment methods exist that can be used to assess view quality?

Chapter 2

Windows: Benefits and Preferences

Windows provide a connection between inside spaces and the outside world. By means of a window rooms are lit with daylight, naturally ventilated, and the room occupants can view the outside environment. On the other hand, windows can cause visual or thermal discomfort or limit the privacy of the room occupants. It is therefore important that windows are carefully designed and that they are provided with proper sun shading devices and lighting systems.

The size and shape of the windows in a building is originally a design decision by the architect, sometimes motivated by a certain philosophy. The façade design is often a reference to neighbour buildings or the urban situation and its historical background. Nowadays, decisions on window size and materialization are increasingly driven by demands regarding the access of daylight on the one hand and energy demands and available budget on the other hand. By taking all this into account, it is easy to forget the preferences of the occupants of the building. Should this not be the first and most important variable to consider?

This chapter discusses literature on the need for windows and the window preferences of room occupants. Furthermore, it gives an overview of legislation on windows regarding daylight and outside view. Three research questions will be answered in this chapter:

- What are the benefits of windows and people's preferences regarding windows?
- What are the optimal window configurations with regard to the access of daylight and outside view?
- What requirements for windows are prescribed by the building standards?

Chapter outline

2.1. Benefits of Windows

2.1.1. The need for windows

In indoor spaces people generally like to have access to a window and outside view (e.g. Ariës, 2005; Bodart & Deneyer 2004; Collins 1976; Farley & Veitch, 2001). Ariës (2005) performed a questionnaire research in 10 office buildings in the Netherlands, which was answered by 351 respondents. Almost all respondent (94%) answered that they find it important to have a window in their office space. Similar results were found by Bodart and Deneyer (2004), who performed a questionnaire research amongst Belgian office workers. In this research 99% of the respondents answered that offices should have windows.

In Ariës' research (2005) daylight availability turned out to be the most important reason that the participants would like to have access to a window. On the contrary, Farley and Veitch (2001) concluded from their literature study that, of all the functions of a window, the provision of a view is most valued by building occupants. The respondents in Bodart and Deneyer's study (2004) answered on a multiple choice question about the positive aspects of a window that sunlight is the most positive aspect, followed by visual contact with the outside, and preference to work by daylight rather than electric light.

The result of a study on seating preferences confirms that in work environments room occupants are attracted to sunlight and outside view (Wang & Boubekri, 2010, 2011). On the other hand, the results also suggest that viewing the entire room, which gives the room occupants a feeling of control, might be even more important than having access to an outside view. Seating preference appeared to be related to the available lighting and view, but also to the sense of control and privacy. Kim and Wineman (2005) studied which seats are selected most in a cafeteria and a library. They found that people tend to choose a seat near a window and with a view outwards. Areas near a view were more occupied and filled up more quickly than areas distant from a view.

Windows also have negative aspects. The most important one found in Bodart and Deneyer's study (2004) is that windows make details on computer screens difficult to see. Many respondents also selected glare, overheating and/or draughts as negative aspects of a window. In the research of Ariës et al. (2010) participants which were further from the window reported fewer problems with heat and glare. In addition, Newsham et al. (2008) found in a field study on open-plan office buildings in the US and Canada that having access to a window from a workstation, on the one hand, had a positive effect on satisfaction with lighting, but, on the other hand, could also have a negative effect on other environmental aspects like satisfaction with the privacy and ventilation.

2.1.2. Performance, productivity and health

Preferences for windows are well established. The scientific literature is less consistent about the influence of windows on performance, productivity and health. Several studies show that daylight can have a positive effect on office worker's performance (e.g. Edwards & Torcellini, 2002; Figueiro, 2006). Furthermore, outside views of nature are found to influence the sense of well-being of building occupants (e.g. Boyce et al., 2003; Kaplan, 1993, 2001; Leather et al., 1998). Being close to a window, however, can also lead to more complaints about glare, heat and ventilation. All these aspects affect overall environmental satisfaction.

Leather et al. (1998), who performed a study amongst 100 employees with different kinds of jobs, found that the more direct sunlight was penetrating into the workroom, the higher was the job satisfaction and general well-being, and the lower the chance that someone intended to quit the job. Studies on windowless versus windowed classrooms also showed significant positive effects of windows on schoolchildren and students (Edwards & Torcellini, 2002; Farley & Veitch, 2001). In a research of Heschong (2002) students in the classrooms with the biggest windows obtained 7% to 18% higher scores on standardized tests, than student in the classrooms with the smallest windows.

Wang and Boubekri (2011), however, did not find that people always perform better when sitting close to sunlight and a window. Without evaluating the room environment as a whole, the benefits of daylighting, sunlight, or an outside view are not clear. In Wang and Boubekri's research (2011) the presence of control and privacy also had an important influence on the outcome. In a research of the Heschong Mahone Group (2003) on office worker's performance, having a better outside view was consistently found to be associated with better performance, but glare from windows was found to be associated with reduced performance.

It can be concluded that windows have a positive impact on environmental satisfaction for the daylight they deliver and outside view they provide, as long as they do not cause glare or thermal discomfort or a loss of privacy and control. There is no consensus amongst scientists about the influence of environmental satisfaction on job satisfaction and productivity (Boyce, 2003), but several studies in the US and Canada show strong evidence that the physical conditions in an open-plan office environment influence office worker's well-being and performance (Heschong Mahone Group, 2003; Newsham et al., 2006; Newsham et al., 2009).

The Heschong Mahone Group (2003) found that physical comfort conditions of office workers was able to explain about 2% to 5% of the total variation observed in a measure of worker productivity or in performance on short cognitive assessment tests. In two other field studies, open-plan office occupants who were more satisfied with their environments were also more satisfied with their jobs (Newsham et al., 2009; Veitch et al., 2007) Furthermore, job satisfaction was found to contribute to stress-reduction, which in turn contributes to general occupant well-being (Newsham et al., 2006).

2.2. Windowless Spaces

As pointed out before people like to have access to a window in their office rooms, but not in every country office rooms necessarily have windows. Research has indicated that people working in windowless spaces have a stronger desire for windows, than people working in windowed spaces (Nagy et al., 1995). Collins (1976) suggests that the smaller and more restrict a windowless space is, the more repetitive and monotonous the task is, and the more reduced the freedom of movement and interaction room occupants have, the more unpleasant and oppressive the space will be and the stronger the desire for a window.

Several researchers investigated if employees who work in windowless offices use visual decoration to compensate for the lack of having access to a window (Heerwagen & Orians, 1986; Bringslimark, 2011; Biner er al, 1993). Other researchers investigated the desirability of artificial windows or inside windows as a real window substitute (Young & Berry, 1979; Biner et al., 1991). Results are not consistent, but give more insight into the benefits of windows in office rooms.

In 1986 Heerwagen and Orians examined the use of visual decoration in windowed and windowless offices. They found that people in windowless offices used more visual materials for decoration, than occupants of windowed spaces. The second finding was that the content of the materials in windowless spaces was dominated by nature themes. There were more landscapes and fewer cityscapes in the windowless spaces, than in the windowed spaces. The results of a recent research by Bringslimark et al. (2011) agrees with the findings of Heerwagen and Orians. They also found that office workers use decoration dominated by nature to compensate for having no access to a window. The researchers used the survey data of 385 Norwegian office workers and found that office employees who lack a view are likely to bring more plants and pictures of nature into their workspaces.

Biner et al. (1993), however, found, different results. They asked students and full-time office workers what office features they consider to be window substitutes. Four types of window substitutes were mentioned, namely other apertures (e.g. skylights), paintings or art, living things (e.g. plants), and (light) panels. Subsequently, the researchers investigated if any of these window substitutes were more prevalent or larger in offices without windows. In this study no significant difference between windowed and windowless spaces was found. The office occupants appeared to find other things, like space personalization, to be more important than compensation for the absence of a window in their offices.

Bringslimark et al. (2011) discusses several possible reasons why the outcome of their study differs from the results of Biner et al. (1993), and agrees with the results of Heerwagen and Orians (1986). One reason might be that the character and policy of the organizations that were involved in the studies were different. Participants in the study of Biner et al. (1993) might have had the opportunity to spend more time outdoors or in rooms with windows. Furthermore, the researchers used different types of analysis, and dealt with intervening variables like space personalization in a different way.

Young and Berry (1979) investigated window preferences in a realistic office setting with a real window and an artificial window. All eleven participants in this study preferred a windowed office to a windowless office. A remarkable outcome of the research is that the artificial window was rated nearly as desirable as an outside window for long-term comfort and productivity by the participants. The question arises if an artificial window can have the same qualities as a real window. According to Markus (1967) artificial windows are unrealistic and after a while they will not be satisfying anymore. An artificial window lacks depth and therefore there is no clear distinction between the aperture and the view. It is questionable if the participants in Young & Berry's study would have given the same rating to the artificial window, when they had been using the test room as their workplace for several months.

Another way to compensate for a lack of windows in the outside facade, is the use of windows to an indoor space. Biner et al. (1991) investigated the desirability of inside windows. The researchers found that inside windows are generally preferred, when outside windows are not present. For comparable spaces, the selected size for inside windows was smaller than for outside windows. The desire for inside windows, and the preferred size depended on the presence of outside windows in the adjacent space. If the space being viewed had an outside window, people preferred bigger inside windows than if the space had no windows.

A similarity between all the studies discussed in this paragraph is that they focus on the compensation of having no view instead of having no daylight access. In architecture window designs are mainly driven by requirements regarding the access of daylight and ventilation. The function of window substitutes, on the other hand, is mainly to imitate a view. This can be due to two reasons. First of all, it is difficult to imitate the dynamic qualities of daylight by a window substitute. It might be easier to compensate for the lack of a view, than for the lack of daylight. Another reason might be that office employees who work in a windowless rooms consider the view to be more important than the access of daylight.

2.3. Window Size, Shape, and Position

2.3.1. Window size

Several studies found in the literature made use of scale models to investigate what window sizes are preferred in indoor spaces. Ne'eman and Hopkinson (1970) did not only use a scale model for their research, but also a full scale mock-up of an office room. They concluded that the preferred window size is mainly dependent on the view and not on the access of daylight. They also found that near objects in the view attract more attention and require wider window opening than distant objects. If objects are distant, their apparent size is smaller and they cannot be observed in detail. In that case, a smaller window can be sufficient. Furthermore, acceptable window width appeared to be dependent on a subjects' distance from the window.

The minimal window size, found by Ne'eman and Hopkinson (1970) can be written as a percentage of the total wall area. The average window width chosen by the respondents was 2.42 meter, and in that case the window covered 23% of the total wall area. Only 15% of the respondents found that the minimal width of the window should be more than 3.35 meter; which is a window area of more than 32% of the wall area.

A research of Keighley (1973b), with a 1:12 scale model, shows a similar result. The view was most appreciated when the windows area was 25-30% of the wall area. When the window area was less than 25%, appreciation dropped down very quickly. Butler and Steurwald (1991) also used a 1:12 scale model for their research. These researchers found that the preferred window size is not a fixed percentage of the size of the wall, but that it is influenced by the nature of the view and the size, shape and function of the room. However, Butler and Steuerwald also found that the average preferred window area for small rooms was about 30% of the total wall area, which is similar to the results of the previous studies. The average percentage was lower for a big wall or room. Moreover, in case of an attractive view a bigger window size was desired than in case of a less attractive view.

The results of the previous studies quite consistently show that the minimum size of the windows in a room for visual comfort is about 20-25% of the wall area and the preferred size is about 30%. It remains unclear, though, if the results of scale model studies are applicable to real settings, especially to rooms with windows in more than one wall. Examining window preferences in real setting is complex (Veitch, 2001). In a study of Butler and Biner (1989) 59 students answered a questionnaire in which they were asked to indicate for several types of spaces their window preferences. Window preference appeared to vary a lot across the spaces. Several factors were found to affect preference, like having a view or good ventilation. The amount of windows desired in a space depended on how important these factors were to individuals in that particular space. Again, view was found to be an important predictor of window preference.

In a post-occupancy evaluation of Danish office buildings, 87% of the occupants found that the window size in their office is "just right", although window sizes were very different (Christoffersen et al.1999). On the other hand, the researchers also found that if the window area was less than 20-25% of the façade, the number of occupants who found their window too small was increasing. Furthermore, if the window area exceeded 30-35% the number of occupants who think that their window is too large was increasing. These results agree with the results of the scale model studies.

2.3.2. Window shape and position

The literature gives different recommendations for window shape and position. According to Markus (1967) the view should be leading in the design of window shape and position. This finding is confirmed by Keighley's research (1973a), which shows that different window shapes and heights were preferred for different views. This would mean that different window shapes and heights would be preferred for different parts of a building. Indeed, Keighley found that window heights and vertical displacement were slightly lower for ground floor views than for views from upper floors. However, because Keighley did not study the effect of daylight on the subjects preferences conclusions could not be drawn yet. The access of daylight might lead to different preferences, but no studies are found that study preferred window configurations in presence of daylight.

If the preferred geometry of windows indeed mainly depends on the outside view, what would then be the best configuration for most office buildings? According to Markus and Keighley almost all views contain three layers: i.e. a layer of ground, a layer of city or landscape, and a layer of sky (Markus, 1967; Keighley, 1973a and 1973b). The researchers do not agree on the preferred geometry for views containing all of these three elements.

According to Markus (1967) the choice for relatively small, vertical windows gives the opportunity to display a cross section of the three layers of a view. He also presumes that by reducing window areas and dividing them into a number of elements, the dynamic qualities of the window would be improved. When the windows consist of multiple elements the view changes more when the observer moves to another position than when the windows consist of huge, transparent planes.

In contradiction, Keighley (1973a) found that the subjects in his studies preferred wide horizontal apertures, especially when the view contains objects far away from the window. The preferred position of the window depended on the elevation of the skyline. For the distant views a window sill height of about 0.8 m and window head height of about 1.9 above floor level was found to be most satisfactory. For views with the skyline at a higher level the preferred head height was also higher, in order to include the sky in the view. When the view was fully blocked by a façade subjects had more difficulties to define the optimum window configurations, and individual differences were bigger.

A second study of Keighley (1973b) examined the effect of placing different windows with different shapes in one wall. The participants in the study did not appreciate it when windows had different shapes. Satisfaction also decreased when a horizontal window was divided in multiple elements, because in this way the view was interrupted. Most appreciated was a regularly placement of big, horizontal windows. It has to be noted that this research focuses on windows in only one wall. A possible effect of windows in two or more walls was mentioned, but not investigated.

2.4. Building Standards

Legislation on windows and daylight access in buildings differs from one country to another. In an overview of daylight legislation, Boubekri (2004, 2008) makes a distinction between three types of regulations. The first type are requirements on the availability of direct sunlight. Subsequently, there are requirements for a certain window area for various types of spaces. The third type relates to the quantity of daylight inside the building. In this thesis a fourth category is added, namely legislation on the availability of an outside view.

2.4.1. Legislation on the availability of direct sunlight

Legislation on sunlight attempts to guarantee that buildings and their occupants have access to direct sunlight for a certain length of time. Some regulations prescribe a minimum number of uninterrupted sun hours in indoor spaces, for example the German standard DIN 5034 (1999). In other regulations, the maximum building height and the minimum distance to the property lines are prescribed, which is easier to test, but leaves less design freedom to the architect.

The DIN 5034 (1999) only prescribes a minimum amount of direct sunlight in habitable rooms and hospital rooms, not in work rooms. A room is considered to be sufficiently sunlit if the room receives at least 1 hour of direct sunlight on the 17th of January. The incidence of sunlight is considered to be direct if the altitude of the sun is at least 6° and the light falls directly into the room.

The British Code BS 8206-2 (2008) prescribes that sunlight should be admitted unless it is likely to cause thermal or visual discomfort or deterioration of materials. The minimum amount of direct sunlight hours should be at least 25% of probable sunlight hours between 21 March and 21 September and at least 5% of probable sunlight hours between 21 September and 21 March. The building code gives a procedure for calculating the probable sunlight hours by a sunpath diagram.

The Dutch NEN 2057 (2011) only gives recommendations for direct sunlight during the summer months, i.e. between 1 March and 1 September. During this period at least 25% of the occupancy spaces in a building should receive at least 2 hours of direct sunlight in the middle of the window at the height of the window sill. The incidence of sunlight is considered to be direct if the altitude of the sun is at least 10°.

2.4.2. Legislation on window area

Building standards prescribe that the window size should be a minimum percentage of floor area of the room. For workrooms and/or habitable rooms generally minimum window areas of about 8-10% of the floor area are required (Boubekri, 2008; Tiimus, 2007).

In the Netherlands, a minimum equivalent daylight area is prescribed for different functions of indoor spaces. The equivalent daylight area is a measure for the minimum window area which supplies the indoor space with daylight. It has to be determined in accordance with the Dutch standard NEN 2057 (2011) and takes into account window height and possible obstructions. In offices the total equivalent daylight area has to be at least 2.5% of the floor area, with an minimum of 0.5 m^2.

Exceptionally the minimum window size is expressed as a percentage of the area of the wall containing the window. The British Code BS 8206-2 (2008) recommends that windows should be at least 20% of the external window wall for rooms measuring less than 8 meters in depth and 35% of the external wall for rooms deeper than 14 meters.

The German standard DIN 5034 is the most extensive standard for interior daylighting in Europe. It does not only prescribe a certain window area, but also gives requirements for opening heights and widths. General requirements for rooms with windows and requirements specifically for workrooms are given in table 2.1.

Table 2.1: General requirements for rooms with windows, DIN 5034-1 (1999)

General requirements
The sum of all glazing widths shall be at least 55% of the width of the wall containing the window.
The sill shall be no more than 0.9m, the bottom of the glazing not more than 0.95m, and the window head at least 2.2 m above the floor
Requirements specifically for workrooms
Window opening height: >1.3m, glazing width >1m, min. glazing area for room depths under 5m: 1.25m2; for greater room depths: 1.5m^2.
Total glazing area at least 30% of product of room width and room height, and at least 10% of room area.

According to Boubekri (2008) requirements on window size are not intended to supply daylight, but rather to facilitate ventilation or to provide exits in case of emergencies. The windows are allowed to have a very low daylight transmission coefficient, and, therefore, the requirements do not necessarily lead to sufficient daylight inside the building. For this reason, Boubekri (2008) thinks that this type of legislation should not be considered daylight legislation. In for instance the Netherlands and Germany, however, legislation clearly explains that minimum window areas are required in order to provide sufficiently access of daylight into the indoor spaces. In the Netherlands the daylight transmittance coefficient of the glazing is taken into account when the equivalent daylight area of a window is calculated (Bouwbesluit 2011, afd. 11: Daglicht).

Countries do not only prescribe minimum window sizes, but sometimes also limit the maximum window area from the perspective of thermal insulation. In Denmark, for instance, the total area of window and door openings may not exceed 22% of the heated floor area (Boubekri, 2008). In Finland the total window area in a building may be no more than 15% of the gross floor area of the building. Furthermore, the proportion of the window area must not exceed 50% of the total area of outside walls (Boubekri, 2008).

2.4.3. Legislation on daylight quantity

Legislation on daylight quantity can be divided into illuminance-based standards and daylight factor-based standards. In most countries recommended or prescribed illuminance levels do not necessarily have to be supplied by natural light, but can be provided by electric light sources as well. Daylight levels are not described as being mandatory but preferred or recommended (Boubekri, 2004; Tiimus, 2007). More information about daylight legislation is given in Chapter 3.

2.4.4. Legislation on outside view

Requirements on outside view are rather exceptional. In many countries, however, access to a view is recommended in spaces meant for work (Tiimus, 2007). Recommendations in for example France and Denmark require that workspaces should have windows with a view, unless this is not possible due to the type of activity taking place in that space. The National Building Code of Finland requires that the view from the windows is taken into account in the design of habitable rooms.

In the Netherlands, no legislation on outside view exists anymore. In 1997 the requirement for having an outside view from workplaces was eliminated from the work legislation Arbobesluit. Six years later, outside view was also not required anymore by the building legislation Bouwbesluit 2003. It was expected that meeting the requirements for daylight access automatically would mean that the former view requirement would be met (http://duurzaambouwen.senternovem.nl). Building standards still give suggestions how to assess view quality, but these are not mandatory. More information can be found in Chapter 4.

2.5. Key Findings

The key findings of the literature study on the benefits and preferences of windows are:

- Windows are generally desired in workspaces for the daylight they deliver and the outside view they provide.
- Windows have a positive impact on performance, productivity and health, as long as they do not cause glare or thermal discomfort or a loss of privacy.
- In windowless spaces posters of natural elements, inside windows, or artificial windows are desired, in order to compensate for the absence of a view.
- Preferred window size, shape, and position might vary with the size and function of workspaces, the office layout and distance from a window, but seems to be most dependent on the outside view.
- Research on preferred window sizes indicate that, if only one wall of a space contains windows, they should be at least 20-25% of the wall area. The preferred window size is 30% or more.
- Legislation on sunlight in Europe prescribe a minimum number of uninterrupted sun hours which varies between the different countries from 1 to 2 hours during the summer and/or winter months.
- Legislation on windows often expresses the minimum window size as a percentage of the floor area. For workrooms and/or habitable rooms generally minimum window areas of about 8-10% of the floor area are required.
- From the perspective of thermal insulation windows should not be too large.
- Regulations on providing an outside view are very exceptional.

It is clear that windows have many benefits for building occupants. Little research has been done so far on the optimal window configurations in real workplace environments and by taking into account many different variables. Building legislation on windows is very different from one country to another and standards are often not mandatory. The next two chapters explore what variables affect perceived daylight and view quality and what computation or analysis methods are available.

2.6. References

Ariës, M.B.C., Human Lighting Demands: Healthy Lighting in an Office Environment, Eindhoven: Technical University of Eindhoven, Faculty of Architecture, Building and Planning, 2005

Ariës, M.B.C., Veitch, J.A., Newsham, G.R., Windows, view, and office characteristics predict physical and psychological discomfort, Journal of Environmental Psychology, Vol. 30, No. 4, 2010, p. 533-541

Biner, P.M., Butler, D.L., Lovegrove, T.E., Burns, R.L., Windowlessness in the Workplace: A Reexamination of the Compensation Hypothesis, Environment and Behavior, Vol. 25, No. 2, 1993, p. 205-227

Biner, P.M., Butler, D.L., Winsted III, D.E, Inside Windows: An Alternative to Conventional Windows in Offices and Other Settings, Environment and Behavior, Vol. 23, No. 3, 1991, p. 359-382

Bodart, M., Deneyer, A., Analyse of the survey on the office workers' interest in windows, IEA 31, Subtask A, working document, 2004

Boubekri, M., An overview of the current state of daylight legislation, Journal of the Human-Environmental System, Vol. 7, NO. 2, 2004, p. 57-63

Boubekri, M., Daylighting, Architecture and Health: Building Design Strategies, 2008

Bouwbesluit 2012, Hoofdstuk 3: Voorschriften uit het oogpunt van gezondheid, Afdeling 3.11: Daglicht

Boyce, P., Hunter, C., Howlett, O., The benefits of daylight through windows, New York: Lighting Research Center, Daylight Dividend Program, 2003

Bringslimark, T., Hartig, T., Patil, G.G., Adaptation to Windowlessness: Do Office Workers Compensate for a Lack of Visual Access to the Outdoors? Environment and Behavior, Vol. 43, No. 4, 2011, p. 469-487

British Standard BS 8206-2, Lighting for Buildings – part 2: Code of practice for daylighting, 2008

Butler, D.L., Biner, P.M., Effects of setting on window preferences and factors associated with those preferences, Environment and Behavior, Vol. 21, No. 1, 1989, p. 17-31

Butler, D.L., Steuerwald, B.L., Effects of view and room size on window size preferences made in models, Environment and Behavior, Vol. 23, No. 3, 1991, p. 334-358

Christoffersen, J., Johnsen, K., Peterson, E., Hygge, S., Post-occupancy evaluation of Danish office buidings, Proceedings of the 24th Session of the Commission Internationale de l'Eclairage, Warsaw, Poland, Vienna, Austria: CIE Central Bureau, 1999, p. 333-337

Collins, B.L., Review of the psychological reaction to windows, Lighting Research and Technology, Vol. 8, No. 2, 1976, p. 80-88

Deutsche Norm DIN 5034-1, Daylight in interiors, Part 1: General requirements, 1999

Edwards, L., Torcellini, P., A literature review of the effects of natural light on building occupants, National Renewable Energy Laboratory, 2002

Farley, K.M.J., Veitch, J.A., A room with a view; a review of the effects of windows on work and well-being, Research Report, Institute for Research in Construction, NRC-CNRC, 2001

Figueiro, M.G., Rea, M.S., Stevens, R.G., Rea, A.C., Daylight and productivity – a possible link to circadian regulation, Light and Human Health, Proceedings of EPRI/LRO 5th International Lighting Research Symposium, Palo Alto, 2002, p. 185-193.

Heerwagen, J.H., Orians, G.H., Adaptations to Windowlessness: A Study of the Use of Visual Décor in Windowed and Windowless Offices, Environment and Behavior, Vol. 18, No. 5, 1986, p. 623-639

Heschong , L, Daylighting and human performance, ASHRAE Journal, 2002, p. 65-67

Heschong Mahone Group, Windows and offices: A study of office worker performance and the indoor environment, Technical Report for the California Energy Commission, 2003

Kaplan, R, The Nature of the View from Home: Psychological Benefits, Environment and Behavior, Vol. 33, No. 4, 2001, p. 507 - 542

Kaplan, R., The role of nature in the context of the workplace, Landscape and Urban Planning, Vol. 26, No. 1-4, 1993, p. 193-201

Keighley, E.C, Visual requirements and reduced fenestration in office buildings — A study of window shape, Building Science, Vol. 8, No. 4, 1973a, p. 311-320

Keighley, E.C, Visual requirements and reduced fenestration in offices — A study of multiple apertures and window area, Building Science, Vol. 8, No. 4, 1973b, p. 321-331

Kim, J.J., Wineman, J., Are windows and views really better? A Quantitative Analysis of the Economic and Psychological Value of Views, Rensselaer Polytechnic Institute, Lighting Research Center, New York: Daylight Dividend Program, 2005

Markus, T.A., The function of windows— A reappraisal, Building Science, Vol. 2, No. 2, 1967, p. 97-121

Leather, P., Pyrgas, M., Beale, D., Lawrence, C., Windows in the workplace: sunlight, view and occupational stress, Environment and behavior, Vol. 30, No. 6, 1998, p. 739-762

Nagy, E., Yasunaga, S., Kose, S., Japanese office employees' psychological reactions to their underground and above-ground offices, Journal of Environmental Psychology, No. 15, 1995, p. 123-134

Ne'eman E., Hopkinson, R.G., Critical minimum acceptable window size: a study of window design and provision of a view, International Journal of Lighting Research and Technology, Vol. 2, No. 17, 1970, p. 17-26

Nederlandse Norm NEN 2057: Daglichtopeningen van gebouwen – Bepaling van de equivalente daglichtoppervlakte van een ruimte, 2011

Newsham, G.R., Brandt, J., Donnelly, C.L., Veitch, J.A., Ariës, M.B.C., Charles, K.E., Linking indoor environment conditions to job satisfaction: a field study, Building Research & Information, Vol. 37, No. 2, 2009, p. 129-147

Newsham, G.R., Donnely, C.L., Ariës, M.B.C., Charles, K.E., Indoor environment conditions and occupant satisfaction: Analysis of Haworth field study data, Final Report, National Research Council Canada, 2006

Newsham, G.R., Veitch, J.A., Charles, K.E., Risk factors for dissatisfaction with the indoor environment in open-plan offices: an analysis of COPE field study data, Indoor Air, Vol. 18, No. 4, 2008, p. 271-282

Tiimus, P., Daylighting standardisation in northern Europe, MSc report, University College London, The Barlett School of Graduate Studies, 2007

Veitch, J.A., Charles, K.E., Farley, K.M.J., Newsham, G.R., A model of satisfaction with open-plan office conditions: COPE field findings, Journal of Environmental Psychology, Vol. 27, No. 3, 2007, p. 177-189

Veitch, J.A., Psychological processes influencing lighting quality, Journal of the Illuminating Engineering Society, Vol. 30, No. 1, 2001, p. 124-140

Wang, N., Boubekri, M., Design recommendations based on cognitive, mood and preference assessments in a sunlit workplace, Lighting Research and Technology, Vol 43, No. 1, 2011, p. 55-77

Wang, N., Boubekri, M., Investigation of declared seating preference and measured cognitive performance in a sunlit room, Journal of Environmental Psychology, Vol. 30, No. 2, 2010, p. 226-238

Young, H.H., Berry, G.L., The impact of environment on the productivity attitudes of intellectually challenged office workers, Human Factors, Vol. 21, No. 4, 1979, p. 399-407

Websites

www.duurzaambouwen.senternovem.nl, accessed: 30-06-2009

Chapter 3

Daylight Quality

Daylight is the main natural light source and has a dynamic character. It varies in level, direction and spectral composition with time, which is very beneficial for people. Daylight affects both visually and non-visually the well-being of building occupants. Visually the daylight distribution inside a space does not only influence the visibility of the tasks, but also has an enormous influence on the visual appearance of that space.

By optimizing the use of daylight as the main light source for visual tasks, it has the potential to reduce energy use by artificial lighting. However, as explained in the previous chapter, an overflow of day- or sunlight should not lead to visual or thermal discomfort. Therefore, sufficient daylight and sunshading devices should be provided in indoor spaces. In order to benefit most of the available day- and sunlight, architects preferably integrate these devices into the design of the building facade. Besides exploring how aims concerning energy savings can be met, it is also important to know what preferences building occupants have with respect to light levels and access of direct sunlight.

This chapter gives an overview of literature on daylight quality and daylight computation and assessment methods. The aim is to answer three research questions:

- What are the benefits of daylight?
- Which characteristics of daylight influence the assessment of daylight quality?
- What computation and assessment methods exist to study daylight quality?

Chapter outline

3.1. Benefits of Daylight

3.1.1. Benefits of daylight over electric light

People are convinced that daylight is superior to electric light (Bodart & Deneyer, 2004; Galasiu & Veitch, 2006). Bodart and Deneyer (2004) found that 91% of the participants in their research prefer to work in daylit spaces. When questioned why daylight is preferred, almost all respondents indicated that daylight is more comfortable than electric lighting and that it reduces stress of work. The respondents were also questioned what type of lighting is best to work by. Daylight was selected by 62% of the respondents and 37% selected that daylight and electric light are equally good to work by. Very few people prefer electric lighting to daylight.

Roche et al. (2000) also found that people prefer windows in their work environment. A total of 73% of the participants considered having a window in their work area to be very important and only 4% preferred electric lighting to daylight. In a questionnaire research of Veitch and Gifford (1996) about half of the office workers and university students believed that they do their best work when they are in places lit by daylight.

Although electric light can make a work task very well visible, the addition of daylight can make a room look more attractive. As Collin (1976) mentions, the short term variations in natural light provides variety and interest in a way that continuous electric lighting cannot. However, the main reasons that people prefer daylight in their work environment seems to be the believe that daylight supports better health (Galasiu & Veitch, 2006).

The results of many studies show that daylight is not only perceived as being beneficial for health, but that it also really improves the health and productivity of employees and students (Edwards & Torcellini, 2002; Van den Beld & Van Bommel, 2002; Figueiro et al., 2006). In a study of the Heschong Mahone Group (2003) office workers who reported that they did not have enough daylight, were more likely to report that they suffered from fatigue, headache and/or eye strain.

3.1.2. Daylight and health

Daylight can have a positive influence on the health of people through three different systems:

- Via the visual system daylight influences perception and visual comfort
- Via the circadian system daylight influences the rhythm of waking and sleeping and the metabolism
- Via the skin sunlight regulates the production of vitamine D

Researchers currently have much interest in how light affects the circadian rhythm, the 24 hour cycle of waking and sleeping. In 2002 a third photoreceptor was found on the retina, other than rods and cones, which forms a direct connection between the eye and the SCN (suprachiasmatic nucleus) in the hypothalamus (Berson et al., 2002). The SCN directs the circadian rhythm and influences the level of the hormones melatonin and cortisol. Supplementary studies give more insight into the spectral composition of the lighting and the illuminances that are needed to send signals to the SCN (Ariës, 2005; Van Bommel, 2006).

Before the non-visual receptor was discovered, it was already known that light influences the sleep quality of people (Begemann et al., 1979; Edwards & Torcellini, 2002). Researchers also discovered a relationship between stress, winter depressions, and little exposure to daylight (Boubekri, 2008; Edwards & Torcellini, 2002; Boyce et al., 2003).

It is clear that daylight affects people's health and well-being. This should be taken into account when a building is designed. It is important not to design for visual comfort only, but also to take into account the health aspects of light.

3.2. Daylight Preferences

3.2.1. Human assessment of lighting

By continuous changes in the eye and adaptation of the brain, people have an enormous natural capacity to change their sensitivity to light (Boyce, 2003; Nicol et al., 2006). Moreover, light perception and preferences are very variable from one person to another (Boyce, 2003; Galasiu & Veitch, 2006). This makes it hard to assess light quality. Concerning the daylight access through windows there are even two more factors that make it difficult to assess light quality (Fontoynont, 2002):

- Daylight is dynamic, requiring a long term approach
- The brightness of a window cannot be disconnected from the content and pleasantness of the view

In any case, the psychological aspect of daylight perception could not be ignored. It can be investigated by subjective assessment criteria, like (Fontoynont, 2002):

- How esthetic is the daylight component (window, sunshading, materials etc.)
- How attractive are the light patterns indoors (light distribution, light rays, reflections, color etc.)
- How pleasant and necessary is the outside view (Chapter 4)

Post occupant evaluations (POE) give insight in the perception of light quality in real work environments. Results of questionnaires on the human assessment of lighting can be compared to quantitative measures of lighting, like illuminance and luminance levels. The following paragraphs will discuss what light levels are preferred by building occupants.

3.2.2. Workplane illuminance and illuminance uniformity

Illuminance is a measure for the amount of light which falls onto a surface area. Traditionally, lighting standards require a certain minimal horizontal illuminance level on the task area. In the European standard EN 12464-1 (2011) minimum illuminance levels are listed for different room types. The minimal horizontal illuminance on the task area in offices, for instance, is 500 lux. Because daylight levels vary throughout the time, these requirements apply in the first place to artificial lighting.

Scientific research shows that preferred illuminance levels in offices are very variable from one person to another (Galaciu & Veitch, 2006; Veitch & Newsham, 1996). In daylit rooms the preferred illuminance levels by artificial lighting appears to depend on, amongst others, the distance of the workplace to the window (Galaciu & Veitch, 2006)

Logadottir et al. (2011) investigated preferred illuminance levels in a workplace environment by using the method of adjustment. The results show that both the stimulus range offered to the participants and the initial illuminance level offered to the participants before the adjustments were made have significant effect on the preferred illuminance levels. In the experiment three different stimulus ranges were used (21-482, 38-906, and 72-1307 lux), which did lead to significantly different preferred illuminance levels (respectively 337, 523, and 645 lux).

Several studies show that in work rooms generally higher illuminance levels are preferred than the standards recommend (Fleischer et al. 2001; Veitch & Newsham,1996). Fleischer et al. (2001) found in her research that the higher the illuminance of a workplace in a room, the higher the assessment of pleasantness of the room, although a higher illuminance did not necessary lead to a better individual performance. Kim and Kim (2006) found that if sun shading devices are automatically controlled, the minimum light level in offices should be 650 lux at the task. Furthermore, the fluctuation of light in time should stay within 40% of the task illuminance.

Although research indicates that higher light levels are preferred, a research on the contemporary lighting of offices in Europe shows that most people participating in the research are satisfied with the lighting of their workplace (Nicol et al., 2006). In this research the assessment of the lighting appeared to be almost independent of the illuminance level. Furthermore, The Heschong Mahone Group (2003) found that horizontal illuminance levels have an inconsistent relationship to performance. The study indicates that people are more sensitive to changes of daylight illumination levels, especially at lower levels of illumination.

Because large spatial variations in illuminances around a work task area might lead to visual discomfort, standards require that the illuminance ratio between the task and the immediate surrounding stays within certain limits. Maximum ratios are found of 0.8 (minimum/mean illuminance) or 0.7 (minimum/maximum illuminance), although some studies show that a ratio of 0.5 (minimum/maximum illuminance) could also be acceptable (Dubois, 2001; Newsham et al., 2008). In daylit rooms the acceptance of non-uniform illuminance seems to be higher than for rooms that are only lit by artificial lighting (Dubois, 2001; Veitch & Newsham, 1996).

The literature discussed in this paragraph is just a small selection of all literature about preferred illuminance levels at the workplace. Results are inconsistent about what illuminance levels are preferred. One probable reason is that the adaptation level before the experiment starts differs between the experiments. Furthermore, the light distribution in the spaces is not always known and in some studies the number of participants is limited. Building standards prescribe minimum illuminance levels at the workplane, but higher levels seem to be preferred. Also higher illuminance ratios between a work task and its immediate surrounding seem to be accepted than standards prescribe.

3.2.3. Vertical illuminances

Researchers currently plead for the use of vertical instead of horizontal illuminance as the basic principle of light quality, because office work nowadays is mainly done by using computer screens and because people's non-visual needs for daylight seem to be more related to vertical illuminance levels than to horizontal illuminance levels (Ariës, 2005; Begemann et al., 1997; Cuttle, 2010; Heschong & Roberts, 2009).

The literature does not yet give a clear and consistent answer on how high vertical illuminance levels at the workplace should be. The European standard 12464-1 (2011) requires a mean cylindrical illuminance, which is the average vertical plane illuminance, in the activity and interior areas of at least 50 lux with a minimum illuminance uniformity of $U_0 > 0.10$. Ariës (2005) found that vertical illuminance levels at the eye of 1000 to 2000 lux are fine and may not lead to glare, but that these levels are not demanded all day.

3.2.4. Daylight Factor (DF), Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI)

The daylight factor is a very common measure which can be used to predict illuminance levels by daylight in a room. The daylight factor is the ratio between the illuminance inside a room and the illuminance outside at the same time (Linden, 2006; Robbins, 1986). The daylight factor only applies to overcast sky conditions according to the C.I.E. Standard Overcast Sky. The luminance distribution of the overcast sky is defined by the Moon and Spencer's formula (Hopkinson, 1972, p. 41):

$$L(\alpha) = L_z \frac{1 + 2\cos\alpha}{3} \qquad (3.1)$$

where $L(\alpha)$ is the sky luminance, L_Z is the luminance at the zenith, and α the angle of elevation.

The sky component is the most important component of the daylight factor. Other factors are the internal and external reflection components and the light losses in the daylight opening. The daylight factor is calculated by the following equation (Robbins, 1986, p. 173):

$$DF = (SC + ERC + MF \cdot IRC)C_g \qquad (3.2)$$

where DF is the daylight factor, SC is the sky component, ERC is the external reflection component, MF is the maintenance factor, IRC is the internal reflection component and C_g is the glazing factor.

In many countries daylight standards prescribe minimum daylight factor levels inside a room on work plane height (Tiimus, 2007). Sometimes it is a minimum level in the entire room, but in most standards the daylight factor has to be determined on a reference plane or in one or two reference points. Minimum levels vary from 0.75% to 2.0%, although a level of 2.0% can hardly been met in rooms with only side windows (Tiimus, 2007). In the UK the requirement of a daylight factor $\geq$ 2% in classrooms was dropped and in Denmark the requirement that all work areas should have a daylight factor $\geq$ 2% can be overruled if the window area is greater than 10% of the floor area (Tiimus, 2007).

In the literature generally an average daylight factor of 1% is being described as the minimum level that people will really experience daylight (Dietrich, 2006; Dubois, 2001). If the average daylight factor at the workplace is lower, the user is more likely to be dissatisfied. When the daylight factor on a workplace is more than 3%, it is considered to be a daylight oriented workplace. Dubois (2001) presumes that a daylight factor higher than 5% might give glare problems, especially for work on a computer screen. Dietrich (2006) found that when the value is over 10%, it is likely that heat problems will occur. A scientific basis for these values is given by Roche et al. (2000, 2001). They calculated for 16 buildings in the United Kingdom the average daylight factor as a function of the angle of the sky that is visible from the middle of the window, the glass area, the light transmission of the glass, the area of all room surfaces (walls, floor, ceiling and windows), and their average reflection factor. The results show that the general light level in a room can be predicted well in this way. Office employees in the buildings were asked to answer a questionnaire. It was filled out by 270 respondents. They appeared to be satisfied with a daylight factor between 2% and 5%. When the daylight factor was more than 5% they were less satisfied with the daylight and there were complaints about sunlight and glare. Meerdink et al. (1988) found no relationship between daylight factor and perceived light quality. Only if the average daylight factor is below 1% people appeared to be dissatisfied.

As an alternative for the daylight factor, climate-based daylight metrics are developed, which can be used to explore the access of daylight into a model under realistic conditions which are specific for the location and building. The most commonly used metrics are Daylight Autonomy (DA, Reinhart & Walkenhorst, 2001) and the Useful Daylight Illuminance (UDI, Nabil & Mardaljevic, 2006). The DA is defined as ‘the percentage of the occupied hours of the year when a minimum illuminance threshold is met by daylight alone’ (Reinhart & Walkenhorst, 2001). The illuminance threshold used by the metric is 500 lux. Dietrich suggests to require a minimal DA of 30% for offices (Dietrich, 2006). The UDI uses two thresholds in order to determine what part of the year there might be an oversupply of daylight and what time of the year there is too little daylight (Nabil & Mardaljevic, 2006). The upper threshold is 2000 lux and the lower threshold 100 lux.

The conclusion can be drawn that the daylight factor is a suitable measure for the daylight access in indoor spaces. A daylight factor of at least 1% at the workstation is generally found to be acceptable and levels between 2% and 5% are preferred. For more precise calculations the climatic based metrics Daylight Autonomy and Useful Daylight Illuminance can be used.

3.2.5. Absolute luminances and luminance ratios

Luminance is a quantity for the amount of light that is radiated by a surface area in a certain direction. People generally like indoor spaces with bright lit walls and ceiling, so with high luminance values (Wright et al., 1999; Dubois, 2001; Newsham et al., 2005). According to Dubois (2001) there is enough evidence that low wall luminances are unacceptable, but there is no consensus about the minimal luminance levels required. The minimal values found by Dubois vary between 20 and 100 cd/m^2. The optimal values found for wall luminances vary between 20 and 157 cd/m^2. The maximum luminance values vary between 500 and 1500 cd/m^2. Ariës (2005) in her research in Dutch office buildings found that the maximum luminance value for visual comfort was on average 1600 cd/m^2. When luminances levels of the light sources stayed below 1500 cd/m^2, this had a positive influence on the total satisfaction with the lighting conditions.

The absolute values found in the different experiments vary, which indicates that absolute luminance levels are no good measure for visual comfort. As mentioned in paragraph 3.2.1. the human eye is able to adapt continuously to the prevailing light conditions. For this reason preferred luminance levels will always depend on the light distribution in a space and the adaption level of the eye. Light sensitivity decreases when luminance levels increase (Boyce, 2003). When the visual system is adapted to a certain luminance, much higher luminances are experienced as glaring and much lower luminances as black shadows (Boyce, 2003, p.61). Consequently, luminance ratios will better be able to predict the perceived brightness of a space.

Several standards recommend a luminance ratio between task (paper or computer screen) and the direct surrounding of 3:1 (ergorama) and a ratio of 10:1 between the task and the wider surrounding (panorama) (Dubois, 2001; Andersen, 2002). In daylight situations these values are often exceeded. It is questionable whether this will give problems, because people seem to tolerate higher light levels from daylight than from artificial light (Hopkinson, 1965; Veitch, 2001).

Parpairi et al. (2002) did a research on visual comfort in Cambridge libraries. The researcher concluded that in daylit rooms the aim should not be to create a uniform luminance distribution within the visual field. In a daylit environment people expect that there will be brightness contrasts. Spaces with a uniform luminance distribution can look dull and monotonous. Nevertheless, people find it pleasant when the luminance contrast between the task and the intermediate surrounding is not too high.

It remains unclear to what point luminance contrast are acceptable (Dubois, 2001, Veitch, 2001). The Dutch standard NEN 3087 (2011) requires that in work rooms the maximum luminance ratio between window and computer screen should not exceed 30:1. Ariës (2005) found that the ratios between bright sources and adjacent surfaces should not exceed 40:1, but preferable stays within 20:1.

The literature discussed in this paragraph shows that there is little consistency about what luminance levels are preferred. Preferred luminance levels will always depend on the light distribution in a space and the adaption level of the eye. Standards prescribe that luminance ratios between a task and its surroundings should be very small, although research has shown that much higher contrast ratios between bright sources and adjacent surfaces are acceptable.

3.2.6. Healthy Lighting

The current standards and recommendations for lighting are mainly based on visual criteria. Results of research on the influence of light on the circadian rhythm are not yet implemented in the regulations. Moreover, the requirements for certain light levels are based on a static situation, while daylight is dynamic. People appreciate the dynamic features of daylight. Begeman et al. (1997) concluded from their research on daylit offices, that the aim for a constant light level at the work plane/desk (by daylight and artificial light together) is not an approach which meets the human needs of lighting. Moreover, the current standards would be too low for biological stimulation.

It is probable that in the future standards and recommendations will be extended with non-visual criteria. It seems that the vertical illuminance at the eye will be taken as the most important measure. Ariës (2005) and Hubalek (2010) found that exposure to higher vertical illuminances during the day than the usual levels of today, namely 1000 to 2000 lux instead of 200 to 500 lux, has a positive influence on sleep quality during the night.

Heschong and Roberts (2009) suggest that also the spectral distribution of the lighting should be measured, because the light sensitivity of the circadian system is different from the visual system (480nm versus 555nm peak). Hubalek (2010) also found that light color influences sleep quality. Different results might be found for elderly people than for young people. Due to the ageing of the eye, the lens of elderly absorbs more light in the lower part or the light spectrum (Boyce, 2003, p. 428-431).

3.3. Glare by Daylight

One of the main disadvantages of daylight is that it can cause glare discomfort, which might negatively affect office worker performance Heschong (2003). A distinction can be made between two types of glare: discomfort glare and disability glare. In contrary to discomfort glare, disability glare makes it impossible to observe (CIE, 1987 in Dubois, 2001).

Discomfort glare is very subjective and therefore it is hard to predict when it will occur. Moreover, there are many variables that influence the amount of glare that will be experienced. If the main glare source is a window, the amount of glare caused by daylight depends, for instance, on the quality of the view through the window (Kim et al., 2011; Tuaycharoen & Tregenza, 2007), or on the distance of the workplace to the window (Galaciu & Veitch, 2006).

Throughout the time, many models are developed for the evaluation of glare by electric light: GI (Glare Index), CGI (CIE Glare Index), UGR (Unified Glare Rating), GSV (Glare Sensation Vote), and PGSV (Predicted Glare Sensation Vote). The European standard EN 12464-1 (2011) gives for different rooms, functions and tasks maximum value for the UGR. An overview of the glare models can be found in the PhD thesis of Velds (1999) and report of Dubois (2001).

Glare through windows was found to be less problematic than models for glare by electric light predict (Galaciu & Veitch, 2006). For this reason, several models are developed for glare by daylight, which are often extensions of the models that are developed for electric lighting. The most important ones are DGI (Daylight Glare Index, Hopkinson, 1972), DGIN (Nazzal, 2000), PGSV (Predicted Glare Sensation Vote, Tokura et al., 1996; Iwata & Tokura, 1998), and DGP (Daylight Glare Probability, Wienold & Christoffersen, 2005, 2006).

In order to get a first indication of the chance on glare, it is also possible to study luminance contrasts or luminance ratios. For this type of analysis luminance histograms can be used (Davies et al., 2005; Osterhaus, 2008). Luminance ratios abstracted from luminance histograms will give a better prediction of discomfort glare, than ratios based on the comparison of single luminance values measured with a luminance meter (Davies et al., 2005; Wienold & Christoffersen, 2005, 2006).

Luminance histograms can be based on pictures made with a HDR (High dynamic range) camera or professional luminance mapping camera. Computer programs like Radiance (see next paragraph) can be used as well, because with this software it is possible to generate the luminance value of each pixel of a rendered picture. Wienold & Christoffersen (2005, 2006) found that simulations with Radiance are very similar to results of measurements in laboratory.

Iwata en Osterhaus (2010) studied the validity and applicability of three glare assessment method in a test room with real windows. They compared the subjective rating of subjects in the study, the Glare Sensation Vote, by the calculated DGP, PGSV and ratio of mean luminance to median luminance. The researchers concluded that all three methods are valid and applicable method for realistic daylighting conditions. The correlation between the Glare Sensation Vote and the glare assessment methods ranged from r= 0.64 to r=0.77.

3.4. Daylight Assessment Methods

Many different tools are available for designers and researchers to estimate or measure the light levels in indoor spaces. Nowadays it is common to use light simulation software to calculate daylight levels in a future building. An overview of currently available software is given in the paragraph 3.4.1.

Before the introduction of computers, designers and researchers used equations, diagrams, and/or tables. Baker et al. (1993) divided these tools into the following categories:

1. Equations
2. Single stage methods
3. Lumen methods (these are a type of single stage methods)
4. Tables
5. Nomograms
6. Protactors
7. Dot diagrams
8. Waldram diagrams
9. Methods of urban analysis
10. Glare control

The nomograms, protactors, dot diagrams, and waldram diagrams are all graphical methods, which have the important advantage over equations and tables that the daylight access is made visible in a drawing. The visualization of daylight levels can give more insight into the pros and cons of different design solutions. In paragraph 3.4.2. more information is given about dot diagrams, which can be used to assess how much daylight will enter a room when the sky is clouded.

Baker et al. (1993) did not include sun diagrams in their overview of design tools. These diagrams give insight in the period of time that direct sunlight will shine onto a façade when the sky is clear. An overview of sunpath diagrams can be found in Hopkinson et al. (1966). Paragraph 3.4.3. gives more information about sunpath diagrams.

By interviews and questionnaires the preferences of people regarding the lighting in inside spaces can be explored. Post occupant evaluations (POE) give insight in the perception of light quality in real work environments. Paragraph 3.4.4. gives more information about questionnaires and procedures which are developed for POE's.

3.4.1. Software for daylight simulation

Since the eighties of the last century several simulation programs are developed that calculate the light distribution in computer models. The most well-known software package is Radiance, which in 2006 was the most frequently used program for light simulations (Reinhart & Fitz, 2006). It is a ray-tracing software system, which can be used to perform calculations on very complex building geometries or materials (Larson & Shakespeare, 1998). Drawback of the software is that it runs on Unix computers and has no interface, which makes it difficult to use, especially for people who have little expertise in light simulation software.

In order to make it easier to perform light simulations or to make more extensive simulations possible, several computer programs are made that are based on, or linked to the Radiance software. Examples are Desktop Radiance (http:// radsite.lbl.gov/deskrad), Adeline (http://radsite.lbl.gov/adeline/features.html), and DAYSIM (www.daysim.com).

Desktop Radiance is a plug-in in AutoCAD v14 or AutoCad 2000. It is the original Radiance version for Windows. Due to the graphic interface it is more user friendly than Radiance. Unfortunately, the program is not adjusted to recent versions of AutoCAD. Another problem with the Beta version is that the daylight factor is not calculated in the correct way (Hellinga, 2006). For this reason, daylight factors have to be calculated manually by dividing the indoor illuminance by the outdoor illuminance on a horizontal surface area in the free field.

Another widely used light simulation program is DIALux (www.dial.de). It is developed by DIAL GMBH, a company in lighting design and planning. Originally DIALux was a simulation program for artificial lighting, but since the release of DIALux 4.1 in September 2005 it can also simulate daylight radiation. This program is very user friendly, but it is also more limited than Desktop Radiance. Because the program uses radiosity instead of ray tracing techniques, specular reflectance cannot be calculated. The geometry of the models is limited and, compared to Desktop Radiance, the user has little influence on the simulation parameters (Hellinga, 2006). An important advantage of the radiosity technique, is that calculations do not have to be repeated for each measurement point in the model. The program is very suitable for the early stages in the design process in order to make a quick comparison of different design solutions.

Other programs for light simulation are for example ReluxSuite (www.relux.biz) and Daylight Visualizer (http://viz.velux.com). These programs are frequently used by architects and engineers to study day- and artificial lighting.

The computer programs for light simulation have in common that they do not include the possibility to analyses view quality, and therefore cannot be used to study the overall visual quality of a window.

3.4.2. Dot diagrams

Dot diagrams are based on a graphical projection of the sky dome. The dots are distributed in the diagram as a function of the luminance distribution. A projection of the daylight openings and visible obstructions is made into the diagram. Subsequently, the direct component, generally called the sky component, is determined by counting the dots which lie within the visible sky and by relating the outcome to the total number of dots in the diagram. These methods are accurate and can be used for windows with uncommon shapes (Baker et al., 1993). Three examples are:

- Pepper Pot Diagram by Pilkington Brothers: This method is applicable to vertical windows. It shows the CIE standard overcast sky luminance distribution. It can be used to calculate the sky factor at a single point, taking into account effects of glazing and simple external obstructions.
- Pleijel's Diagrams (Pleijel, 1954): This method is applicable to vertical, horizontal and tilted windows. It shows the standard overcast sky luminance distribution. The diagrams can be used to calculate the sky factor, sky component and externally reflected component on a single reference point. There are diagrams for horizontal and vertical planes and it can take into account the effects of complex external obstructions.
- Gnomic projection of the sky dome on a vertical plane (Santen & Hansen, 1985): The diagrams were developed by the TH Delft Architecture and Civil Engineering. It shows a gnomonic projection of the uniform or CIE overcast sky on a vertical plane. The benefit of this projection is that straight horizontal and vertical lines in the real world will also be straight lines in the projection, which makes it easier to draw the windows.

3.4.3. Sunpath diagrams

Sunpath diagrams are graphical projections of the paths of the sun through the sky. These diagrams exist in many different forms and were common tools to study sunlight problems, until it recently became common to use three dimensional modelling software like SketchUp (www.sketchup.com) for studies on sunlight and shadows.

A common feature of sunpath diagrams is that they always represent a fixed latitude. The diagrams differ in the way the hemispherical sky vault is projected in two dimensions (Hopkinson et al., 1966). Many solar diagrams are drawn in terms of solar time in order to simplify their construction and use. Three examples of sunpath diagrams are:

- Pleijel's stereographic sunpath diagram (Pleijel, 1954): The advantage of this method is that sunpath and time-of-day curves are arcs of circles in the diagram. The centre of the diagram represents the zenith and the outermost circle the horizon. The wall is drawn as a line across the diagram through the origin. The diagram shows when the wall will begin to receive and to lose sunlight. The diagram enables to read off the altitude of the sun directly. It can also be used to determine the duration of sunlight in the presence of obstructions. Drawback of the method are the dense packed lines towards the centre of the diagram. As a result the solar altitudes for high latitude locations are not easy to read from the diagram.
- Equidistant sunpath diagram: Similar to Pleijel's stereographic sunpath diagrams, diagrams have been made on the equidistant projection. An example are the

sunpath diagrams in Smithsonian Meteorological tables (List, 1966). Solar altitude lines are not geometrically projected but are equally spaced as concentric circles. This method is widely used in the USA.

- Burnett’s sun diagrams: Unlike the former methods, the Burnett’s sun diagrams enable to read off directly the direction of the sun’s rays in horizontal and vertical planes. Burnett’s solar bearing diagram gives the azimuth of the sun and can be used to determine the duration of sun shine on a facade or in a room as determined by vertical obstructions. Burnett’s solar altitude diagram can be used to study the effect of horizontal obstructions, for example the head of a window, on the duration of sunshine in a room.

3.4.4. Post Occupancy Evaluations (POE’s)

For Post Occupancy Evaluations several questionnaires were developed in the past, which can be used to explore perceived light quality by building occupants. Hygge and Löfberg (1999) developed a method to study reactions to indoor environments, with special attention to daylight. The questionnaire includes questions about the building as a whole, different aspects of the interior work environment, with a focus on the lighting, and questions about how well the lighting and daylighting control systems work.

Ariës (2005) developed a questionnaire for her PhD research, which does not only include questions about the interior work environment and daylight quality, but also about physical and psychological discomfort and sleep quality. Meerdink et al. (1988) developed a questionnaire that besides questions about the indoor environment and the lighting, also includes questions about outside views.

Before an experiment is started, the decision has to be made what procedure will be followed to compare light levels to human assessment of light quality. Monitoring procedures are developed by for instance Velds and Christoffersen (1997), Fontoynont et al. (1997) and Knoop et al. (2006).

3.5. Key Findings

The key findings of the literature study on the benefits of daylight are:

- People prefer to have daylight in their work environment, mainly because daylight is believed to be more healthy than electric lighting. The short term variations in natural light provides variety and interest in a way that continuous electric lighting cannot.
- Daylight affects people's health and well-being both visually and non-visually. This should be taken into account when a building is designed. It is important not to design for visual comfort only, but also to take into account the health aspects of light.

The key findings regarding daylight preferences are:

- People have an enormous natural capacity to change their sensitivity to light. Moreover, light perception and preferences are very variable from one person to another. When studying daylight preference the psychological aspect of daylight perception could not be ignored.
- The literature shows no consistency in preferred illuminance levels in offices, but higher light levels seem to be preferred than the building standards prescribe. The literature also indicates that higher illuminance ratios between a work task and its immediate surrounding are accepted than prescribed by the standards.
- The daylight factor is suitable to get an indication of the illuminance levels in indoor spaces. A daylight factor of at least 1% at the workstation is generally found to be acceptable and levels between 2% and 5% are preferred. For more precise calculations the climatic based metrics daylight autonomy (DA) and useful daylight illuminance (UDI) can be used.
- People generally like indoor spaces with brightly lit walls and ceiling, so with high luminance values. Because the human eye is able to adapt continuously to the prevailing light conditions, the maximum accepted luminance levels inside a space will always depend on the daylight distribution inside a space.
- Standards prescribe that luminance ratios between a work task and its surrounding should be no more than 10:3:1, although research shows that ratios between bright sources, like a window, and adjacent surfaces up to 40:1 are also acceptable.
- The current standards and recommendations for lighting are mainly based on visual criteria. They probably will be extended in the near future with non-visual criteria. It seems that the vertical illuminance at the eye will be taken as the most important measure. Probably, higher levels will be recommended than the usual levels of today.

The key finding with respect to glare and daylight assessment methods are:

- Many models are developed to predict glare discomfort, amongst which the PGSV and DGP. A less complicated way to obtain information about the chance on glare, is by comparing luminance contrasts in an image of the visual field. For the latter type of analysis luminance histograms can be used. All three methods were found valid and applicable to daylit office rooms.
- Many different computation methods exist which can be used to predict the access of day- and sunlight in a future building. Nowadays it is common to use computer software like Radiance and DIALux. In the past, often diagrams were used like dot and sunpath diagrams for the visual representation of day- and sunlight.
- Post occupant evaluations (POE) give insight in the perception of light quality in real work environments.

Much research has been done on people’s lighting preferences and what light levels are necessary to perform visual tasks. In the past, research focused on the effects of lighting on visual comfort, but the last decennium the focus has shifted towards the effects of lighting on health, which has led to new insights. A large number of methods and standards are developed for the assessment of light quality, some more complex than others. The ability of these methods to predict perceived light quality is limited, since light perception is very personal and depends on many different variables.

Although research on daylight from windows shows that glare perception is related to the quality of the outside view, still little is known about the relation between light and view quality. Existing assessment methods for daylighting do not include the possibility to take into account the quality of the outside view. The next chapter explores what variables affect perceived view quality and what methods are available for the analysis of outside views.

3.6. References

Andersen, M., Light distribution through advanced fenestration systems, Building Research & Information, Vol. 30, No. 4, 2002, 264-281

Ariës, M.B.C., Human lighting demands: Healthy lighting in an office environmentEindhoven: Technical University of Eindhoven, Faculty of Architecture, Building and Planning, 2005

Baker, N.V., Fanchiotti, A., Steemers, K., Daylighting in Architecture: A European Reference Book, London: CEC DGII/James & James, 1993 (Chapter 9: Evaluation and design tools, and Appendix F: Review of design tools).)

Begemann, S.H.A., Van den Beld, G.J., Tenner, A.D., Daylight, artificial light and people in an office environment, overview of visual and biological responses, International Journal of Industrial Ergonomics, Vol. 20, No. 3, 1997, p. 231-239

Berson, D.M., Dunn, F.A., Takao, M., Phototransduction by retinal ganglion cells that set the circadian clock, Science, Vol. 295, No. 5557, 2002, p. 1070-1073

Bodart, M., Deneyer, A., Analyse of the survey on the office workers' interest in windows, IEA 31, Subtask A, working document, 2004

Boubekri, M., Daylighting, Architecture and Health: Building design strategies, Oxford: Architectural Press, Elsevier, 2008

Boyce, P.R.,Human factors in lighting, 2nd edition, Lighting Research Center, London: Taylor & Francis, 2003

Collins, B.L., Review of the psychological reaction to windows, Lighting Research and Technology, Vol. 8, No. 2, 1976, p. 80-88

Cuttle, C., Towards the third stage of the lighting profession, Lighting Research and Technology, Vol. 49, No. 1, 2010, p. 73-93

Davies, M., Raynham,, P., Osterhaus, W., Curtis, S., A different toolbox for glare studies – can new techniques improve our understanding of glare, LUX-Europa 2005, Proceedings of the Tenth European Lighting Conference, Berlin, 2005, p. 452-456

Dietrich, U., Daylight - Characteristics and Basic Design Principles, Lighting Design: Principles, Implementation, Case Studies, 2006, p. 16-41

Dubois, M., Impact of shading devices on daylight quality in offices; Simulations with Radiance, Lund University, Lund Institute of Technology, Department of Construction & Architecture, 2001

Edwards, L., Torcellini, P., A literature review of the effects of natural light on building occupants, National Renewable Energy Laboratory, 2002

European Standard EN 12464-1 Light and lighting – Lighting of work places – Part 1: Indoor work places, 2011

Figueiro, M.G., Rea, M.S., Stevens, R.G., Rea, A.C., Daylight and productivity – a possible link to circadian regulation, Light and Human Health, Proceedings of EPRI/LRO 5th International Lighting Research Symposium, Palo Alto, 2002, p. 185-193.

Fleischer, S., Krueger, H., Schierz, C., Effect of brightness distribution and light colours on office staff: Results of the 'Lighting Harmony' project, Lux Europa 2001, Proceedings of the Ninth European Lighting Conference, Reykjavik, June 18-20, 2001, p. 76-80

Fontoynont, M, Berrutto, V., Daylight performance of buildings; Monitoring procedure, Proceedings of Right Light 4, Vol. 2, 1997, p. 119-127

Fontoynont, M., Perceived performance of daylighting systems: lighting efficacy and agreeableness, Solar Energy, Vol. 73, No. 2, 2002, p 83-94 (www.sciencedirect.com)

Galasiu, A.D., Veitch, J.A., Occupant preferences and satisfaction with the luminous environment and control systems in daylit offices: a literature review, Energy and Buildings, Vol. 38, No. 7, 2006, p. 728-742

Hellinga, H.IJ., Daglichtsimulatie met Desktop Radiance en DIAlux, Bouwfysica, Vol. 19, No. 4, 2006, p 21-27

Heschong, L, Roberts, J.E., Linking daylight and views to the reduction of sick building syndrome, Proceedings of Healthy Buildings 2009, paper 797

Heschong Mahone Group, Windows and offices: A study of office worker performance and the indoor environment, Technical Report for the California Energy Commission, 2003

Hopkinson, R.G, Bradley, R.C., Glare from very large sources, Journal of the Illuminating Engineering Society, Vol. 55, No. 5, 1965, p. 288–297

Hopkinson, R.G., Glare from daylighting in buildings, Applied Ergonomics, Vol. 3, No. 4, 1972, p 206-215

Hopkinson, R.G.; Petherbridge, P.; Longmore, J., Daylighting, London: Heinemann, 1966

Hubalek, S., Brink, M., Schiertz, C., Office workers' daily exposure to light and its influence on sleep quality and mood, Lighting Research and Technology, Vol. 42, No. 1, 2010, p. 33-50

Hygge, S., Löfberg, H.A., Post occupancy evaluation of daylight in buildings, Report of IEA Task 21/Annex 29, 1999

Iwata, T., Osterhaus, W., Assessment of discomfort glare in daylit offices using luminance distribution images, Proceedings of CIE 2010: Lighting Quality and Energy Efficiency, 2010, p. 174-179

Iwata, T., Tokura, M., Examination of the limitations of predicted glare sensation vote (PGSV) as a glare index for a large source: Towards a comprehensive development of discomfort glare for evaluation, Lighting Research and Technology, Vol. 30, No. 2, 1998, p. 81-88

Kim, J.T., Shin, J.Y., Yun, G.Y., Prediction of discomfort glare from windows: Influence of the subjective evaluation of window views, Indoor and Built Environment, Vol. 21, No. 1, 2011, p. 92-97

Kim, S.-Y, Kim, J.-J., Influence of light fluctuation on occupant visual perception, Building and Environment, Vol. 42, No. 8, 2007, p. 2888-2899

Knoop, M., De Groot, E.H., Zonneveldt, L., De Bruin-Hordijk, G.J., Daglichtprotocol: Evaluatie van daglicht in gebouwen, Proceedings of the NSVV conference, Ede, 2006, p. 48-53

Larson, G.W., Shakespeare, R., Rendering with Radiance, the art and science of lighting visualization, San Francisco: Morgan Kaufmann Publishers, 1998

List, R.J. Smithsonian Meteorological Tables, Smithsonian Miscellaneous Collections, Vol. 114, 6th edition, Smithsonian Institution, 1966

Logadottir, A., Christoffersen, J., Fotios, S.A., Investigating the use of an adjustement task to set preferred illuminances in a workplace environment, Lighting Research and Technology, Vol. 43, NO. 4, 2011, p. 403-422

Meerdink, G., Rozendaal, E.C., Witteveen, C.J.E., Daglicht en uitzicht in kantoorgebouwen, DGMR, ISBP, 1988

Nabil, A., Mardaljevic, J., Useful daylight illuminances: A replacement for daylight factors, Energy and Buldings, Vol. 38, No. 7, 2006, p. 905-913

Nazzal, A.A., A new daylight glare evaluation method, Journal of Light and the Visual Environment, Vol. 24, No. 2, 2000, p. 19-27

Nederlandse Norm NEN 3087: Ergonomie – Visuele ergonomie in relatie tot verlichting – principes en toepassingen, 2011

Newsham, G.R., Marchand, R.G., Veitch, J.A., Preferred surface luminances in offices, by evolution, Journal of the Illuminating Engineering Society, Vol. 33, No. 1, 2004, p. 14-29

Newsham, G.R., Veitch, J.A., Charles, K.E., Risk factors for dissatisfaction with the indoor environment in open-plan offices: an analysis of COPE field study data, Indoor Air, Vol. 18, No. 4, 2008, p. 271-282

Nicol, F., Wilson, M., Chiancarella, C., Using field measurements of desktop illuminance in European offices to investigate its dependence on outdoor conditions and its effect on occupant satisfaction, and the use of lights and blinds, Energy and Buildings, Vol. 38, No. 7, 2006, p. 802-813

Osterhaus, W., Analysis of luminance histograms for the assessment of discomfort glare in daylit offices, Proceedings of Balkan Light, 2008, p. 155-164

Parpairi, K., Baker, N.V., Steemers, K.A., Compangon, R., The luminance differences index: a new indicator of user preferences in daylit spaces, Lighting Research and Technology, Vol. 34, No. 1, 2002, p. 53-66

Pleijel, G., The computation of natural radiation in architecture and townplanning, Stockholm: Victor Pettersons Bokindustri Aktiebolag, 1954
Reinhart, C., Fitz, A., Findings from a survey on the current use of daylight simulations in building design, Energy and buildings, vol. 38, 2006, p. 824-825
Reinhart, C.F., Walkenhorst, O., Validation of dynamic RADIANCE-based daylight simulations for a test office with external blinds, Energy and Building, Vol. 33, No. 7, 2001, p.683-697
Robbins, C.L., Daylighting: Design and Analysis, New York: Van Nostrand Reinhold Company Inc, 1986
Roche, L., Dewey, E., Littlefair, P., Slater, A., Daylight in offices: occupant assessments, Proceedings of Lux Europa 2001, Reykjavik, Iceland, 2001, p. 435-440
Roche, L., Dewey, E., Littlefair, P., Occupant reactions to daylight in offices, Lighting Research and Technology, Vol. 32, No. 3, 2000, p. 119-126
Santen, C. van, Hansen, ir. A.J, Daglicht/Kunstlicht: Een leidraad, Delft: Delftse Universitaire Pers, 1989
Santen, C. van, Hansen, ir. A.J., Licht in de architectuur: Een beschouwing over dag- en kunstlicht, Amsterdam: J.H. De Bussy bv, 1985
Tiimus, P., Daylighting standardisation in northern Europe, MSc report, University College London, The Barlett School of Graduate Studies, 2007
Tokura, M., Iwata, T., Shukuya, M., Experimental study on discomfort glare caused by windows: Development of a method for evaluating discomfort glare from a large light source, Journal of Architecture, Planning and Environmental Engineering – Transactions of Architecture Institute (Japan), No. 489, 1996, p. 17-25
Tuaycharoen, N., Tregenza, P.R., View and discomfort glare from windows, Lighting Research and Technology, Vol. 39, No. 2, 2007, p. 185-200
Van Bommel, W.J.M., Non-visual biological effect of lighting and the practical meaning for lighting for work, Applied Ergonomics, Vol. 37, No 4, 2006, p. 461-466
Van den Beld, G. Van Bommel, W., Industrial lighting, productivity, health and well-being, 2001
Van der Linden, A.C., Bouwfysica, Utrecht/Zuthpen: ThiemeMeulenhoff, 2006
Veitch, J.A., Gifford, R., Assessing beliefs about lighting effects on health, performance, mood, and social behavior, Environment and Behavior, Vol. 28, No. 4, 1996, p. 446–470
Veitch, J.A., Newsham, G.R., Determinants of lighting quality 2: Research and recommendations, National Research Council of Canada, 1996
Veitch, J.A., Psychological processes influencing lighting quality, Journal of the Illuminating Engineering Society, Vol. 30, No. 1, 2001, p. 124-140
Velds, M., Assessment of lighting quality in office rooms with daylighting systems, Delft: Technical University of Delft, Faculty of Architecture, 1999
Wienold, J., Christoffersen J., Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras, Energy and Buildings, Vol. 38, Issue 7, 2006, p. 743-757
Wienold, J., Christoffersen J., Towards a new daylight glare rating, LUX-Europa 2005, Proceedings of the Tenth European Lighting Conference, Berlin, 2005, p. 157-161
Wright, M.S., Hill, S.L., Cook, G.K., Bright, K.T., The perception of lighting quality in a non-uniformly lit office environment, Facilities, Vol. 17, No. 12/13, 1999, p. 476-484

Websites

Desktop Radiance, http://radsite.lbl.gov/deskrad, accessed: 28-09-2013
Adeline, http://radsite.lbl.gov/adeline/features.html, accessed: 28-09-2013
Daysim, www.daysim.com, accessed: 28-09-2013
DIALux, www.dial.de, accessed: 28-09-2013
Relux light simulation tools, www.relux.biz, accessed: 28-09-2013
Daylight Visualizer, http://viz.velux.com, accessed: 28-09-2013
Sketchup, www.sketchup.com, accessed: 28-09-2013

Chapter 4

View Quality

Windows provide building occupants with the opportunity to have visual contact with the outside environment. If an outside view is available from the workplaces in an office building depends upon the architecture of the building and the interior layout. The size and geometry of the windows and the distance and orientation of the workplaces to the window affect what view will be available from the different workplaces. Furthermore, possible obstructions, like partitions or cupboards might block the view.

In many cases the architectural design includes also the interior design, so architects have much influence on the availability of a view. It depends upon the surroundings of the building what the character of the outside views will be. The building can be located in a dense urban environment, but also be surrounded by natural landscape. Often the architect of a building is not involved in the design of the surroundings of the building. The neighboring buildings, streets and so on, have already been there for years, are too distant, and/or are designed by other architects. However, within the range of possibilities given by a specific location there will always be design opportunities for the optimization of the outside views.

This chapter gives an overview of literature on view quality and landscape assessment methods. It deals with the following research questions:

- What are the benefits of a view to the outside?
- Which features of a view affect the assessment of view quality?
- What assessment methods exist that can be used to assess view quality?

Chapter outline

4.1. Benefits of Outside Views

4.1.1. The need for an outside view

Generally an outside view is not listed high as an important feature of a pleasant office (Collins 1976; Menzies & Wherett, 2005; Ne'eman et al., 1984). On the other hand, many studies show that office workers very much like to have access to a window and outside view from their workplace (e.g. Ariës, 2005; Bodart & Deneyer 2004; Collins 1976; Farley & Veitch, 2001). Research indicates that people working in windowless spaces have a stronger desire for windows, than people working in windowed spaces (Nagy et al., 1995). As Ne'eman et al. (1984) suggest, people may have the tendency to consider the things they are least satisfied with to be the most important things in their work environment, while the things they are satisfied with are not considered to be important. In a survey research of Kaplan (1993) respondents made comments at the end of the questionnaire about the view from their workplace. Those who did not have access to a window made complaints about it and those who had access to a window made remarks about how much they like their view.

Research in the US shows that also the size of the outside view matters (Cetegen et al., 2008; Heschong Mahone Group, 2003). Cetegen et al. (2008) showed subjects HDR (High Dynamic Range) images of different combinations of office settings on a HDR monitor. Ratings for pleasantness, satisfaction with the view, and satisfaction with the visual comfort were higher for images with larger view sizes. In a research of the Heschong Mahone Group (2003) view quality was determined primarily by view size and by the vegetation.

4.1.2. Benefits for well-being, productivity, and health

Office workers not only like to have access to an outside view, but outside views are also found to influence well-being, productivity, and health. The Heschong Mahone Group (2003) found that having an outside view had a strong relationship with worker performance. Office workers performed 10% to 25% better on tests of mental function and memory recall when they had the best possible view versus those with no view. Furthermore, office worker's self-reported health conditions were better when they had better views. In a study of Heschong and Robers (2009) office workers who had better access to an outside view reported fewer complaints about fatigue, headache and difficulty concentrating. They also had fewer complaints about environmental comfort conditions in the building, such as air quality, thermal and acoustic conditions.

According to Kaplan (1993) it is not the availability of an outside view, but the view content that effects office workers' perceived well-being and health. A total of 615 participants having sedentary jobs answered a survey containing questions about the view from work. Those with a view of nature felt less frustrated and more patient, found their job more challenging, expressed greater enthusiasm for it, and reported higher life satisfaction as well as overall health. A study of Leather et al. (1998) shows that a view of natural green buffers the negative impact of job stress on intention to quit the job. Views of nature also appeared to be beneficial for health care environments. Ulrich (1984) found that surgical patients who were placed in a room with windows looking on nature took fewer painkillers and could leave earlier than patients who had a view of a brick building wall.

In contrary to the previous results, Ariës et al. (2010) did not find a significant relationship between view type or view quality and environmental utility. A path analysis on the field study data, did not show that nature views led to fewer problems with heat or glare than urban views. This was also the case for views rated as being more attractive. Their explanation is that, because all office employees participating in the field study are within relatively close distance of a window and do all have access to a view, window access has a smaller impact on the questionnaire results. On the other hand, views which were rated as being more attractive were found to be beneficial for building occupants by reducing self-reported discomfort. The latter result confirms the finding of the other studies that a higher view quality has a positive effect on occupant's wellbeing.

4.1.3. Economic benefits

Views and daylight have economic value too (Boyce, 2003; Kim & Wineman, 2005). In the US rent charges for daylit offices are higher than for non-daylit office spaces (Boyce, 2003). Kim and Wineman (2005) found in their research that availability of a view is positively related with assigned property value. They polled and interviewed hotels, residential buildings, and office buildings, and found that a significant number of the companies considered view when pricing their units. The results also indicate that the relationship between view and cost is influenced by the business conducted in the building and that the psychological preference of people depends on the type of activity performed in a space.

4.1.4. View and glare perception

Research on glare perception shows that occupant's subjective impression of an outside view can influence their sensation of glare. Tuaycharoen (2006) found that an increased interest in a glare source leads to a decreased perception of glare discomfort. This result was found for both images projected on a screen as for views through a real window. In one of the experiments matched pairs of images were used, one being a nature scene and the other an urban scene (Tuycharoen, 2006; Tuaycharoen & Tregenza, 2005). The pairs were similar in composition, hue distribution, color saturation, size and mean luminance. Overall, the images of natural scenes were reported as less glaring than pictures of urban scenes and the elements water and ground also seemed to have a significant effect (Tuaycharoen & Tregenza, 2005). In the study with real windows, also the luminance range within the view was found to affect the experience of glare (Tuaycharoen, 2006; Tuaycharoen & Tregenza, 2007). This suggests that current glare formulae could be improved by adding information about the view interest and light distribution within the view.

Kim et al. 2011 used a simulated window to study the influence of the subjective evaluation of window views on glare perception. Ten views were chosen, half being distant and half being near views. The 48 participants in the research answered a questionnaire in which they were asked questions related to the subjective impression of the given outside views. Factor analysis was performed on the results, which lead to the construction of four components. The researchers found that when the outcome of these components are added to existing glare formulae, glare sensation could be predicted better. It remains unclear in what way the four components represent view quality. The researchers do not mention if the variables together measure for example preference or interest.

4.2. View Preferences

It is very difficult to rate the quality of a view, because it includes human value judgments. Human perception in very complex and preferences differ from one person to another. It is not only a result of sensory perception of the environment, but also influenced by someone's previous experiences; by his values, beliefs and attitudes; by his social and economic well-being; and by his expectations for the future (Zube et al., 1975, p. 59) Nevertheless, some view characteristics seem to be generally appreciated and other characteristics not.

The most consistent finding of research on view preferences is that people prefer a natural view over a build view. Furthermore, people generally prefer distant views over near views. If an outside view contains water, for example a lake, this leads to higher ratings of view quality. Finally, four characteristics of buildings are found to influence view quality: building distance, building age, maintenance, and complexity.

4.2.1. Preference for natural views

One of the earliest and most consistent findings of window research is people's preference for nature over built or urban views (e.g. Christoffersen et al., 1999; Ulrich 1981; Kaplan, 1987; Kaplan, 1985, 2001). Views of urban environments with natural elements were also found to be preferred over those without (Herzog, 1989; Kaplan, 1993). Kaplan's survey amongst office workers shows that those who could even see a minimum amount of nature were significantly more satisfied with their view than those who could not see natural elements (Kaplan, 1993). Research on windowless spaces shows that office worker mainly chose decoration with a nature theme to compensate for having no access to a window (Heerwagen & Orians, 1986; Bringslimark et al., 2011), although Biner et al. (1993) did not find a significant difference between windowed and windowless spaces (Chapter 2).

Apart from the fact that people generally prefer to see natural views, the literature also shows that, compared to urban views, views of nature have a stronger positive effect on perceived well-being and health (e.g. Kaplan, 1993, 2001; Velarde et al., 2007).

Kaplan (2001) performed a study amongst people living in low-rise apartment buildings. The resident's satisfaction with the neighborhood was significantly affected by the presence of natural elements or settings in the view from the window. Furthermore, evidence was found that presence of natural elements was related to diverse aspects of the resident's well-being. Shin (2007), who conducted a survey research amongst Korean office workers, found that those who could see a forest from their windows were more satisfied with their job and perceived less stress than those without a forest view. Ulrich (1981) showed subjects in his research sixty color slides of either nature with water, nature dominated by vegetation, or urban environments with no natural elements. The effect of the slide presentation on the subject's alpha amplitude, heart rate, and emotional states were measured. The results show that nature views had more positive influences on psychological and emotional states than urban scenes.

In order to study the effect of nature on stress recovery, both Ulrich et al. (1991) and Van der Berg et al. (2003) showed participants in their research a frightening movie, and then a video of either a natural or a built environment. In the research of Van der Berg et al. (2003) the participants rated the natural environment as more beautiful than the built environments. The mood of the participants also changed more positively by the video of the natural environment then by the built environment. However, only a marginally better performance was found on a concentrations test. In the study of Ulrich et al. (1991) recovery time was self-rated and measured physiologically. The results indicated that subjects recovered faster and more complete when exposed to nature rather than to urban environments.

All these experiments support that someone does not need to have physical contact with nature in order to benefit from it positive qualities. An outside view makes the outside world visible, but not touchable. The visual connection with nature apparently is sufficient to have a positive effect on someone's well-being and health.

4.2.2. Preference for distant views

Overall, people have a preference for wide and spacious outside views. Markus (1967) asked 404 occupants in a survey what they prefer to see: the sky, distant city and landscape or nearby ground. The far majority (88%) preferred to see distant city and landscape. Herzog and Shier (2000), in a research on building preference, also found that distant views are preferred over near views. Similarly, Keighley's experiments (1973a, 1973b) show that, independently of window configuration, a view with distant elements is preferred over a view of only a façade. Kfir et al. (2002), who studied view preferences of residents living in apartment buildings at man-made islands in Osaka Bay, found that residents who live at the upper floors tend to assess the view more positively than residents who live at the lower floors, which is likely to be related to the wideness of the view from the apartments.

Some studies show that very limited views are much disliked, for instance views totally filled by buildings or vegetation (Meerdink et al., 1988; Keighley, 1973a, 1973b).

Meerdink et al. (1988), who performed a questionnaire research in four office buildings in the Netherlands, found that a view of nature generally will be assessed positively, but not if it is frame-filling and blocking the view of objects further away.

Several papers indicate that the distance or wideness of a view affects the overall appearance of indoor spaces. The presence of a window can make a room appear more spacious than it really is (Collins, 1976; Ozdemir, 2010). Ozdemir (2010) studied the effect of the openness of outside views on the perception of small office rooms in a three story high building. The results show that rooms on the upper floor of the building were perceived larger due to the expanded open window views. Furthermore, occupants in offices which had more open and natural views were more satisfied with their rooms.

4.2.3. Preferences for water

People not only prefer to see some sort of vegetation, but also to see water, for instance a lake, river, or the sea. In the research of Kfir et al. (2002) outside views containing the sea got higher ratings than those without. Furthermore, Tuaycharoen and Tregenza (2005) found in their research that the most highly scored scenes were natural scenes containing some form of water and the sky. Research of Shafer et al. (1977) shows that adding a lake to an image of a landscape scene, which originally does not contain water, leads to considerable higher preference ratings. Ulrich (1981) found that water, and to a lesser extent vegetation holds attention and interest more effectively than urban scenes.

White et al. (2010) investigated if water elements in photographs of both natural and built scenes influence preferences, affect and perceived restorativeness ratings. In both scene types the presence of water was associated with higher preferences, greater positive effect, and higher perceived restorativeness. An interesting outcome is that photographs of built environments containing water, on the whole, got equal ratings as natural scenes without water. This would imply that in urban views water could compensate for the lack of natural elements in the view.

4.2.4. Building preferences

Outside views from office buildings are often urban views dominated by neighboring buildings, streets, and/or parking lots. There are many differences types of urban views, but, compared to the number of studies on landscape preference, only a few studies have been performed on the perception of built views. The literature, nevertheless, gives a good indication of what features of buildings are important predictors of view quality.

First of all the distance to the buildings in the view appears to affect satisfaction with the outside view. As discussed in paragraph 4.2.2. people do not like it when an outside view is fully obstructed by a façade. Meerdink et al. (1994), in a study on atrium buildings, found that when buildings are within 20 to 30 meters from a window, they limit the feeling of spaciousness of the view through the window, which will lead to lower satisfaction ratings. Kfir et al. (2002) also found that if a view contains buildings at a close distance from the windows, the buildings have a negative influence on the satisfaction with the outside view. In this research the view of apartment buildings was found to be an important predictor of the assessment of view quality if the distance to the buildings is within 200 meter. If the apartment buildings were more than 500 meters away, or if the sea could be seen, the buildings were found to have little influence on satisfaction with the view.

Two more predictors of building preference which are found in the literature are building age and maintenance. Herzog (1989), who studied preference for urban environments with prominent natural elements, found that older building are less liked than contemporary buildings. In a second research, however, Herzog and Gale (1996) found that modern buildings are only preferred over old buildings, if maintenance is not taken into account. When maintenance was statistically controlled, old buildings were preferred over modern building. This result was confirmed by a later research of Herzog and Shier (2000). Herzog and Gale (1996) conclude that when older buildings are disliked, poor maintenance is likely to be a contributing factor.

A fourth aspect found in the literature, which seems to affect building preference is complexity. Herzog and Shier (2000) found a positive influence of complexity on building preference. They also found that the effect was stronger for older buildings than for modern buildings. If complexity was low, age was negatively related to preference, but if complexity was high, there was no relation between age and preference. Another finding is that buildings with visible entrances are preferred to those without.

The research of Tuaycharoen (2006) also indicates that complexity plays a role in building preference. In this research the view of lowest interest was one of a monotone concrete wall. Tuaycharoen argues that this view is least preferred because it is a view showing a man-made construction with the lowest degree of complexity with regard to the homogeneity of elements, texture, color, material, and form. In this study the scene which was rated as the most interesting view by the subjects, was very complex due to aspects such as high irregularity in shape, variety of colors and contains heterogeneity of elements.

Finally, Herzog and Gale’s research (1996) shows that a natural context enhances building preferences, but only if both the building and nature are well maintained. Rated building care and nature care were positively related to preference and to each other. Kaplan (1993) found that the restorative quality of urban views with natural elements is significantly higher than for urban views which do not contain any natural elements. The research of Kaplan (1993) did not show significant differences in satisfaction with the view between respondents who could see more or fewer built elements. Views of other buildings, streets or parking lots were all found to contribute equally to the restorative quality of the view.

4.3. The Information Content of an Outside View

Several studies demonstrate that it is the information content of an outside view which explains why certain views are preferred over others (Kaplan & Kaplan, 1989; Tuacharoen, 2006). Tuacharoen (2006) found that the more information a view contains about the outside environment, the more interesting the view is. A spacious and wide view contains more information than a limited view and this is why people prefer to have wide views.

In a small office, the view out of the window may be the only source of environmental stimulation (Boyce et al. 2003). In these restricted environments the need for outside views with a lot of information might be more important than in large size office rooms. One of the human needs is variety (Boyce, 2003). As Collins (1975) mentions daylight and sunshine can bring some change and variety into an otherwise static environment. The same counts for an outside view. However, windows should not lead to a loss of privacy (Boyce, 2003; Meerdink et al., 1994). A view that contains some sort of activity is generally appreciated as long as the privacy of the room occupants is not disturbed (Meerdink et al., 1994).

4.3.1. Differentiation between distant and close objects

In his paper Markus (1967) argues that the most important characteristic of almost all views is their horizontal stratification. He divides views in three layers: layer of sky, a layer of city or landscape and a layer of ground. Each layer has its own function.

- The sky is the dominant source of light and keeps building occupants in touch with seasonal changes, time of day and the weather.
- The mainly horizontal view of landscape or the city gives the maximum amount of information about the inanimate environment.
- The view of ground and activities going on upon it gives the view a human, social character.

Both experiments of Keighley (1973a, 1973b) demonstrated that views of the horizon, with a margin of ground and the sky are most appreciated. Similarly, Tuaycharoen (2006) found that the most interesting view is a distant view with three horizontal layers and a balanced presentation of natural and urban qualities. On the other hand, when a view is almost totally filled by elements and when the sky cannot be seen Meerdink et al. (1994) found that the feeling of spaciousness is strongly limited and people will be less satisfied with the view.

In the study of Markus (1967) 404 occupants were asked whether they considered their outside view ‘plentiful, adequate, rather poor, or mean’. Distant views of the whole city and the surrounding countryside appeared to be thoroughly liked by the occupants but interestingly, occupants on the lower two floors appeared to have a strong preference for a view of the ground. This would mean that preference also depends on what outside view someone is used to have.

It is worth noting that some researchers refer to ‘horizon’ as predictor of view quality, while others use the word ‘skyline’. People might interpreted these terms differently. Often it is not clear if the line is meant that separates the earth from the sky, or if the terms refer to distant city or landscape. In the remainder of this thesis the influence of distant city or landscape on perceived view quality is explored.

4.3.2. Information about the weather, season, and time of day

Most people like to be able to see the weather conditions from their workplace (Meerdink et al., 1988). Maning (1965, in Tuaycharoen, 2006) found that one of the main reasons for a desire of windows is the ability to obtain information about the weather and the time of day. According to Meerdink et al. (1994) the lack of possibilities to see the weather might lead to people wander around more in order to gain information about the outside environment.

A study of Kaplan (2001) at six low-rise apartment communities did not show a relation between view of the sky and weather, and residents’ satisfaction and sense of well-being. Butler and Biner (1981), however, found in their research that the ability to keep track of time and the weather was one of the most important variables influencing window size preferences.

As Markus (1967) mentions people would like to see the sky, because it shows what weather and time of day it is. Meerdink et al. (1994) found that in atrium buildings an outside view of the sky through a glass roof is appreciated more than a view of just an atrium façade. Also the preference for natural elements in a view might be related to the need for information about the season and time of day. As Kaplan et al. (1998) mention even the view of a single tree outside brings opportunities for observing its changes over the year’s cycle.

4.3.3. Spatial configuration

It is not only the content of an outside view, but also the spatial configuration which influences view preferences (Herzog, 1989; Kaplan & Kaplan, 1989; Ulrich, 1981). Kaplan and Kaplan (1989) developed a so called information matrix for landscape preferences based on the information need of people (Table 4.1). All four items of the preference matrix are, according to Kaplan and Kaplan, from an evolutionary viewpoint important for people, because they enhance understanding and exploration.

Table 4.1: Preference matrix (Kaplan, 1987; Kaplan & Kaplan, 1989)

	Understanding	Exploration
Immediate	Coherence	Complexity
Inferred, predicted	Legibility	Mystery

In addition Kaplan and Kaplan (1989) made a table that describes the relationship between complexity and coherence (Table 4.2).

Table 4.2: Relation between coherence and complexity (Kaplan & Kaplan, 1989)

Coherence	Complexity	
	Low	High
Low	Not much there	Visually messy
High	Clear and simple (boring)	Rich and organized

According to the Kaplans (Kaplan & Kaplan, 1989; Kaplan et al., 1998) considerations of what makes particular views enjoyable is closely related to the preference matrix. Views enhance understanding and give opportunity for mental exploration even when the view is far distant. However, when a view is obstructed, one cannot tell what might lie ahead, whether there is a richness of things to see, or whether one could make one's way in the setting. This means that the view scores low on respectively mystery, complexity, and legibility.

Complexity alone not necessarily is a significant predictor in preference studies (Kaplan, 1987). According to Kaplan preference cannot be predicted by a single factor, but a combination of variables should be considered. Tuaycharoen (2006) also found that complexity in a view influences view preference when it is combined with other factors, in particular with the horizontal stratification of a view in three layers. Ulrich (1981) found that complexity is a less important factor in attention and interest than environmental content.

Herzog (1989) studied preference for urban environments with prominent natural elements as a function of content categories, viewing time, and nine predictor variables (Table 4.3). Herzog found three variables as independent positive predictors of preference: coherence, mystery, and nature. The researcher concludes that, especially in the case of older urban settings, planners better concentrate their efforts on manipulating these three variables.

The conclusion can be drawn that the spatial configuration in a view is likely to affect perceived view quality, and that the effect cannot be predicted by a single variable, but that a combination of variables should be considered.

Table 4.3: Predictor variables in the research of Herzog (1989); coherence, mystery and nature are found to be significant predictors of preference

Predictor variable	Explanation
Spaciousness	The feeling of spaciousness or depth the scene conveys, how much room there is to wander into it. To what extent does the structure of the scene suggest that one would have to go a long way to each its farthest points?
Refuge	The opportunity for being hidden, the chance to see without being seen.
Coherence	How well the scene ‘hangs together’. How easy is it to organize and structure the scene?
Legibility	How easy it would be to find your way around in the environment depicted … to figure out where you are at any given moment, or to find your way back to any given point in the environment.
Complexity	How much is going on in the scene, how much there is to look at, how much the scene contains a lot of elements of different kinds.
Mystery	Present when a setting promises more to be seen if you could walk deeper into it.
Typicality	The extent the scene seems to be a representative example of its class. How good an example is the scene of whatever category it belongs to
Nature	How much foliage or vegetation there is in the scene
Age	How old the elements in the scene seem to be

4.4. Landscape Assessment Methods

Throughout the time, numerous techniques of landscape evaluation have been developed. Landscape evaluation or assessment methods are used for several purposes. Environmental psychologists for example use these methods to study the impact of different variables on landscape quality. On the other hand, landscape architects use landscape assessment methods as an aid to develop a strategy for landscape planning. No landscape assessment methods are found which have specifically been developed for the evaluation of views through windows, although some methods could also be suitable for the assessment of view quality. This will be discussed in paragraph 4.4.6.

The wide range of landscape assessment methods which have been developed throughout the time can be classified by various ways. Arthur et al. (1977) split them into descriptive inventories and public preference models. The first category are methods that try to exclude human’s perception from the model and the second category place humans in a central position. Daniel and Vining (1983) make a distinction between five conceptual models:

1. Ecological
2. Formal Aesthetic
3. Psychological
4. Phenomenological
5. Psychophysical

The models represent different assumptions about the relevant properties or features of the landscape and use different aesthetics standards. The ecological and formal aesthetic model can be put into the category of descriptive inventories. The psychological and phenomenological model are public preference models. The psychophysical combines the two approaches: public preference and inventory of landscape features.

4.4.1. The ecological and formal aesthetic model

Ecological and formal aesthetic models both determine landscape quality entirely by features of the environment, and do not include human perception (Daniel & Vining, 1983). The ecological model characterizes the natural elements of a landscape by describing the species of plants and animals which are present, the ecological zones or processes. The formal aesthetic model analyses the landscape by describing its formal properties, for instance the form, line, unity and variety.

The models have in common that they heavily rely on the judgment of individual experts (Daniel & Vining, 1983). They cannot be used to explore what features of outside views are preferred by office workers.

4.4.2. The psychological and phenomenological model

In contrary to the first two models, psychological and phenomenological models place humans in a central position. Landscape quality is determined by the effects of the landscape on people. Both models do this, however, in a different way.

Instead of focusing on the environmental features of a landscape, the psychological model explores the cognitive and affective reactions to landscapes (Daniel & Vining, 1983). The model aims to define landscape quality by expressing the feelings and perception of people who inhabit, visit or view the landscape. Systematic relationships are tried to be found between features of the landscape and landscape preference. The landscape is described in terms like complexity, coherence, mystery and legibility (Kaplan, 1987; Kaplan et al., 1989). A complex array of cognitive, affective, and evaluative psychological dimensions may be required to fully characterize the landscape experience of humans. Psychological models are often developed by environmental psychologists and get much interest in the scientific literature.

The phenomenological model represents the extreme of subjective determination of relevant landscape features. Landscape perception is considered as an intimate encounter between a person and the environment. The emphasis is put on the individual’s subjective feelings, expectations, and interpretations. The effects of any environmental experience is seen as highly complex and subjective, depending as much on the state of the human as on the features of the environment (Daniel & Vining, 1983). With phenomenological methods it is not possible to establish systematic relationships between psychological responses to a landscape and landscape features.

4.4.3. Attention Restoration Theory

An example of a psychological model which can be used to predict human value judgment of different landscapes is the well-known Attention Restoration Theory of Kaplan and Kaplan (ART, Kaplan, 1987; Kaplan & Kaplan, 1989)

Kaplan proposed in 1987 a theoretical framework for the analyses of environmental preference, because previous research demonstrated that preference varies a lot between different scenes and that preference could not be predicted by complexity alone. For this reason Kaplan and Kaplan started to search for other predictor variables.

ART presumes that many daily activities in contemporary society demand so called directed attention. This leads to mental fatigue, which might cause difficulty concentrating, an increased rate of errors on tasks that require concentration, and increased irritability. The more stress is experienced, the higher the need for psychological restoration.

According to ART, natural environments provide relatively good opportunities for psychological restoration, because natural environments possess several qualities that, in combination, emerge less commonly in other types of environments. Restorative environments are supposed to have four characteristics in order to meet the information needs of people. First of all, they give someone the sense of being away and, secondly, they allow a sense of extent, which could be described as the experience that what is seen is part of a larger area. The environments, furthermore, give a sense of fascination, which means that they encourage exploration and that they attract and hold a person’s attention effortlessly. The final characteristic is compatibility, which can be explained as that it offers someone the kind of experience that that person needs (Kaplan & Kaplan, 1989; Kaplan et al., 1998).

In order to meet these characteristics, an environment should enhance understanding and exploration (Kaplan, 1978; Kaplan & Kaplan, 1989). If this will be the case depends upon the content of the landscape and on the spatial configuration. It can be predicted on the basis of four variables: complexity, coherence, mystery, and legibility (paragraph 4.3.3).

What the four predictors mean for landscaping is described and illustrated with pictures in the book With People in Mind (Kaplan et al., 1998). The model has been the starting point of many researches on the restorative qualities of natural landscapes (e.g. Hartig et al., 1991; Van den Berg et al., 2007)

4.4.4. The psychophysical model

The fifth type of conceptual models of Daniel and Vining (1983) is the psychophysical model. An interesting feature of landscape assessment methods which are based on the psychophysical model is that they explore the relationship between physical characteristics of a landscape and the landscape quality as it is perceived by human observers.

The characteristics of the landscape are measured and described by objective physical or biological terms. According to Daniel and Vining (1983) this can be done by relatively abstract features like "perimeter squared of dense brush", or by more concrete features, like "number of trees greater than 16 inches in diameter". The characteristics are not necessarily measured by direct inventory, but are often measured from photographs.

After measuring the objectively defined landscape characteristics these are compared to the personal experience of people who are asked to judge the landscape. They express their preference or relative appraisals, which directly determines landscape quality (Daniel & Vining, 1983).

4.4.5. Example of a mathematical model for landscape preference

Shafer and Brush (Shafer & Brush, 1977; Brush & Shafer, in Zube et al., 1975 p. 168-182) developed a psychophysical model for landscape preference. They use a mathematical approach, using multiple regression analysis to predict preference scores for black and white photographs of natural landscapes.

According to this method, photographs of a scene must be separated into three zones: an immediate zone, an intermediate zone, and a distant zone. Subsequently, the area of perimeter of major vegetation, nonvegetation, and water have to be measured in each zone.

The six landscape features used in the model are:

- Area of immediate vegetation
- Area of intermediate nonvegetation
- Area of distant vegetation
- Area of intermediate vegetation
- Area of water in the entire scene
- Area of distant nonvegetation

By entering this data into the predictive model a landscape-preference score can be computed. Landscape-preference scores change as features in the landscape change. This information can be used by decision makers to plan and manage naturel landscapes for optimum scenic quality.

In contrast to the input variables used in the Kaplan and Kaplan’s model (1989), this method only uses physical resources in the landscape that can be measured. The predictive model is based on preference measurements from the past. Drawback is that these measurements from the past might not be valid for different situations. Shafer and Brush note that the model can only be used for natural landscapes without man-made structures, because man-made structures were not part of their research.

4.4.6. Assessment of outside views

The landscape assessment models found in the literature have in common that they are made for the assessment of landscape quality. No landscape assessment methods have been found, which have specifically been developed for the evaluation of views through windows, although the preference matrix of Kaplan and Kaplan (1989) can also be used for the evaluation of outside views. Furthermore, the focus of the landscape assessment methods has always been on the assessment of natural landscapes and not on urban environments. The model of Kaplan and Kaplan might also be applicable to urban environments, but the model of Shafer and Brush is certainly not.

It depends upon the aim of the analysis which type of landscape assessment model would be most suitable for the analysis of outside views. Each approach does have both advantages and limitations. The most appropriate models are the psychological model and the psychophysical model. Both try to find a systematic relationship between features of the landscape and landscape preference, but do this in a different way.

The psychological model has a strong intuitive approach. The models are generally quiet complex and rely more on the experts' opinion than the psychophysical model does (Daniel & Vining, 1983). Furthermore, results cannot easily be translated into design criteria for architects. On the other hand, this type of model is stronger on the psychological side. It recognizes the complexity of human perception and takes many different aspects into account.

The psychophysical model compares the psychological response to a scene with a physical measure. These type of models are more objective and easier to understand for a non-expert. The disadvantage of this method is that human response is simplified into one quality dimension (Daniel & Vining, 1983). However, this might be sufficiently if view preference is the only assessment criteria.

In this thesis the aim is to express view quality in objectively measurable and easy manipulatable properties of the physical environment. From that viewpoint, the psychophysical model seems to be the most suitable approach for the development of a method for the assessment of view quality. However, the literature also demonstrates that landscape preference variables like complexity play an important role in the assessment of view quality. Therefore, the decision is made to develop a method for the analysis of view quality which combines the approach of the psychophysical model and the psychological model. This method is described in chapter 10.

4.5. Key Findings

The key findings regarding the benefits of outside views are:

- Access to an outside view is not only desired by office workers, but also beneficial for their well-being and health. Furthermore, availability of a view leads to higher rental and cost prices of buildings.
- Research in the US shows that besides the availability of an outside view from a workplace, the size of the outside views also influences satisfaction with the view and the visual comfort.
- Occupant's subjective impression of an outside view can influence their sensation of glare.

The literature study on view preferences leads to the following key findings:

- Three characteristics of an outside are found to be generally appreciated:
  1. People prefer a natural view over a build view;
  2. Distant views are preferred over near views;
  3. People like to see water (for example a lake or a river).
- Views of nature have, compared to urban views, a stronger positive affect on perceived well-being and health. Even when an urban view has some natural elements, for example a few trees or some vegetation, the restorative quality is likely to be higher than if the view does not contain any natural green.
- Four characteristics of buildings are found to influence view quality:
  1. Building distance: If a view contains buildings at a close distance, the buildings are likely to have a negative influence on the satisfaction with the outside view;
  2. Maintenance: Buildings which are well maintained are preferred over buildings which are poorly maintained;
  3. Complexity: Buildings having a high degree of complexity are generally preferred over buildings having a low degree of complexity;
  4. Building age: Generally, older buildings are preferred over modern buildings. However, if buildings are poorly maintained or if complexity is low, modern buildings are preferred over older buildings.

The key findings regarding the information content of an outside view are:

- Views with a high information content are found to me more interesting than views containing little information about the outside environment.
- A view having a horizontal stratification, containing different layers of information are presumed to be preferred over single layer views, because the information content is higher.

- People like to obtain information about the weather, season and time of day.
- Besides the content of a view, the spatial configuration also influences perceived view quality. The overall perception of an outside view can be described by landscape preference variables coherence, complexity, mystery, and legibility.
- Windows should not lead to a loss of privacy of the office worker.

With respect to landscape assessment methods the key findings are:

- Throughout the time, numerous techniques of landscape evaluation have been developed. The psychological model and the psychophysical model are most suitable for the assessment of view quality, because they try to find a systematic relationship between features of the landscape and landscape preference.
- The psychological model explores the cognitive and affective reactions to landscapes. It has a strong intuitive approach. It recognizes the complexity of human perception and takes many different aspects into account.
- The psychophysical model compares the psychological response to a scene with a physical measure. From the viewpoint of the architect this model is preferred, because it combines an objectively measurable properties of the physical environment with human preference judgment.

The studies on view preferences which were found in the literature use different approaches. For the same reason as it is difficult to rate light quality, it is also very difficult to rate view quality. It includes human value judgments and view preference will always depend on a combination of factors. No assessment methods were found which are specifically developed for the analysis of outside views. On the other hand, features of landscape assessment methods appear to be suitable for the analysis of outside views. The approach of the psychophysical model and the psychological model are used to develop a method for the analysis of view quality. This method is described in chapter 10.

Part 2 of the thesis is about a research in real office environments. It shows how office workers rate the lighting and view in their own office environment, and it explores if similar results are found as in the literature study. Furthermore, the relationship between assessment of light, view, and workplace quality is investigated.

4.6. References

Ariës, M.B.C., Human Lighting Demands: Healthy Lighting in an Office Environment, Eindhoven: Technical University of Eindhoven, Faculty of Architecture, Building and Planning, 2005

Ariës, M.B.C., Veitch, J.A., Newsham, G.R., Windows, view, and office characteristics predict physical and psychological discomfort, Journal of Environmental Psychology, Vol. 30, No. 4, 2010, p. 533-541

Arthur, L.M., Daniel, T.C., and Boster, R.S. Scenic assessment: an overview, Landscape Planning, Vol. 4, No. 2, 1977, p. 109-129

Biner, P.M., Butler, D.L., Lovegrove, T.E., Burns, R.L., Windowlessness in the Workplace: A Reexamination of the Compensation Hypothesis, Environment and Behavior, Vol. 25, No. 2, 1993, p. 205-227

Bodart, M., Deneyer, A., Analyse of the survey on the office workers' interest in windows, IEA 31, Subtask A, working document, 2004

Boyce, P.R., Veitch, J.A., Newsham, G.R., Myer, M., Hunter, C., Lighting quality and office work: A field simulation study, 2003

Boyce, P.R.,Human factors in lighting, 2nd edition, Lighting Research Center, London: Taylor & Francis, 2003

Bringslimark, T., Hartig, T., Patil, G.G., Adaptation to Windowlessness: Do Office Workers Compensate for a Lack of Visual Access to the Outdoors? Environment and Behavior, Vol. 43, No. 4, 2011, p. 469-487

Butler, D.L., Biner, P.M., Effects of setting on window preferences and factors associated with those preferences, Environment and Behavior, Vol. 21, No. 1, 1989, p. 17-31

Cetegen, D., Veitch, J.A., Newsham, G.R., View size and office luminance effects on employee satisfaction, Proceedings of Balkan Light 2008, Ljubljana, Slovenia, p. 242-252

Chauvel, P., Collins, J.B., Dogniaux, R., Longmore, J., Glare from windows: current views of the problem, Lighting Research and Technology, Vol. 14, No. 1, 1982, p. 31-46

Christoffersen, J., Johnsen, K., Peterson, E., Hygge, S., Post-occupancy evaluation of Danish office buidings, Proceedings of the 24th Session of the Commission Internationale de l'Eclairage, Warsaw, Poland, Vienna, Austria: CIE Central Bureau, 1999, p. 333-337

Collins, B.L., Review of the psychological reaction to windows, Lighting Research and Technology, Vol. 8, No. 2, 1976, p. 80-88

Daniel, T.C., Vining, J., Methodological issues in the assessment of landscape quality, In Altman, I., Wohlwill, J.F. (Ed) Behavior and the natural environment, New York: Plenum Press, 1983, p.39-84

Farley, K.M.J., Veitch, J.A., A room with a view; a review of the effects of windows on work and well-being, Research Report, Institute for Research in Construction, NRC-CNRC, 2001

Hartig, T., Mang, M., Evans, G.W., Restorative effects of natural environment experiences, Environment and behavior, Vol. 23, No. 3, 1991, p. 3-26

Heerwagen, J.H., Orians, G.H., Adaptations to Windowlessness: A Study of the Use of Visual Décor in Windowed and Windowless Offices, Environment and Behavior, Vol. 18, No. 5, 1986, p. 623-639

Herzog, T.R. A cognitive analysis of preference for urban nature, Journal of Environmental Psychology, Vol. 9, No. 1, 1989, p. 27-43

Herzog, T.R., Gale, T.A., Preference for urban buildings as a function of age and nature context, Environment and Behavior, Vol. 28, No. 1, 1996, p. 44-72

Herzog, T.R., Shier, R.L., Complexity, Age, and Building Preference, Environment and Behavior, vol. 32, No. 4, 2000, p. 557-575

Heschong, L, Roberts, J.E., Linking daylight and views to the reduction of sick building syndrome, Proceedings of Healthy Buildings 2009, paper 797

Heschong Mahone Group, Windows and offices: A study of office worker performance and the indoor environment, Technical Report for the California Energy Commission, 2003

Kaplan R., The analysis of perception via preference: a strategy for studying how the environment is experienced, Landscape planning, Vol. 12, No. 2, 1985, p. 161-176
Kaplan, R, The nature of the view from home: Psychological benefits, Environment and Behavior, Vol. 33, No. 4, 2001, p. 507 – 542
Kaplan, R., Kaplan, S., Brown, T., Environmental preference: a comparison of four domains of predictors, Environment and Behavior, Vol. 21, No. 5, 1989, p. 909-530
Kaplan, R., Kaplan, S., Ryan, R.L., With People in Mind: Design and Management of Every Day Nature, Washington, D.C.: Island Press, 1998
Kaplan, R., Kaplan, S., The Experience of Nature: A Psychological Perspective, Cambridge: Cambridge University Press, 1989
Kaplan, R., The role of nature in the context of the workplace, Landscape and Urban Planning, Vol. 26, No. 1-4, 1993, p. 193-201
Kaplan, S., Aesthetics, Affect, and Cognition: Environmental Preference from an Evolutionary Perspective, Environment and Behavior, Vol. 19, No. 1, 1987, p. 3-32
Keighley, E.C, Visual requirements and reduced fenestration in office buildings — A study of window shape, Building Science, Vol. 8, No. 4, 1973(a), p. 311-320
Keighley, E.C, Visual requirements and reduced fenestration in offices — A study of multiple apertures and window area, Building Science, Vol. 8, No. 4, 1973(b), p. 321-331
Kfir, I.Z., Munemoto, J., Sacko, O., Kawasaki, Y., Evaluation of the view from the dwelling units on man-made islands in Osaka Bay: Multiple regression analysis based on residents' evaluation and image processing of photographs taken from the living room, Journal of Architecture, Planning and Environmental Engineering, Vol. 554, 2002, p. 357-364
Kim, J.J., Wineman, J., Are windows and views really better?, Taubman College of Architecture and Urban Planning, University of Michigan, 2005
Kim, J.T., Shin, J.Y., Yun, G.Y., Prediction of discomfort glare from windows: Influence of the subjective evaluation of window views, Indoor and Built Environment, Vol. 21, No. 1, 2011, p. 92-97
Leather, P., Pyrgas, M., Beale, D., Lawrence, C., Windows in the workplace: sunlight, view and occupational stress, Environment and behavior, Vol. 30, No. 6, 1998, p. 739-762
Markus, T.A., The function of windows— A reappraisal, Building Science, Vol. 2, No. 2, 1967, p. 97-121
Meerdink, G., Rozendaal, E.C., Witteveen, C.J.E., Daglicht en uitzicht in kantoorgebouwen, DGMR, ISBP, 1988
Meerdink, G., Weersink, A.M.S., Rozendaal, E.C., Beleving van daglicht en uitzicht in buitenlandse atriumgebouwen, Den Haag: Sdu Uitgeverij Plantijnstraat, 1994
Menzies, G.F., Wherrett, J.R., Windows in the workplace: examining issues of environmental sustainability and occupant comfort in the selection of multi-glazed windows, Energy and Buildings, Volume 37, Issue 6, 2005, p. 623-630
Nagy, E., Yasunaga, S., Kose, S., Japanese office employees' psychological reactions to their underground and above-ground offices, Journal of Environmental Psychology, No. 15, 1995, p. 123-134
Ne'eman, E., Sweitzer, G., Vine, E., Office worker response to lighting and daylighting issues in workspace environments; a pilot study, Energy and Buildings, No. 6, 1984, p. 159–171
Ozdemir, A., The effect of window views' openness and naturalness on the perception of rooms' spaciousness and brightness: A visual preference study, Scientific Research and Essay, Vol. 5, No. 16, 2010, p. 2275-2287
Shafer, E.L., Brush, R.O., How to measure preferences for photographs of natural landscapes, Landscape Planning, No. 4, 1977, p. 237-256
Shin, W.S., The influence of forest view through a window on job satisfaction and job stress, Scandinavian Journal of Forest Research, Vol. 22, No. 3, 2007, p. 248-253
Tuaycharoen, N., Tregenza, P.R., Discomfort glare from interesting images, Lighting Research and Technology, Vol. 37, No. 4, 2005, p. 329-341

Tuaycharoen, N., Tregenza, P.R., View and discomfort glare from windows, Lighting Research and Technology, Vol. 39, No. 2, 2007, p. 185-200

Tuaycharoen, The Reduction of Discomfort Glare from Windows by Interesting Views, PhD Thesis, Sheffield: The University of Sheffield, School of Architecture, 2006

Ulrich, R.S., Natural Versus Urban Scenes: Some Psychophysiological Effect, Environment and Behavior, Vol. 13, No. 5, 1981, p. 523-556

Ulrich, R.S., Simons, R.T., Losito, B.D., Fiorito, E., Miles, M.A., Zelson, M., Stress recovery during exposure to natural and urban environments, Journal of Environmental Psychology, Vol. 11, No. 3, 1991, p. 201-230

Ulrich, R.S., View through a window may influence recovery from surgery, Science, Vol. 224, No. 4647, 1984, p.420-421

Van den Berg, A.E., Hartig, T., Staats, H., Preference for nature in urbanized societies: Stress, restoration, and the pursuit of sustainability, Journal of social issues, Vol. 63, No. 1, 2007, p. 79-96

Velarde, M.D., Fry, G., Tveit, M., Health effects of viewing landscapes – Landscape types in environmental psychology, Urban Forestry & Urban Greening, Vol. 6, No., 2007, p. 199-212

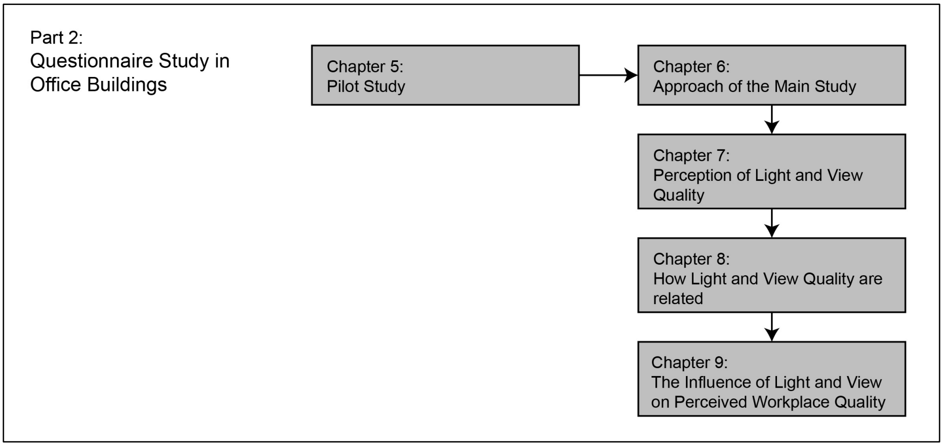
White, M., Smith, A., Humphryes, K., Pahl S., Snelling, D., Depledge, M., Blue space: The importance of water for preference, affect, and restorativeness ratings of natural and built scenes, Journal of Environmental Psychology, Vol. 30, No. 4, 2010, p. 482-493

Zube, E.H., Brush, R.O., Fabos, J.Gy., Landscape assessment: values, perceptions, and resources, Stroudsburg: Dowden, Hutchinson & Ross, 1975

Part 2

Questionnaire Study in Office Buildings

Part 2 is a questionnaire study in office buildings. It describes a survey which has been done to investigate to what extent different variables influence satisfaction with the lighting and outside view in real office environments. The questionnaire research also studies the influence of daylight and view on the general perception and overall satisfaction with the workplace and the relationship between the assessment of light, view, and workplace quality. Part 2 consists of five chapters, chapters 5 to 9.



The research questions of chapter 5 are:

- What are, according to office workers the most important functions of windows, and the view outwards?
- How do office workers assess their workplace, the lighting in the office and the outside view?

Chapter 6 describes the approach of the main study and does not aim to answer any research questions.

The research questions of chapter 7 are:

- Which features of a building, office room and workplace influence the perceived daylight and view quality of office workers?
- Which features of an outside view are significant predictors of perceived view quality?

The research questions of chapter 8 are:

- How can the questionnaire variables related to light and view be combined in a factor for light and a factor for view quality?
- How are perceived light and perceived view quality related?

The research questions of chapter 9 are:

- How can the questionnaire variables related to the perception of the workplace, but not related to the visual quality be combined in one factor for workplace quality?
- Does perceived light and view quality influence the perception of workplace quality?

Chapter 5

Pilot Study

This chapter explores how office employees assess their visual environment and what according to them are important quality aspects of windows, daylight and outside view. It describes a questionnaire research conducted in the faculty of Architecture at the Delft University of Technology.

A questionnaire is developed which is distributed amongst the employees of the faculty. The results give insight in how different aspects of the environment in the offices are assessed by the respondents. The research questions are:

- What are, according to office workers the most important functions of windows, and the view outwards?
- How do office workers assess their workplace, the lighting in the office and the outside view?

The pilot study described in this chapter is an exploratory study. The outcome was used as input for an extensive field survey which is described in chapters 6 to 9.

Chapter outline

5.1. Questionnaire and Procedure

For the pilot study at the faculty of Architecture an internet questionnaire is developed, based on the variable scheme in figure 5.1. The aim is to study the influence of light and outside view variables on the assessment of the visual quality of indoor spaces. Because other variables might affect the assessment of visual quality too, several of these intervening variables are included in the questionnaire. They can be divided into five categories: personal preferences, weather conditions and time of the day, work environment, indoor climate and degree of adaptive opportunity.

The online questionnaire tool NetQuestionnaires is used to construct the internet questionnaire and the results are stored on a local server at the Delft University of Technology. The participants received the questionnaire in Dutch language. Appendix A gives the English translation.

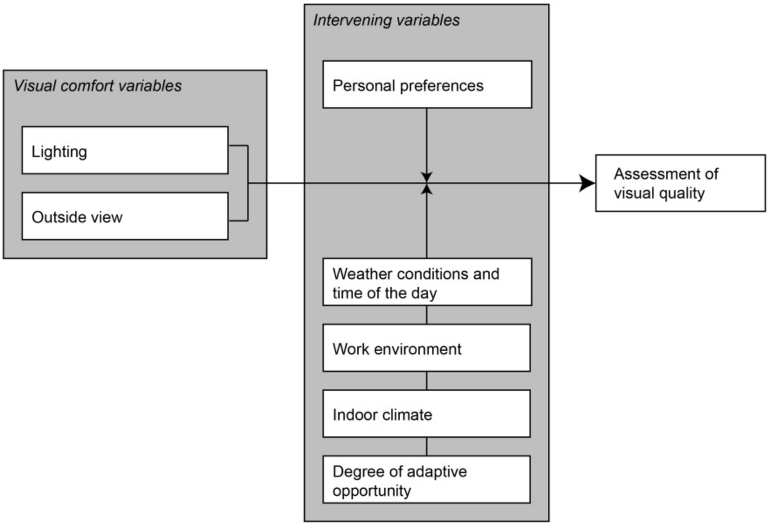


Figure 5.1: Scheme with variables

The questionnaire starts with general and finishes with specific questions. Most questions ask the respondents to assess their current workplace. In addition, some questions are asked about the respondent's preferences regarding the lighting and outside view.

Different sources are used to construct the questionnaire. Questions are derived from the PhD theses of Velds (1999) and Ariës (2005). Other sources are reports of IEA task 21: Annex 29 (Hygge & Löfberg, 1999) and a study on daylight and view in office buildings (Meerdink et al., 1988). Finally, questions are selected from an assessment tool of the Dutch Rijksgebouwendienst and Delft University of Technology (Leijten & Kurvers, 2007).

The questions are divided into six categories:

PA. Weather and date
PB. Personal well-being
PB. Personal information
PC. The office space
PD. Indoor climate, specifically lighting
PE. Outside view

After asking a few questions about the weather and date, the questionnaire asks for some personal information like age and gender. Subsequently, information is collected about the workplace and the respondent's job. The fourth part contains questions about the indoor climate with a focus on the lighting. The respondents give their opinion about the light levels, degree of adaptive opportunity, and how often they are hindered by light reflecting in their computer screen or directly shining into their eyes. The sixth part of the questionnaire is about the view through the window. The employees define the content of the view and assess the view quality. The final question is a picture question which shows six different views, which are not related to the respondent's view from the workplace. The respondents assess which view they prefer most and which one they would prefer least.

The respondents get a maximum of 76 questions, partly multiple-choice and partly open questions. Irrelevant questions are not asked, for example when the respondent answers there is no sun shading, questions about the control of the sun shading are omitted. Most questions are obligatorily and the respondent gets a reminder when he or she forgets to answer a question.

Employees of the faculty were invited to answer the questionnaire by a message on the website the Faculty of Architecture and by an e-mail with a link to the questionnaire. They were asked to fill in the questionnaire during daytime at their workstation in the office.

5.2. Examined Building

During the pilot study the faculty of Architecture was located in a building with fourteen floors (Figure 5.2, 5.3). The building was designed by the Architectural office Van den Broek en Bakema and has been occupied by the faculty of Architecture from 1970 to 2008.[2] The questionnaire research took place between 1st and 22nd of June 2007.

[2] At the13th of May 2008 the building was destroyed in a fire.

Figure 5.2: The faculty of Architecture (Source: Wikipedia, Michiel1972, 2008)

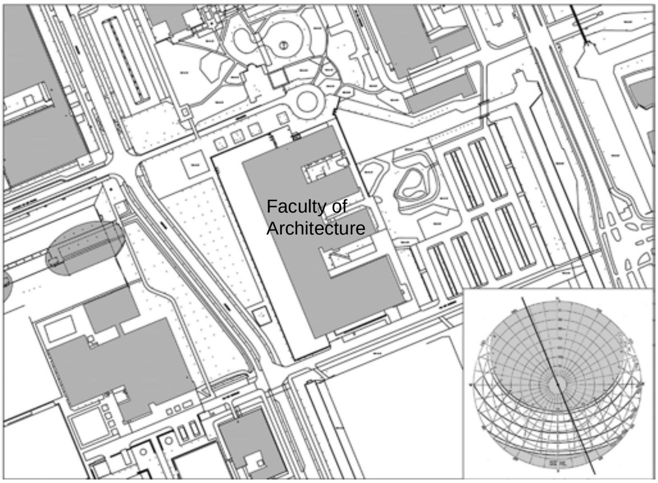


Figure 5.3: Location and orientation of the faculty of Architecture

The building is thirteen stories high and consists of a lower and upper part, with different floor plans (Figure 5.4). Most offices are located in the upper part of the building, from the second until the thirteenth floor. The floor plan exists of two wings, with offices at respectively the east side and west side of the building (Figure 5.5). The cellular offices are 2.7, 5.4, or 8.1 meters wide and 5.4 meters deep. At a few floors offices are located in a former atelier space, with an open-plan layout. These offices are not consistent in shape and window configuration and have different types of sunblind than the other offices.

The size of the windows in the office rooms is about 60-65% of the façade between floor and ceiling. The windows exist of two parts with different materialization (Figure 5.6). The lower part contains two glass panes with Venetian blinds in between. The blinds can be operated by the occupants of the room. The upper part of the window consists of a single glass pane with, in most cases, blue transparent foil on the inside. The upper part of the window can be manually opened.

The view from the windows is very diverse. At the lower floors the view from the offices is more limited than the views from the upper part of the building. The building is surrounded by trees and water. At the Eastside there is a big parking lot and at the Westside there is road and further away there are some low rise buildings.

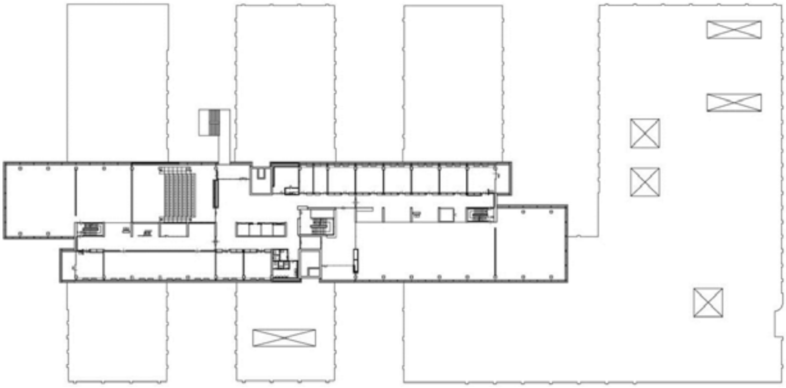


Figure 5.4: Floor plan 2nd floor with contour of ground floor and 1st floor

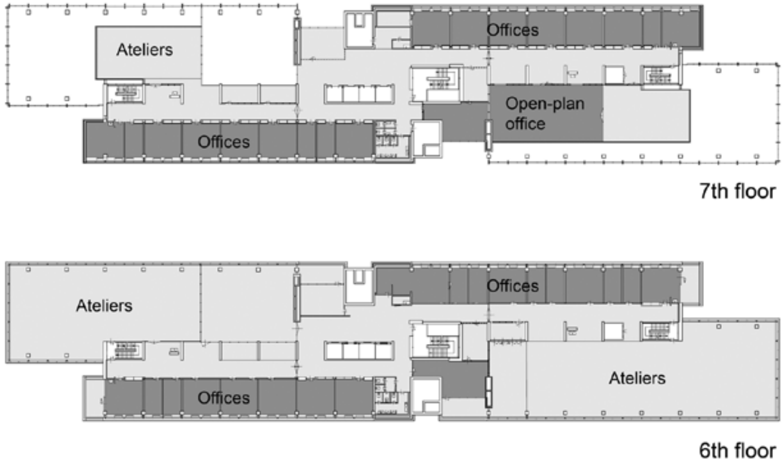


Figure 5.5: Floor plans upper part of the building

Figure 5.6: The windows exist of an upper and lower part with different sun shading

5.3. Participants

The number of respondents obtained in the pilot research is 103. Tables 5.1 and 5.2 show respectively the age and gender of the respondents. More than half of the respondents are younger than 40 years.

Table 5.1: Age of respondents of faculty of Architecture

Age	Percentage
< 30	26%
30-39	28%
40-49	17%
50-59	17%
> 59	11%

Table 5.2: Gender of respondents of faculty of Architecture

Gender	Percentage
Male	54%
Female	46%

Table 5.3 shows that 54% of the respondents sometimes or always wear glasses and 20% sometimes or always wear contact lenses during work. The number of respondents who have an eye disease or eye disorder which cannot fully be compensated by glasses or contact lenses is 13%.

Table 5.3: Respondents who wear glasses and/or contact lenses during working hours

	Percentage glasses	Percentage contact lenses
Yes, always	35%	17%
Yes, sometimes	19%	3%
Never	46%	81%
Total	100%	100%

5.4. Questionnaire Results

This paragraph studies the results of the pilot questionnaire. First, the results of questions about the respondents' satisfaction with several aspects of their workplace are examined. Subsequently, the advantages and disadvantages of windows mentioned by the respondents are discussed. After that, results are examined of questions on the indoor climate with a focus on the lighting in the offices. The paragraph ends with a discussion of the results on questions about the outside view.

Background information about the questions and their rating scales can be found in text box 5.1. Appendix A contains the entire questionnaire. Variables are listed according to their codes. These codes have two letters and one or two numbers. The first letter, the letter P, stands for pilot study and the second letter for one of the six parts of the questionnaire (Paragraph 5.1). Subsequently, the number of the question is given and, if relevant, a second number for the sub question.

Text box 5.1: Questions pilot study

The employees of the faculty of Architecture were asked if they are satisfied with several aspects of their workplace by Yes/No questions. They were also asked if their workplace is less or more than two meters from the window and what they can see when they look straight ahead by a 5-item question. Subsequently, they were asked to indicate what the biggest advantages and disadvantages are of windows by open-ended questions.

Table 5.4: General variables in the pilot study

Workplace position		
PD13	Satisfaction with the position of the desk	1 = Yes, 0 = No
PD14	Satisfaction with the position of the computer screen	Idem
PD15	What is seen when looking straight ahead	1 = A window, 2 = The workplace of a colleague, 3 = A sidewall of the office space, 4 = The back wall of the office space, 5 = Something else
PD17	Distance between workplace and window	1 = 0-2 meter, 2 = more than 2 meter
PD21	Satisfaction with the size of the windows	1 = Too big, 2 = Good, 3 = Too small
Advantages and disadvantages of windows		
PD19	Advantages of windows	Open
PD20	Disadvantages of windows	Open

The respondents got a 5-itemquestion about their satisfaction with several aspects of the indoor climate in their workroom. The answered ranged from (1) very satisfied to (5) very dissatisfied. The respondents' gave their opinion about the light levels by answering a question with answers ranging from (1) far too much light to (5) far too little light.

Questions about the frequency that the lighting is on, the possibility to work with only daylight, and the frequency that the respondents experience discomfort by heat of sunlight or annoying reflections were measured on a scale from (1) always to (5) never. Subsequently the respondents got multiple-choice questions about the location and source of annoying reflections. Satisfaction with the sunshading was asked by a Yes/No question.

Table 5.5: Light variables in the pilot study

Light quality		
PE1-1	Satisfaction with the lighting	1 = Very satisfied, to 5 = Very dissatisfied
PE1-2	Satisfaction with the temperature	Idem
PE1-3	Satisfaction with the ventilation	Idem
PE1-4	Satisfaction with the amount of privacy	Idem
PE1-5	Satisfaction with the outside view	Idem
PE4	Light level at the workplace	1 = Far too much light, to 5 = Far too little light
PE5	Frequency that artificial light is on	1 = Always, to 5 = Never
PE6	Possibility to work with only daylight	Idem
PE9	Satisfaction with the artificial lighting Explanation	1 = Yes, 0 = No Open
PE12	Discomfort by heat of sunlight	1 = Always, to 5 = Never
PE13	Annoying reflections	Idem
PE14	Location annoying reflections	1 = Glossy paper, 2 = Computer screen, 3 = Other, 4 = Not applicable
PE15	Source of annoying reflections	1 = Daylight, 2 = Artificial light, 3 = Other, 4 = Not applicable
PE22	Satisfaction with sun shading	1 = Yes, 0 = No

The first question about the outside view from the workplace was a 5-item question about what can be seen through the window, e.g. the sky, which could be answered by either Yes or No. The answers of the next question, which is about the pleasant of the items which could be seen through the window, range from (1) very pleasant to (5) very unpleasant. The respondents were asked about their view preference by a multiple-choice question. The final question asks respondents to choose from six pictures which view they prefer most and which least.

Table 5.6: View variables in the pilot study

View quality		
PF6-1	Possibility to see the ground	1 = Yes, 0 = No
PF6-2	Possibility to see the sky	Idem
PF6-3	Possibility to see buildings	Idem
PF6-4	Possibility to see water	Idem
PF6-5	Possibility to see green	Idem
PF7-1	Pleasantness to see the ground	1 = Very pleasant, to 5 = Very unpleasant
PF7-2	Pleasantness to see the sky	Idem
PF7-3	Pleasantness to see buildings	Idem
PF7-4	Pleasantness to see water	Idem
PF7-5	Pleasantness to see green	Idem
PF10	View preferences	1 = The weather, 2 = A diverse impression of the environment, 3 = An extensive view, 4 = What happens outside, 5 = The time
PF13-1	Preferred view	One of six pictures
PF13-2	Most disliked view	One of six pictures

5.4.1. Satisfaction with the workplace

Of the 103 employees who filled out the questionnaire in the pilot study, 86% answered that they have a workplace position closer than two meters from the window. When sitting behind their desk, 44% could see a window when they looked straight ahead. Only three employees answered they did not have access to a view at the time they were filling out the questionnaire.

Most respondents are satisfied with the size of the windows, the position of their desk and the position of their computer screen (Table 5.7). A Pearson χ^2-test is done to investigate if satisfaction with the position of the desk is the same for respondents with a workplace close to the window as for respondents with a workplace further away from the window. Because the outcome shows that more than 20% of the cells have an expected count of less than five, the outcome of the Fishers' exact test is consulted.[3] Satisfaction with the position of the desk is not found to be statistically significantly related to distance to the window (n=103, $\chi^2(1)=2.0$, p=.17). The reason could perhaps be that all respondents have sufficient access to a window and an outside view.

[3] The Fishers' exact test calculates the exact probability of the Pearson χ^2-test (Fields, 2009, p. 690).

Table 5.7: Percentage of respondents who are satisfied with their workplace

Topic	Percentage
Satisfied with the size of the windows	86%
Satisfied with the position of the desk	83%
Satisfied with the position of the computer screen	79%

5.4.2. Advantages and disadvantages of windows

What the biggest advantages and disadvantages are of window according to the respondents is displayed in tables 5.8 and 5.9.

Table 5.8: Six most mentioned advantages of windows

Advantage of windows	Percentage
1. View, contact with outside environment	64%
2. Daylight access	46%
3. Possibility to open the window, ventilation	18%
4. Impression of the weather	14%
5. No locked up feeling	13%
6. Activity, what is going on	5%

Table 5.9: Six most mentioned disadvantages of windows

Disadvantage of windows	Percentage
1. Heat of (direct) sunlight	37%
2. No disadvantages	21%
3. Too much or too bright (sun)light	20%
5. Cold (in winter) or draught (by bad insulation)	15%
4. Light reflection in computer screen	13%
6. Glare by sunlight or sunlight shining into the eye	7%

The most mentioned advantage is outside view or contact with the outside environment and the second most mentioned advantage is daylight access. The results confirm the finding of Christoffersen et al. (1999) and Farley and Veitch (2001) that, of all the functions of a window, the provision of a view is most valued by building occupants.

As expected the disadvantages mentioned by the respondents are mostly related to overheating by thermal radiation or glare caused by direct sunlight. However, a total of 21% respondents answered that windows do not have any disadvantages at all. It seems that either they do not experience any discomfort from windows, or they take the discomfort for granted, because the benefits of windows are more important to them.

5.4.3. Light quality

How satisfied the respondents are with several aspects of the indoor climate in their workroom is displayed in figure 5.7. Respondents are most satisfied with the outside view, and next with the lighting and amount of privacy. They are least satisfied with the temperature and ventilation. Most complaints are about glare and heating by sunlight. More than half of the respondents (55%) are dissatisfied with the sun blinds. Many of them have made remarks about the Venetian blinds, which do not keep the heat of the sun outside and have a badly accessible control device. Another complaint is that the access of sunlight through the top part of the window cannot be controlled at all. Although most windows have blue foil at the upper part, access of sunlight through this part of the window causes glare in some offices.

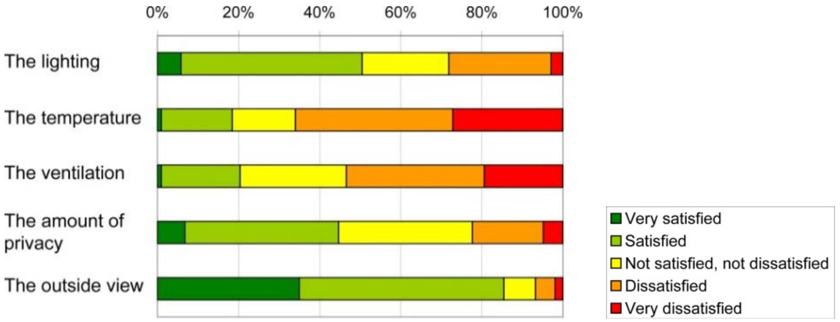


Figure 5.7: Satisfaction with workplace environment

During working hours, the artificial lighting is always on in the offices of 46% of the respondents (Figure 5.8). However, only 14% answered that they can never work without artificial lighting (Figure 5.9), which indicates that the lighting is on more often than necessary.

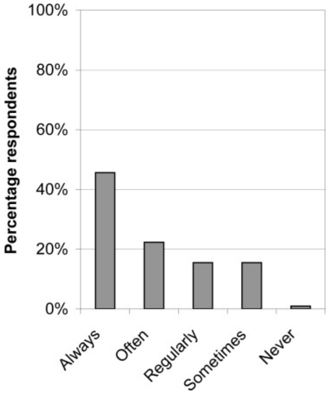


Figure 5.8: Frequency that respondents think the artificial light is on

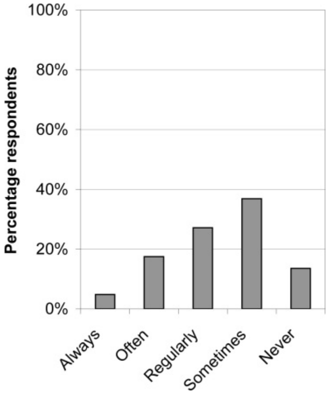


Figure 5.9: Frequency that respondents think they could work without artificial lighting

The overall light level in the offices is good according to 69% of the respondents, but 43% of the respondents answered that they are dissatisfied with the artificial lighting. They have got complaints about the lack of control possibilities and the artificial lighting turning off automatically when they are not moving. Therefore, dissatisfaction with the artificial lighting seems to be more related to the way it is controlled than to the light quality.

More than half of the respondents (52%) experience annoying light reflections. These are mainly reflections in a computer screen (91%), and the reflections are almost always caused by daylight (93%). In order to investigate if the frequency of annoying reflections differs between the two orientations of the offices, the variables are subjected to the non-parametric Mann-Whitney test (Figure 5.10). Respondents with a workplace at the west side of the building turned out to experience annoying reflections statistically significantly more often than respondents at the east side of the building ($n=91$, $U=763.5$, $Z=-2.2$, $p< 05$). The reason for this difference might be that in winter offices at the west side get more direct sunlight during working hours than offices at the east side of the building. In summer the difference is small, because of the daylight saving time.

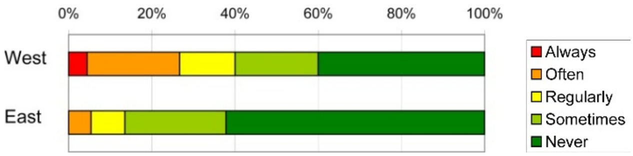


Figure 5.10: Frequency that respondents experience annoying reflections

5.4.4. View quality

The results of the first question discussed in the previous paragraph shows that almost all employees in the pilot study are satisfied with the outside view from their workplace (Figure 5.7). When asked what they would like to see outside by a multiple-choice question, 85% of the respondents answered that they would like to see what weather it is (Table 5.10). Although the literature consistently shows that people like to have access to a distant view (Chapter 4), only 46% of the respondents in the pilot study selected that they like to have an extensive view. The results indicate that a diverse view is more important.

Table 5.10: View preferences

What would you like to see through the window from your workplace?	Percentage
The weather	85%
A diverse impression of the environment	62%
An extensive view	46%
What happens outside	37%
The time	32%

Of the respondents who have an outside view from their workplace, over 90% can see the sky, buildings and green when they are sitting behind their desk, 54% can see the ground and 29% can see water (Figure 5.11). These results indicate that almost all respondents have a wide and diverse view.

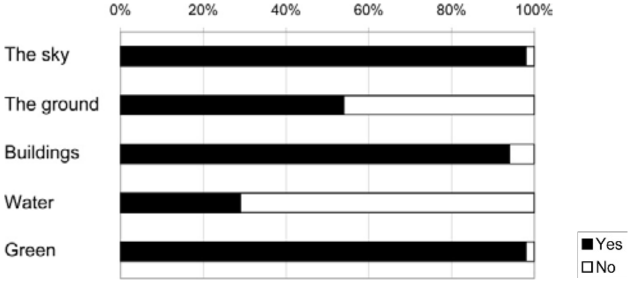


Figure 5.11: Topics which could be seen by the respondents through the window

Generally, the respondents like what they see (Figure 5.12). As expected natural green is found pleasant by most people, but also the possibility to see the sky is much appreciated. Although the literature shows that water is a much preferred landscape element (Chapter 4), the results of the pilot study show that half of the respondents have a neutral opinion about the water in their outside view. Apparently, the water seen from the faculty building has a low quality. The building is surrounded by a concrete water basin, with still dirty water. Streaming water in a river or lake is more natural and might therefore be more appreciated. Some respondents find the buildings in their view unpleasant, but most respondents like the buildings in their view, indicating that buildings can have a positive effect on outside view quality.

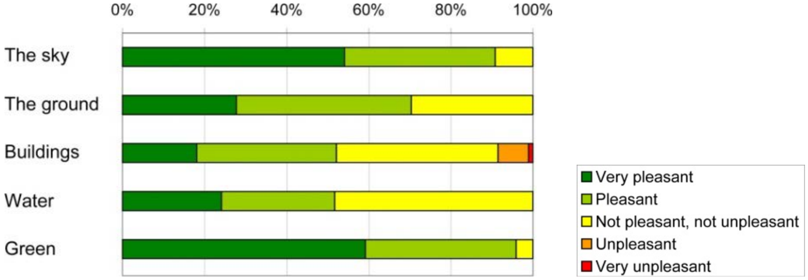


Figure 5.12: Pleasantness of the topics that could be seen by the respondents

Figure 5.13 shows the results of the final question where the respondents had to choose from six pictures which view they prefer most and which they prefer least. The most preferred view turns out to be a wide view from a high floor and the second most preferred view shows a natural landscape. Both views have a high nature content and contain distant city or landscape. Both are described in the literature as important elements of view quality (Chapter 2). The least preferred view is a view of a nearby building and the second least preferred view is dominated by traffic.

About one picture the respondents had very different opinions. The view of the crowns of trees is preferred most by 15% of the respondents and preferred least by 11% of the respondents. The view has characteristics which are generally liked and which are generally disliked. It shows nature, but the view is monotonous and the ground is not visible. It seems that the respondents have a different opinion about which characteristic is most important. It are especially these types of views for which it is difficult to predict how they will be judged by office workers.

1. (+44%, -2%)

2. (+22%, -2%)

3. (+19%, -1%)

4. (+15%, -11%)

5. (+0%, -25%)

6. (+0%, -59%)

Figure 5.13: Assessment of six views. The pictures are numbered from most preferred (+) to least preferred (-)

5.5. Key Findings

The key findings of the pilot study are:

- The most mentioned advantage of windows is the outside view it provides, followed by access of daylight. The results confirm the finding of Christoffersen et al. (1999) and Farley & Veitch (2001) that the provision of a view is most valued by building occupants. The disadvantages mentioned by the respondents are mostly related to overheating by thermal radiation or glare caused by direct sunlight.
- The results of the study did not show that satisfaction with the position of the desk is affected by the distance of the workplace to the window. The reason could be that all respondents are in relatively close distance of a window and have access to a view.
- In the examined building the respondents are less satisfied with the temperature and ventilation than with the lighting and outside view. Dissatisfaction with the lighting seems to be more related to the way the artificial lighting is controlled than to the light quality. The majority of the respondents thinks that the overall light level in the offices is good, but many of them have complaints about control possibilities of the artificial lighting.
- In the offices orientated at the west side of the building respondents have statistically significantly more complaints about glare than in the offices at the east side. The reason for this difference could be that in winter these offices get more hours of direct sunlight.
- Out of five different items, the possibility to see the weather is found to be the most important function of a view. Furthermore, a diverse view is found to be more important than a wide view.
- As expected, the elements that contribute most to the pleasantness of the outside view from the offices are the sky and green. Although the literature shows that water is a much preferred landscape element (Chapter 4), many respondents in the pilot study have a neutral opinion about the water in their outside view. This result is probably caused by the low visual quality of the concrete water basin.
- The only element in the view which is disliked by some respondents in the pilot study is the element buildings. However, most respondents like the buildings in their view, indicating that buildings can have a positive effect on outside view quality.

The results of the pilot study give an indication of what features of the lighting and view from an office affect satisfaction with the lighting and outside view. The main study in chapter 6 to 9 aims to give a more detailed analysis of the influence of different variables on perceived light, view quality and workplace quality. For this study the questionnaire is improved, which is explained in chapter 6.

5.6. References

Aries, M.B.C., Human Lighting Demands: Healthy Lighting in an Office Environment, Eindhoven: Technical University of Eindhoven, Faculty of Architecture, Building and Planning, 2005

Christoffersen, J., Johnsen, K., Peterson, E., Hygge, S., Post-occupancy evaluation of Danish office buidings, Proceedings of the 24th Session of the Commission Internationale de l'Eclairage, Warsaw, Poland, Vienna, Austria: CIE Central Bureau, 1999, p. 333-337

Farley, K.M.J., Veitch, J.A., A room with a view; a review of the effects of windows on work and well-being, Research Report, Institute for Research in Construction, NRC-CNRC, 2001

Hygge, S., Löfberg, H.A., Post occupancy evaluation of daylight in buildings, Report of IEA Task 21/Annex 29, 1999

Leijten, J.L., Kurvers, S.R., Praktijkgids Arbeidshygiëne: Binnenklimaat kantoorgebouwen; onderzoek naar klachten, Alphen aan den Rijn: Kluwer, 2007

Meerdink, G., Rozendaal, E.C., Witteveen, C.J.E., Daglicht en uitzicht in kantoorgebouwen, DGMR, ISBP, 1988

Rijksgebouwendienst and TU Delft, Toetsingsinstrument Binnenmillieukwaliteit Rijksgebouwendienst, Concept version, 2006 (internal report)

Velds, M., Assessment of lighting quality in office rooms with daylighting systems, Delft: Technical University of Delft, Faculty of Architecture, 1999

Websites

http://nl.wikipedia.org/wiki/Faculteitsgebouw_Bouwkunde_(TU_Delft), (accessed 02-08-2013)

Chapter 6

Approach of the Main Study

The pilot study is followed by an extensive field survey in eight office buildings. The aim of the main study is not only to explore what light and view variables influence visual comfort, but also to get insight in the relationship between light and view variables, because in the literature evidence was found that view quality affects perceived amount of discomfort glare (Chapter 3 and 4). Little information was found in the literature on the effect of light and view quality on perceived workplace quality. This will also be investigated in the field survey, in order to get more insight in how people perceive their work environment.

The current chapter describes the approach of the field study. It explains how the questionnaire of the pilot study has been improved, when the main study took place and which methods are chosen for the statistical analysis of the results. Furthermore, it describes the characteristics of the buildings which are surveyed and the number and characteristics of the respondents.

The results of the study are described in chapters 7 to 9.

Chapter outline

6.1. Questionnaire and Procedure

6.1.1. Data collection

Based on the results of the pilot study and discussions with other researchers, the field study questionnaire has been improved. Subsequently, it was distributed to eight office buildings in the Netherlands. The participants received the questionnaire in Dutch again. The English translation can be found in appendix B.

The questionnaire is divided into four parts:

A. Personal information
B. The office space
C. Indoor climate
D. Outside view

The structure is basically the same as the questionnaire of the pilot study (chapter 5), but questions about the weather and data and personal well-being were deleted, in order to limit the number of variable categories and the time to fill out the questionnaire. Information about the date and time could be collected from the internet tool NetQuestionnaires.

The improved questionnaire contains fewer open questions and more questions on a 5-point Likert-scale. This makes the structure of the questionnaire clearer and makes it possible to perform an extensive statistical analysis on the results. Some questions are deleted and other questions are combined, resulting in a maximum number of 53 questions. The number of questions a respondents gets depends on the presence of a window and sun shading, the way the sun shading is controlled and the availability of an outside view.

Employees of the surveyed buildings a invited to fill out the questionnaire by an internal e-mail with a link to the questionnaire, except for the employees of the fifth building who were invited through a message in a digital newsletter. In the main study most questions are again obligatory.

Between February and March 2008 two office buildings were surveyed with the new questionnaire. After examining the results, two questions about discomfort glare were added (Questions 33c and 33d in Appendix B) and the picture question at the end of the questionnaire was changed (Question 51 in Appendix B). An explanation is given in chapter 7. In June and July 2009 the questionnaire was distributed to three more buildings, two of them being faculties at the Delft University of Technology. Another three office buildings were surveyed between October 2009 and January 2010. The exact periods can be found in table 6.1.

Buildings 4 and 8 have flexible workplaces, therefore, some questions had to be rephrased in the questionnaire of these buildings. Respondents were specifically asked to assess the workplace they were occupying at the time they were filling out the questionnaire.

The questionnaire of building 8 contains some more questions than the questionnaire of the other buildings (Last page appendix B). It was a request of the company to add these questions. They are interested in how the different interior layouts inside building 8 are perceived by the office employees. The questions are derived from a tool called WODI Evaluatie Toolkit (Volker, 2005, Van der Voordt & De Been, 2010). The results are discussed in chapters 7-9.

Table 6.1: Period during which the buildings were surveyed

Building	Data
Building 1	18-02 to 04-03 2008
Building 2	15-02 to 29-02 2008
Building 3	05-06 to 26-06 2009
Building 4	02-06 to 08-07 2009
Building 5	22-06 to 09-07 2009
Building 6	06-10 to 28-10 2009
Building 7	09-10 to 04-11 2009
Building 8	11-11 to 23-12 2009

6.1.2. Statistical Analysis of the Results

Aim of the main study is not only to study the influence of light and outside view variables on the assessment of visual quality, but also to study the influence of perceived visual quality on perceived workplace quality.

After collecting the data, several statistical tests are performed to examine whether there are differences in responses between different groups, e.g. employees working at the eight different locations. Furthermore, the relationship between variables is investigated in accordance with the scheme in figure 6.1.

The influence of different variables on satisfaction with the workplace environment and perception of outside view quality is explored in chapter 7. In chapter 8 the relationship between light and view variables is investigated and in chapter 9 the influence of light and view quality on perceived workplace quality is investigated. This is done by performing parametric tests on the data.

Frequently, the data does not meet the criteria for parametric tests, i.e. following a normal distribution in the population and having at least an interval level scale (e.g. Field, 2009, p 131). However, the use of parametric measures allows more sophisticated analyses than non-parametric methods. Furthermore, many researchers make the assumption that rating scales are interval in nature (Lee and Soutar, 2010). Most tests, for example the F-test in ANOVA, are quite robust against violations of normality (Glass et al., 1972 in Field, 2009, p. 155). Furthermore, the central limit theorem argues that in large samples (about 40 or more) the sampling distribution has a normal distribution with a mean equal to the population mean, regardless of the shape of the population from which the sample was drawn (Field, 2009, p 42, 156). An explanation of the specific tests which are used in each phase of the analysis is given in the introductions of chapters 7 to 9.

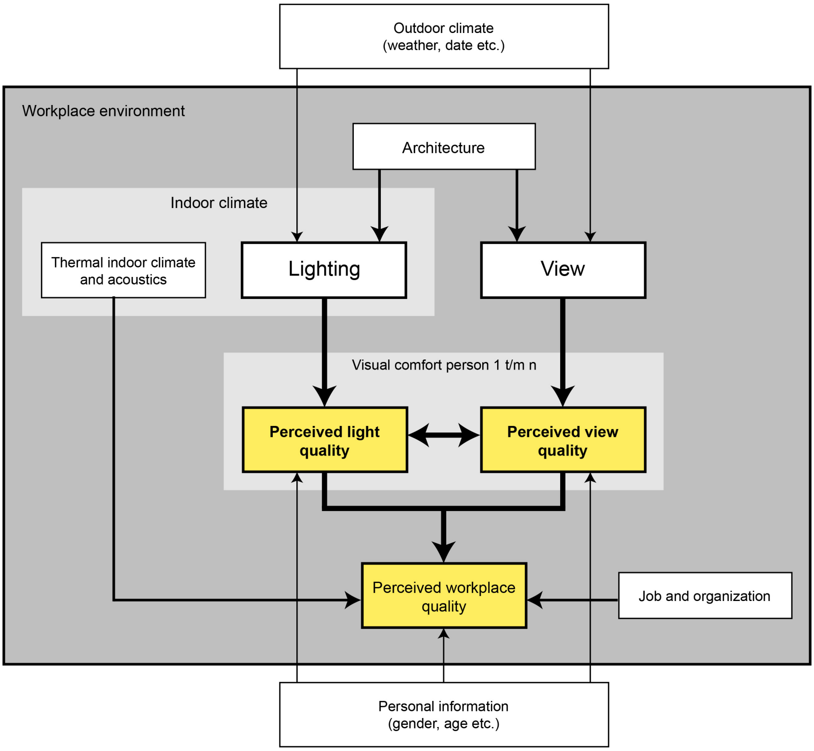


Figure 6.1: Scheme which is followed for the analysis of the results

6.2. Examined Buildings

The size and type of buildings and workplaces in the main study varies (Table 6.2). Most buildings have semi-open office spaces. The number of people sitting in one room varies from one person (9%) to more than thirty persons (6%). In most buildings people have fixed workplaces, except for the employees of buildings 4 and 8. In building 4 most workplaces are flexible and in building 8 they are partly fixed and partly flexible. The window area varies from 25% in building 1 to 75% in building 5 (Table 6.3). The buildings have different types of sun shading devices. Most common are horizontal or vertical lamellae in- or outside the façade

Table 6.2: Surveyed office buildings

Building	Sector	Floors	Type of workplaces
Building 1	Office	1-7	Fixed workplaces, open-plan and cellular offices
Building 2	Office	1, 2	Fixed workplaces, open-plan and cellular offices
Building 3	Office	2, 3	Fixed workplaces, open-plan and cellular offices
Building 4	Education/Research	1-3	Flexible workplaces, open-plan and cellular offices
Building 5	Education/Research	2-11	Fixed workplaces, cellular offices
Building 6	Office	1-7	Fixed workplaces, open-plan and cellular offices
Building 7	Office	1-4	Fixed workplaces, open-plan and cellular offices
Building 8	Office	2-4, 6	Fixed and flexible workplaces, open-plan offices and cellular offices

Table 6.3: Windows and sun shading

	Window area	Available blinds	Control
Building 1	C.a. 25%	Panels outside with small horizontal blinds	Automatic control; can be overruled by employees.
Building 2	Varies from c.a. 30-60%	Vertical lamellae inside, blue screens outside	Manual control, blinds close automatically at night (prevention against burglary)
Building 3	C.a. 30%	Venetian blinds inside, screens between the two layers of the façade	Manual control of Venetian blinds, automatic control of screens
Building 4	Varies from c.a. 30 to 70 %	Venetian blinds or blue screens outside some offices have Venetian blinds inside	Automatic control, can be overruled in some offices
Building 5	C.a. 75%	Venetian blinds between the two layers of the facade	Manual control
Building 6	C.a. 65%	Venetian blinds inside, blue screens outside	Manual control
Building 7	C.a. 40%	Vertical lamella inside, tinted glass	Manual control
Building 8	C.a. 45%	Perforated blinds (renovated floors) or perforated venetian blinds inside, tinted glazing	Manual control

This chapter will now describe per building their main features regarding the number of floors, type of workplaces, the window area, sun shading and the view from the building.

6.2.1. Building 1

Office building 1 is located in Delft and is seven floors high. The semi-open office spaces are situated around the core of the building. The window area is about 25% of the façade between the floor and ceiling. The sun shading consists of translucent panels, which are automatically controlled. The panels close when daylight levels become too high, but the system can be overruled by the employees. At the northern façade there is no sun shading outside. The view from building 1 varies. Some employees have a view of buildings across a street, others have a view on a road with a ditch and trees along it.

Figure 6.2: Building 1

6.2.2. Building 2

Office building 2 is three floors high and located in Rotterdam. The surveyed company is located on the first and second floor. At the first floor there is a large semi-open office space. Furthermore, there are cellular offices at both floors. The window area is, depending on which part of the façade is considered, about 30% or 60% of the façade between the floor and ceiling. The windows have vertical blinds inside and screens outside, except for the windows on the northern side, which have no sun shading. The sun shading can be opened or closed manually. The view on the northern side is very open. It shows the river Maas, green and, further away, the city center of Rotterdam. On the southern side there is a view of a business area, with a parking lot. The majority of the employees has a workplace on the northern side, the side with the most beautiful view.

Figure 6.3: Building 2

6.2.3. Building 3

Building 3 is three floors high. The surveyed company occupies the third floor. The building is situated at an industrial park in Delft. The offices have a semi-open character. The façade is a double skin façade. The inner part has flexible panels and windows are not in a regular pattern. Most windows have a vertical shape and reach from floor to ceiling. The average window area is about 30%. The sun shading consists of blinds between the two layers of the façade and vertical lamellae inside. The employees can all see opposite office buildings from their workplace. Some of them can see natural green and/or a road.

Figure 6.4: Building 3

6.2.4. Building 4

Building 4 is the current building of the faculty of Architecture at the campus of the Delft University of Technology.[4] The building consists of three floors. Most offices are located at the lower two floors, which have a height of about six meters. In some parts of the building the floors are split into two. In those areas, the offices have a height of about three instead of six meters.

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[4] The building was built in the nineteenth century and was the former main building of the university. After the fire of May 2008, the faculty of Architecture moved into the building in November and December 2008.

The floor plan of the building is very wide and it has several wings. The office rooms vary a lot in shape and size, but generally have an open character. The window area and available sun shading varies. At the top floor there are outside screens, and at the other floors rooms have either outside screens or Venetian blinds. All sun shading devices are automatically controlled, but in some cases they can be overruled.

The view from the building differs from one office to the other. Many employees view other parts of the faculty building. Furthermore, they can see one of the squares, which are at three sides enclosed by the building. These squares lead to the entrances of the faculty building and contain parking places for bicycles and/or cars. Also many employees view one or more roads, neighbouring buildings and/or greenery. The neighbour buildings vary in size, character and function. The greenery is part of the faculty building or the park or cemetery next to the faculty building, or greenery near the roads which surround the building.

Figure 6.5: Building 4

Figure 6.6: Glass house and interior building 4

6.2.5. Building 5

Building 5 is the highest building at the campus of the Delft University of Technology. It is occupied by different faculties, amongst which the faculty of Electrical Engineering. The number of floors is 21 and the workplaces are located in cellular offices. The building has a double skin façade. The window area is about 75%. The sunshading consists of Venetian blinds, which is located between the two glass panes in the façade. The blinds are manually controlled. Building 5 is a high-rise building, so there is a very distant view from offices in the upper part of the building. Nearby elements are the park, which lies in between the university buildings, opposite low-rise university buildings, and student houses. On one side there is a parking lot with trees.

Figure 6.7: Building 5

6.2.6. Building 6

Office building 6 is located in the city of Rotterdam, in the (former) harbor area alongside the Maas. The building is six floors high. The offices are cellular offices, which vary in size. The window area is about 65% of the façade between floor and ceiling. For daylight regulation there are horizontal lamella inside the rooms and for sun shading there are blue screens outside, except for the north oriented façade, which has no sun shading outside. At one side of the building employees can see the river Maas. Furthermore, most employees view industrial buildings, which are part of the company. At the higher floors, the view is much wider than on the lower floors.

Figure 6.8: Building 6

6.2.7. Building 7

The seventh building is located in Nijmegen. Building 7 is five stories high and the surveyed company is located at floors 1 to 4. Most workplaces are located in an open office environment with windows on two sides, but there are also smaller cellular offices. The window area is about 60% of the façade between floor and ceiling. The sun shading consists of vertical blinds inside. At the front side of the building there is a road, at the back side a parking lot, which can be seen from the offices. Furthermore, the employees can see opposite buildings and some greenery.


Figure 6.9: Building 7

6.2.8. Building 8

Building 8 is biggest office building that has been surveyed. It is located in Sittard and has nine floors. The building has an atrium with no roof. The questionnaire was distributed to four departments, which are located at floors 2, 3, 4 and 6. The department at floor 3 has small cellular offices and at floor 6 there are big cellular offices. Floors 2 and 4 are recently renovated and have open-plan office rooms. Because the rooms have a new layout and new furniture, the response might be different from floors 3 and 6. For this reason, questionnaire results of the different floors will be compared to each other.

The workplaces are fixed at floors 2, 3 and 6 and flexible at floor 4. The density of the workplaces per square meter can be found in table 6.4. The window area is about 45% of the wall area. The glazing of the windows is tinted in order to decrease the access of sunlight. The renovated offices have screens on the inside for daylight regulation. These screens have a perforation, which makes it possible to look through the window when the blinds are closed. The offices which have not yet been renovated have perforated Venetian blinds inside.

Table 6.4: Type of offices and workplaces in building 8

Floor	Office type	Type of workplaces
2	Open-plan	Fixed
3	Cellular	Fixed
4	Open-plan	Flexible
6	Cellular	Fixed

Building 8 is a tall building and especially from the upper floors the view is very wide. The building is surrounded by much greenery and parking lots. Furthermore, the building is located nearby a railway station. From one side of the building, the employees can see the trains passing by. Some employees view parts of their own office building. The offices along the atrium have a view of the atrium walls and a tree inside the atrium.

Figure 6.10: Building 8

Figure 6.11: Interior of building 8

6.3. Participants

The total number of respondents in the main study is 558. Table 6.5 shows the number of respondents of each building and the response rate.

Table 6.5: Questionnaire response of main study

Building	Number	Response rate
Building 1	39	+ 25%
Building 2	35	+ 90%
Building 3	30	+ 75%
Building 4	88	+ 15%
Building 5	19	unknown
Building 6	71	+ 80%
Building 7	38	+ 50%
Building 8	239	35-40%

Table 6.6 shows the respondent's mean age and gender. The mean age is lowest in building 2 and highest in building 7. The majority of the respondents is male (70%), which might be due to the fact that most participating companies and faculties are operating in the field of technology and science. The highest percentage of female respondents is found in building 5 (47%).

Table 6.6: Age and gender of respondents of main study

Building	Age		Gender	
	Mean	Standard deviation	Male	Female
Building 1	38.6	11.9	61%	39%
Building 2	32.5	7.5	80%	20%
Building 3	36.4	11.9	83%	17%
Building 4	42.5	13.0	61%	39%
Building 5	42.3	12.4	53%	47%
Building 6	41.5	9.8	69%	31%
Building 7	42.6	10.2	84%	16%
Building 8	42.2	10.3	70%	30%
Total	41.0	11.1	70%	30%

The percentage of respondents who wear glasses or contact lenses during work can be found in tables 6.7 and 6.8. A total of 4% of respondents have an eye disease or eye disorder which cannot fully be compensated by glasses or contact lenses.

Table 6.7: Respondents wearing glasses during working hours

Building	Yes, always	Yes, sometimes	Never
Building 1	47%	16%	37%
Building 2	17%	3%	80%
Building 3	27%	17%	57%
Building 4	40%	19%	41%
Building 5	42%	11%	47%
Building 6	38%	10%	52%
Building 7	39%	5%	55%
Building 8	33%	17%	49%
Total	35%	15%	50%

Table 6.8: Respondents wearing contact lenses during working hours

Building	Yes, always	Yes, sometimes	Never
Building 1	16%	3%	82%
Building 2	23%	3%	74%
Building 3	20%	3%	77%
Building 4	10%	3%	86%
Building 5	16%	5%	79%
Building 6	21%	4%	75%
Building 7	26%	0%	74%
Building 8	18%	5%	77%
Total	18%	4%	78%

6.4. References

Field, A., Discovering Statistics Using SPSS, London: Taylor & Francis, 2003

Lee, J.A., Soutar, G., Is Schwartz's Value Survey an interval scale, and does it really matter? Journal of Cross-Cultural Psychology, 2010, no. 41, p. 76-86

Van der Voordt, D.M.M, De Been, I., Werkomgeving: Breinbreker of tevredenheidsgenerator, p. 67-86 in Bakker, I., De Breinwerker, Naarden: Uitgeverij FMN, 2010

Volker, L., Van der Voordt, D.M.M., WODI Evaluatie Toolkit: Hoe presteert uw kantoorhuisvesting?, Delft: Center for People and Building, 2005

Chapter 7

Perception of Light and View Quality

This chapter describes the first results of the main study. It deals with two research questions:

- Which features of a building, office room and workplace influence the perceived daylight and view quality of office workers?
- Which features of an outside view are significant predictors of perceived view quality?

The chapter starts with describing the results of the questions about the workplace, the lighting and the view. In order to explore if there are statistically significant differences in the results obtained from the different buildings or different groups in the main study, two types of parametric statistical tests are performed. An explanation of these tests, the between groups ANOVA and independent sample t-test, can be found in text box 7.1.

After studying the results of the questions separately, the impact of the outside view variables from the questionnaire on the perceived quality of the outside view is explored by hierarchical multiple regression analysis. An explanation of this test can be found in text box 7.2.

The final part of the chapter examines the rating of pictures representing different view types, in order to explore if the preferences of the respondent can be explained by the variables which were found to predict view quality in the literature study and in the hierarchical multiple regression analysis.

Chapter outline

Text box 7.1: Comparison of groups and variables

The two types of statistical tests that are used to compare the data of different groups or categories are the one-way analysis of variance (ANOVA) for three or more independent groups and independent samples t-test for two independent groups.

Between-groups ANOVA

Between-groups ANOVAs are performed to examine whether there are differences in the mean responses obtained from the eight different buildings. Furthermore, ANOVAs are performed to study the differences between the mean results obtained from four different orientations of the workplaces towards the window. A distinction is made between workplaces with the windows behind, in front, right or left of the respondent. Finally, ANOVAs will show if the different orientations of the office rooms in building 8 lead to statistically significantly different results. Office rooms are orientated Northeast, Southeast, Southwest, or Northwest.

The data does not always meet the criteria of ANOVA. If Levene's test is significant, the assumption of homogeneity of variance is violated. This means that the spread of responses is larger in some of the groups than in others. This is the case for all ANOVAs on the variable *building*, so results of these ANOVAs have to be interpreted very carefully.

If a statistically significant difference between the means of different groups is observed, the Contrast option Deviation is selected. This option compares all individual groups against the main results of the entire dataset. In other words, it provides an indication of whether or not a particular group deviates from the mean of all groups with regard to a certain variable. Depending on the number of groups, a Bonferroni correction is performed in order to decrease the chance of finding incorrect statistically significant results (Type 1 error; Field, 2009, p. 565). For example, in case of the eight different buildings eight comparisons are made, and therefore, the alpha level is set on .05/8 = .006.

Independent sample t-tests

Independent sample t-tests are done to compare the mean results of the different seasons in which the questionnaire was filled out. For these analysis the dataset is split into two groups. The first groups consists of the data of buildings 3, 4 and 5, which were surveyed in summer (n=137). The second groups contains the results of buildings 1, 2, 6, 7 and 8, which were surveyed in autumn or winter (n=421).

Furthermore, t-tests will show if respondents who can manually control the access of day- en sunlight and/or who can look outside when the sun shading is closed are on average more satisfied with the possibilities to control the access of day- and sunlight.

If Levene's test is significant, the assumption of homogeneity of variance is violated. In that case, the results from the table labeled "equal variance not assumed" are reported.

Text box 7.2: Hierarchical multiple regression analysis

In paragraph 7.2 the impact of all variables related to the view from the workplace on the perceived view quality is explored by hierarchical multiple regression analysis. The outcome of the analysis shows which items from the questionnaire are significant predictors of perceived view quality.

By multiple regression analysis the outcome of one variable or factor is predicted from several predictor variables.

The general equation of multiple regression analysis is (Field, 2009, p.210):

$$Y_i = b_0+b_1X_1+ b_2X_2 + \ldots + b_nX_n + \varepsilon_i \qquad (7.1)$$

where Y_i is the outcome variable, b_1 is the regression coefficient of the first predictor (X_1), b_2 is the coefficient of the second predictor (X_2), and b_n is the coefficient of the n^{th} predictor (X_n). The residual term ε_n represents the difference between the predicted and the observed value of Y for the i^{th} participant.

By choosing hierarchical multiple regression analysis the impact of the independent variables is explored after correction for the impact of the intervening or socio-demographic variables. A "forward", a "backward" and an "enter" selection procedure are performed in order to search for the most reliable combination of statistically significant predictors. In the final model only the statistically significant predictors are included in order to obtain a parsimonious model.

7.1. Satisfaction with the Workplace, Lighting and View

This paragraph studies how satisfied the respondents are with their workplace, the lighting, and the outside view. First results are discussed about the general satisfaction with the workplace. Subsequently, the paragraph explores how satisfied respondents are with the size of the windows, the lighting, view, and other indoor climatic parameters. It is followed by more detailed analysis of the satisfaction with the light levels and glare perception is. Finally, satisfaction of the respondents with the possibility to manually control the lighting and sun shading is explored.

Background information about the questions and their answering codes can be found in text box 7.3. Variables are listed according to their codes. These codes have a letter and one or two numbers. The letter stands for one of the four parts of the questionnaire and the numbers for the question and, if relevant, the sub question (Appendix B).

Text box 7.3: Questions about satisfaction with the workplace, light, and view

The respondents got questions about how satisfied they are with several aspects of their workplace. Most items are measured on a scale from (1) very satisfied to (5) very dissatisfied. Satisfaction with the size of the window is measured on a scale from (1) far too big to (5) far too small.

The respondents were also asked what the distance is between their workplace and the nearest window by a 3 item question. Furthermore, they were asked how their workplaces are orientated towards the nearest window and in building 8 what the orientation is of their office room by 5 item questions.

Respondents also got questions about the frequency of several kinds of discomfort, like noise, draught, and glare. All these items are measured on a scale from (1) always to (5) never. The same scale is used to measure the frequency that the artificial light is on, and the frequency that respondents can work without artificial lighting.

Furthermore, respondents gave their opinion about the light levels in their offices by answering a three-item question with answers ranging from (1) far too much light to (5) far too little light. By a multiple choice question the respondents had to select for what reasons they open or close the sun shading. Finally, the respondents filled in if they could look outside when the sun shading is closed by a Yes/No question.

Table 7.1:Workplace, light, and view variables part 1

General satisfaction with the workplace		
B13	Satisfaction with the workplace	1 = Very satisfied, to 5 = Very dissatisfied
Workplace position		
B4	Distance between workplace and window	1 = Less than 2 meter, 2 = 2 to 4 meter , 3 = More than 4 meter
B11	Opinion about distance to the window	1 = Preferably closer to the window, 2 = At a good distance, 3 = Preferably further away from the window
B2	Orientation office rooms: building 8	1 = Southeast, 2 = Southwest, 3 = Northwest, 4 = Northeast, 5 = Other
B3	Presence of windows in the office space	1 = Yes, 2 = No
B5	Orientation workplace towards the window	1 = Window behind, 2 = Window in front, 3 = Window right, 4 = Window left, 5 = Other
Satisfaction with the size of the windows		
B10	Opinion about size of the windows	1 = Far too big, to 5 = Far too small
Satisfaction with the light, view, and other indoor climatic parameters		
C1-1	Satisfaction with the lighting	1 = Very satisfied, to 5 = Very dissatisfied
C1-2	Satisfaction with the temperature	Idem
C1-3	Satisfaction with the ventilation	Idem
C1-4	Satisfaction with the amount of privacy	Idem
C1-5	Satisfaction with the amount of daylight	Idem
C1-6	Satisfaction with the outside view	Idem
C2-1	Discomfort by noise	1 = Never, to 5 = Always
C2-2	Discomfort by draught	Idem
C2-3	Discomfort by heat from sunlight	Idem

Table 7.2: Workplace, light, and view variables part 2

Satisfaction with the light levels and glare perception		
C3-1	Discomfort by artificial light shining into the eyes	1 = Always, to 5 = Never
C3-2	Discomfort by artificial light reflecting in the computer screen	Idem
C3-3	Discomfort by daylight shining into the eyes	Idem
C3-4	Discomfort by daylight reflecting in the computer screen	Idem
C4-1	Light level at the desk	1 = Far too much light, to 5 = Far too little light
C4-2	Light level in the entire room	Idem
C4-3	Light level at the computer screen	Idem
C5	Frequency that artificial light is on	1 = Always, to 5 = Never
C6	Possibility to work with only daylight	Idem
Satisfaction with degree of individual /manual control		
C7	Satisfaction with control of (artificial) lighting	1 = Very satisfied, to 5 = Very dissatisfied
C8	Available sunshading	1 = Blinds outside, 2 = Blinds inside, 3 = Foil on the window or tinted glass, 4 = Curtains, 5 = Other, 6 = Not applicable
C9	Manual control of sun shading possible	1 = Yes, 0 = No
C10	Reasons to close the sun shading	1 = To block the heat of solar radiation, 2 = To prevent light shining annoyingly into my eyes, 3 = To prevent annoying reflections on my computer screen, 4 = Because the computer screen will be too dark otherwise, 5 = Because people will no longer be able to look inside, 6 = Other
C11	Reasons to open the sun shading	1 = To increase the access of day- and sunlight, 2 = To look outside, 3 = Other
C12	Keeping the view when sun shading is closed possible	1 = Yes, 0 = No
C13	Satisfaction with control of day- and sunlight penetration	1 = Very satisfied, to 5 = Very dissatisfied

7.1.1. General satisfaction with the workplace

Overall, the respondents in the field study are satisfied with their workplaces (n=558, M=2,3, SD=0,8). A statistically significant difference is found between the data of the different buildings, meaning that respondents in some buildings are significantly more satisfied than respondents of other buildings ($F(7,550)=3.36$, $p<.001$).

Results of buildings 4 and 8 are found to deviate statistically significantly from the results of all buildings together (Table 7.3). Figure 7.1 shows that in building 4 respondents are, on average, less satisfied with their workplaces than the respondents of the other buildings. Building 8 is the building with the highest number of respondents who have filled out the questionnaire. The mean satisfaction with the workplace is slightly less than the mean of all buildings.

Table 7.3: Deviation Contrast Results, satisfaction with workplace

Building	Mean	St.dev.	Deviation from grand mean	Significance
Building 1	2.26	.69	.06	.63
Building 2	2.31	.53	.11	.39
Building 3	1.90	.61	-.30	.03
Building 4	2.52	.99	.32	.000
Building 5	1.95	.62	-.26	.13
Building 6	2.18	.74	-.02	.83
Building 7	2.11	.56	-.10	.43
Building 8	2.39	.90	.19	.000

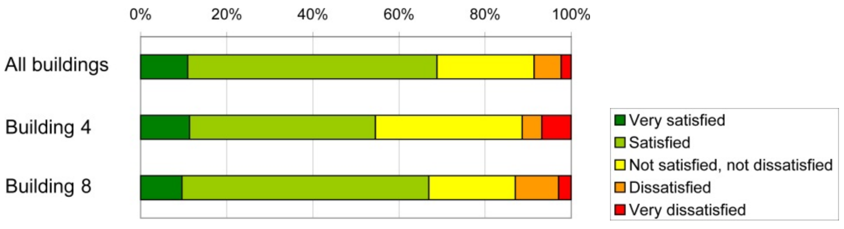


Figure 7.1: Satisfaction with the workplace

7.1.2. Workplace position

All respondents in the main study have a workplace in a room with one or more windows. The respondents were asked what the distance is between their workplace and the nearest window. The results show that 67% of the respondents have a workplace within two meters from the window, 27% between two and four meters, and 6% further than four meters away from the window.

The respondents of buildings 3 to 8 were asked whether or not they are satisfied with the distance to the window (n=485). In total 70% of the respondents indicate to be satisfied with the distance to the window, 15% of the respondents would like to have a workplace closer to the window and 5% a workplace further away from the window. Only 35% of the respondents with a workplace further than two meters from the window would like to have a workplace closer to the window. Apparently, window distance is satisfactory for most respondents, because they have sufficiently access to a window and an outside view. This agrees with the findings from the pilot study (Chapter 5).

Table 7.4 shows the orientation of the workplaces to the nearest window. The number of respondents who can look through the window when they look straight ahead is 30%, and 68% has to turn their head in order to look outside. Only 2% of the respondents does not have an outside view from their workplace.

Table 7.4: Orientation of the workplaces towards the window

Building	Number	Percentage
Window behind	53	9.5%
Window in front	50	9.0%
Window right	174	31.2%
Window left	170	30.5%
Other	111	19.9%

The office rooms in the different buildings have different geographical orientations. The sample of building 8 is large enough to study if the different orientations of the office rooms have an effect on the questionnaire results. Offices are orientated Northeast, Northwest, Southwest and Southeast (Table 7.5). Some offices are located at a corner of the building and therefore have more than two orientations. Those are shared under the number other.

Table 7.5: Orientation of the office rooms in building 8

Building	Number	Percentage
Southeast	62	25.9%
Southwest	68	28.5%
Northwest	46	19.2%
Northeast	52	21.8%
Other	11	4.6%

7.1.3. Satisfaction with the size of the windows

A total of 77% of the respondents in the main study are satisfied with the size of the windows in their offices. Satisfaction with the size of the windows turns out to differ statistically significantly between the respondents of the eight different buildings ($F(7,550) = 9.42$, $p < .001$). More specific analysis shows that the results of buildings 1, 4 and 8 differ statistically significantly from the result of all buildings (Table 7.6).

Table 7.6: Deviation Contrast Results, satisfaction with size of windows

Building	Mean	St.dev.	Deviation from grand mean	Significance
Building 1	3.53	.60	.43	.000
Building 2	2.97	.45	-.12	.16
Building 3	3.17	.53	-.07	.43
Building 4	2.91	.75	-.19	.000
Building 5	2.89	.46	-.20	.08
Building 6	2.93	.35	-.16	.01
Building 7	3.08	.27	-.02	.86
Building 8	3.28	.56	.18	.000

The graph in figure 7.2 shows that in building 1 more respondents find the size of the windows too small. It is the building with the smallest windows in this study; the size is about 25% of the façade between floor and ceiling. In the other buildings the window size is 30% or more, so the results seem to agree with the findings from the literature that a window area of 30% is preferred (Chapter 2). However, in building 8 there are also slightly more respondents who find the size of the windows too small, while the window area is about 45% of the façade. The reason for this outcome probably is the low light transmittance coefficient of the window pane. The window has a coating which partly blocks the sunlight. Due to this coating, the window has somewhat greyish color and less light is entering the space. Perhaps some respondents would like bigger windows so more daylight would enter the spaces, as a kind of compensation for the low transmittance glazing.

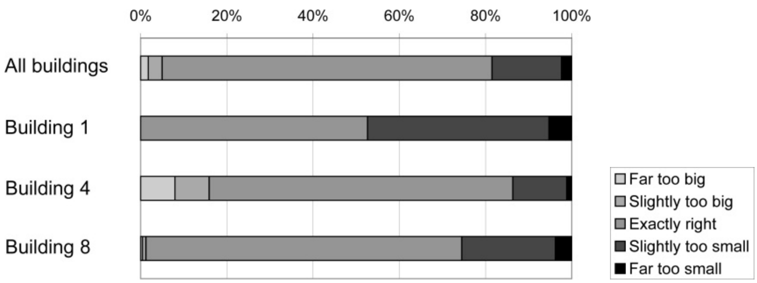


Figure 7.2: Satisfaction with the size of the windows

In building 4 there are somewhat more respondents who think the size of the windows is too big. Most floors in building 4 are very high, with very tall windows. Furthermore, most windows consist of single glazing, which might lead to thermal discomfort. This could be the reason that somewhat more respondents find the windows too big, although most respondents are satisfied with the window size. Overall, the results show that window sizes of more than 30% of the wall between floor and ceiling are preferred.

7.1.4. Satisfaction with the lighting, view, and other indoor climatic variables

Similar to the results of the pilot study, respondents in the main study generally are more satisfied with the lighting and view from their workplaces, than with the temperature and the ventilation (Figure 7.3). In the main study there are fewer respondents who are dissatisfied with the lighting, ventilation and temperature, but more who are dissatisfied with the amount of privacy. The percentages of respondents who are satisfied or unsatisfied with the lighting and amount of privacy are similar to the percentages found by Van der Voordt and De Been (2010) amongst 41 buildings in the Netherlands. Furthermore, the outcome of the item temperature agrees with the outcome of the item indoor climate in Van der Voordt and De Been's study. Concerning these topics, the buildings surveyed in the main study seem to be representative for the Dutch situation.

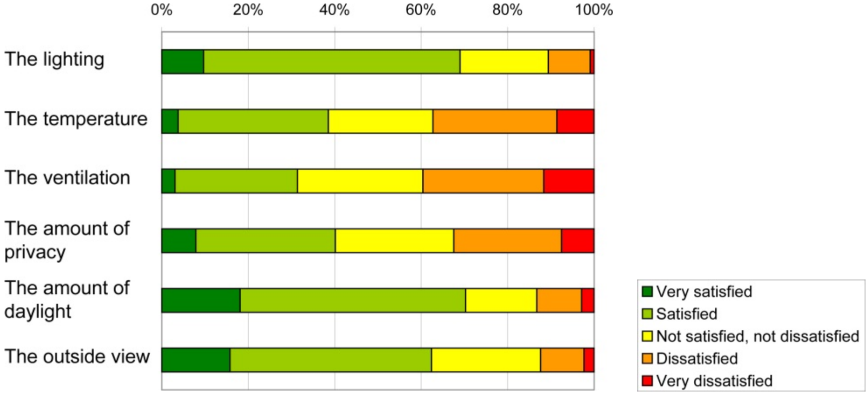


Figure 7.3: Satisfaction with workplace environment

A one-way ANOVA on the item *satisfaction with the lighting* shows that there is a statistically significant difference between the different buildings ($F(7,550)=6.93$, $p<.001$). The respondents of building 1 are found to be significantly less satisfied with the lighting, than the respondents of the other buildings and the respondents of building 5 are found to be significantly more satisfied with the lighting (Table 7.7, figure 7.4). According to one of the participants from building 1 the lighting is too much dimmed by the daylight sensors, which could be the reasons that on average the respondents of this building are less satisfied. Why respondents in building 5 are slightly more satisfied could have different reasons. In the pilot study satisfaction with the lighting was likely to be related to satisfaction with the lighting control. To what extent the variable represents satisfaction with daylighting and/or artificial lighting is explored in chapter 8.

Table 7.7: Deviation Contrast Results, satisfaction with the lighting

Building	Mean	Std. dev.	Deviation from grand mean	Significance
Building 1	2.66	.97	.39	.000
Building 2	2.11	.63	-.16	.21
Building 3	2.17	.53	-.10	.44
Building 4	2.45	.84	-.18	.03
Building 5	1.79	.63	-.48	.000
Building 6	2.48	.86	-.21	.03
Building 7	2.21	.66	-.06	.62
Building 8	2.30	.82	.03	.68

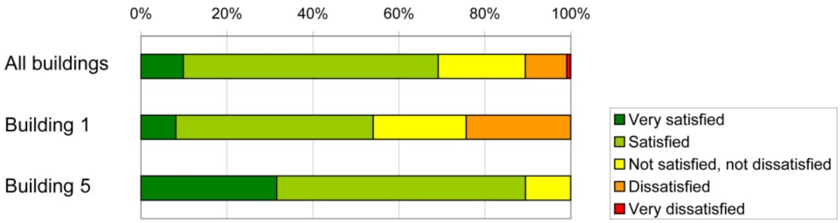


Figure 7.4: Satisfaction with the lighting per building

The procedure is repeated for the four different orientations of the workplaces towards the windows. No statistically significant difference is found between the results from these four orientations (F(3,512)=2.50, p=.06). In order to test if the season in which the questionnaire was answered by the respondents affects the outcome a t-test is performed. Again, no statistically significant difference is found between the results obtained in autumn or winter and results obtained in summer (t(296)=1.13, p=.26). Furthermore, a one-way ANOVA on the data of building 8 does not show a statistically significant difference between the responses obtained from the four different orientations of the workrooms in building 8 (F(3,225)=.84, p=.47).

The statistical tests are repeated for the item *satisfaction with the amount of daylight*. Again a statistically significant difference is found for the different buildings (F(7,550)=6.93, p<.001). Further analysis shows that the mean satisfaction of the respondents of buildings 1, 5, and 8 is statistically significantly different from the mean of all buildings (Table 7.8).

Table 7.8: Deviation Contrast Results, satisfaction with amount of daylight.

Building	Mean	Std. dev.	Deviation from grand mean	Significance
Building 1	2.58	1.00	.47	.000
Building 2	1.97	.62	-.14	.35
Building 3	1.90	.84	-.21	.18
Building 4	2.31	1.03	-.20	.05
Building 5	1.53	.61	-.58	.000
Building 6	1.92	.71	-.19	.08
Building 7	2.18	.80	-.07	.60
Building 8	2.49	1.03	.38	.000

In buildings 1 and 8 respondents are slightly less satisfied and in building 5 respondents are more satisfied with the amount of daylight (Figure 7.5). As discussed in the previous paragraph in buildings 1 and 8 there are also more people who find the size of the windows too small. Moreover, in building 8 a slightly higher percentage of people have a workplace at a larger distance from the window. A total of 34% respondents have a workplace further than 2 meters from the window. This are plausible reasons why respondents in these buildings on average are less satisfied with the amount of daylight at their workplace. The windows in building 5 are big windows and respondents all are within a small distance of the window. This is probably why in this building no respondents are dissatisfied with the amount of daylight.

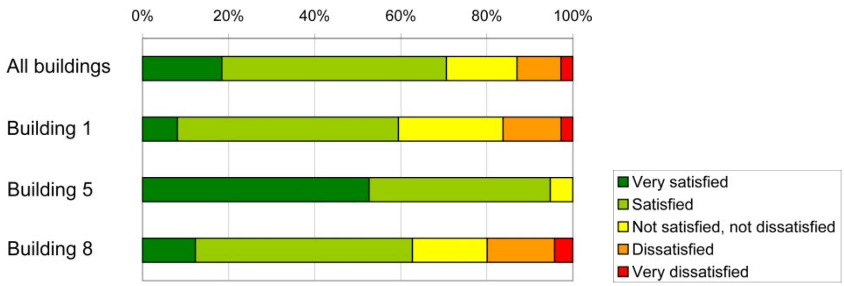


Figure 7.5: Satisfaction with the amount of daylight per building

A statistically significant difference is also found for the different orientation of the workplaces towards the window (F(3,512) =4.36, p<.001). Respondent with a window located right of their workplaces turn out to be significantly less satisfied with the amount of daylight than the respondents who have a workplace with another orientation (Table 7.9, figure 7.6). This could have different reasons. Different companies took part in the research and the position of the workplaces towards the windows was different in the different buildings. Therefore, the different results obtained from the different buildings, due to different window sizes etcetera, could have affected the outcome. Another possibility is that the position of the computer screen was different in these group. If the computer screen faces the window or not, might also have affected the outcome. This could not be explored by the questionnaire results.

Table 7.9: Deviation Contrast Results, satisfaction with amount of daylight.

Building	Mean	Std. deviation	Deviation from grand mean	Significance
Window behind	2.07	.93	-.12	.26
Window in front	1.98	.76	-.20	.04
Window right	2.42	1.00	.23	.000
Window left	2.28	.96	.09	.20

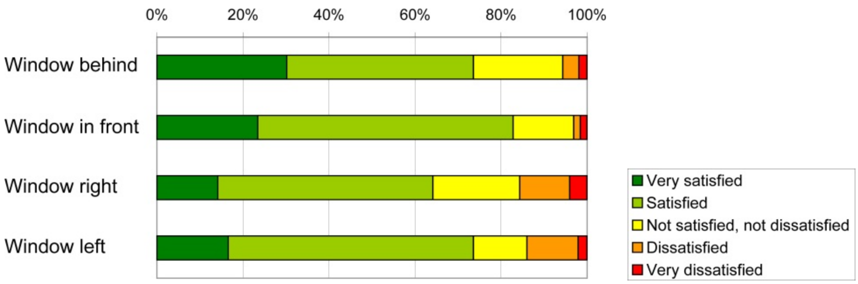


Figure 7.6: Satisfaction with the amount of daylight per workplace orientation

A t-test on the data shows that respondents who filled out the questionnaire in summer are significantly more satisfied with the amount of daylight than the respondents who filled out de questionnaire in autumn or winter ($t(556)=2.35$, $p<.05$, Figure 7.7). In summer daylight levels are higher which could be the reason that respondents who filled out the questionnaire in summer are more satisfied. However, this result should be interpreted very carefully, because in summer buildings with different characteristics were surveyed than in winter and this also might have affected the outcome.

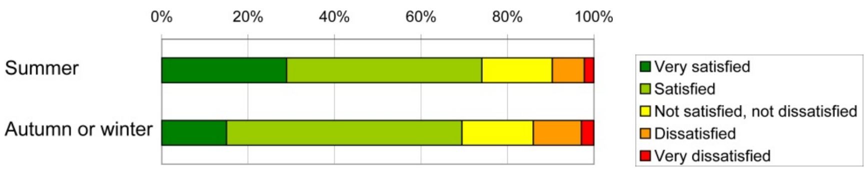


Figure 7.7: Satisfaction with the amount of daylight per season

A one-way ANOVA on the results of building 8 does not show a statistically significant difference between the four different orientations of the office spaces ($F(3,225)=1.29$, $p=.28$).

7.1.5. Satisfaction with light levels and glare perception

The respondents in the field study are generally satisfied with the light levels at their desk, in the entire room, and at their computer screen (Figure 7.8). The results are similar to the results of Ariës' study in ten Dutch office buildings (Ariës, 2005).

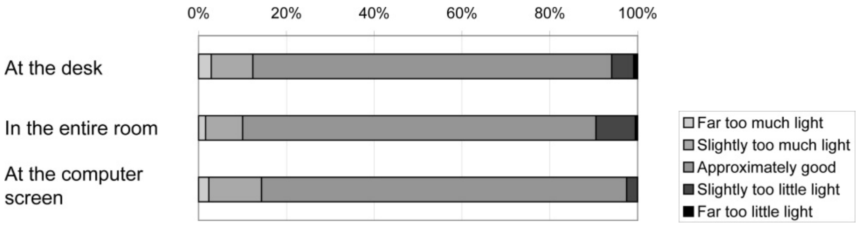


Figure 7.8: Opinion about light levels

Of the 558 respondents, 73% answered that the artificial lighting in their offices is always on, which is more than in the pilot study. Only 21% of the respondents answered that they would never be able to work with daylight only (Figures 7.9 and 7.10). This would mean that in the office buildings the artificial lighting is on more often than necessary. It agrees with the finding of Van den Ham and Haartsen (2006), who examined the possibility to reduce the use of artificial lighting in ten office buildings in the Netherlands. They found that during 12% of the working time the artificial lighting is switched off and that this number could potentially be increased to about 35% of working hours.

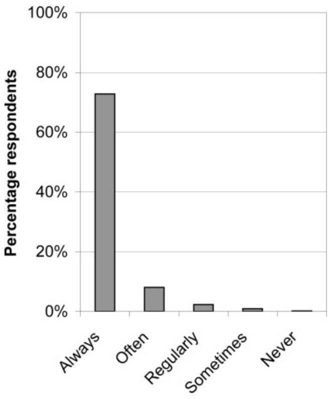


Figure 7.9: Frequency that respondents think the artificial light is on

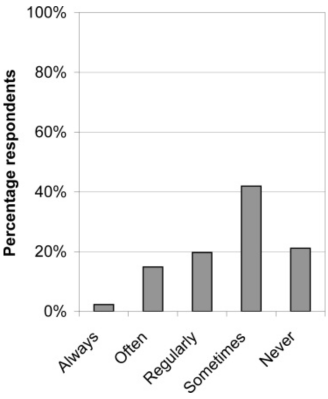


Figure 7.10: Frequency that respondents think they could work without artificial lighting (all building

In the questionnaire a 5-item question asked the respondents about the frequency they experience different types of glare The items *daylight shining into your eyes* and *daylight shining in the computer screen* were not yet included in the questionnaire of building 1 (n=39) and building 2 (n=35). For this reason, the results of these two items are only from buildings 3 to 8 (n=484).

Complaints about glare are mainly caused by daylight. The data is very skewed, but the decision is made to perform some statistical tests on the data. This is done in order to explore if the frequency that daylight causes glare is different for the different orientations of the workplaces towards the window and for the different orientations of the offices in building 8.

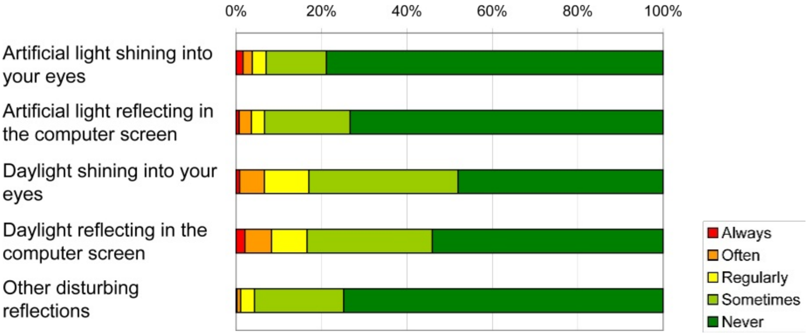


Figure 7.11: Frequency of glare experience

Levene's test is significant in all tests, meaning that the homogeneity of variance is violated. The outcome of the tests however show some trends which confirm findings from the literature study (Chapter 3) and pilot study (Chapter 5).

A one-way ANOVA on the item daylight shining into your eyes shows that there is a statistically significant difference between the different orientations of the workplaces towards the window ($F(3,443)=10.02$, $p<.001$). Further analysis show that respondents who have a window in front of their workplace experience significantly more glare by daylight shining into their eyes and respondents with a window behind them experience significantly less glare (Table 7.10). This result was expected, because when people are facing the window the glare source is within their visual field.

Table 7.10: Deviation Contrast Results, daylight shining into your eyes

Building	Mean	Std. deviation	Deviation from grand mean	Significance
Window behind	4.64	.65	-.41	.000
Window in front	3.72	.95	-.51	.000
Window right	4.29	.81	.06	.35
Window left	4.26	.89	.04	.61

A statistically significant difference is also found for the different orientations of the rooms in building 8 ($F(3,224)=5.33$, $p<.01$). As expected, more glare is experienced in rooms which get more direct sunlight during the day (Table 7.11). Office rooms orientated Southeast appear to give most problems and office rooms orientated Northeast least problems with discomfort by daylight shining into the eyes.

Table 7.11: Deviation Contrast Results, daylight shining into your eyes building 8

Building	Mean	Std. deviation	Deviation from grand mean	Significance
Southeast	4.13	.95	-.27	.002
Southwest	4.32	.85	-.08	.38
Northwest	4.43	.72	.04	.72
Northeast	4.71	.50	.31	.001

Similarly, statistically significant differences are found for the item daylight reflecting in the computer screen. The outcome is different for the different orientations of the workplace towards the window (F(3,443)=15.83, p<.001) and the different orientations of the rooms in building 8 (F(3,224)=8.07, p<.001).

The workplaces with a window behind the respondent are found to give most problems with daylight reflecting in the computer screen (Table 7.12). Furthermore, it is found that office rooms orientated Southeast or Southwest give more problems with daylight reflecting in the computer screen, than rooms orientated Northeast or Northwest (Table 7.13).

Table 7.12: Deviation Contrast Results, daylight reflecting in the computer screen

Building	Mean	Std. deviation	Deviation from grand mean	Significance
Window behind	3.55	1.26	-.69	.000
Window in front	4.68	.65	.44	.000
Window right	4.42	.76	.18	.012
Window left	4.31	.99	.07	.31

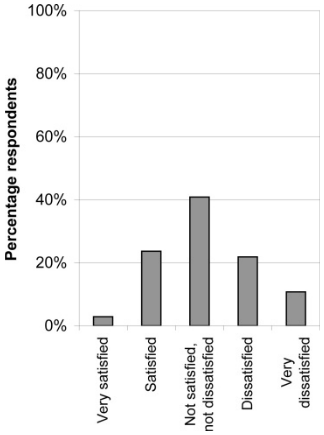
Table 7.13: Deviation Contrast Results, daylight reflecting in the computer screen building 8

Building	Mean	Std. deviation	Deviation from grand mean	Significance
Southeast	4.23	1.00	-.28	.001
Southwest	4.28	.88	-.23	.007
Northwest	4.76	.48	.25	.01
Northeast	4.77	.82	.26	.005

The conclusion is drawn that the chance that office workers will experience glare from daylight is higher in offices which receive higher amounts of direct sunlight. On the other hand, many respondents in south orientated offices do not experience any glare, which might be due to the available sun shading or daylight system which provides them with the opportunity to block the sunlight. Furthermore, the chance that office workers will experience glare is lower when their workplace is orientated perpendicular to the window than when their workplace is orientated parallel to the window.

7.1.6. Satisfaction with the sun shading

Overall, the respondents in the main study are more satisfied with the possibilities to control access of day- and sunlight, than with the possibility to control the lighting (Figures 7.12 and 7.13).



7.12: Satisfaction with possibilities to control the lighting

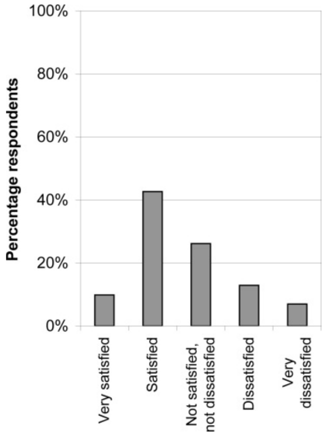


Figure 7.13: Satisfaction with possibilities to control the access of day- and sunlight

All respondents were questioned about which sun shading is available in their offices. A total of 17 respondents (3%) answered that their workroom does not have any sun shading at all. Employees of buildings 3 and 5 to 8, who answered that their office has sun shading were asked if it is possible to control the sun shading. The percentage of respondents who answered ‘yes’ is 86% (n=388).

A t-test is performed to test if the presence of manual control possibilities affects people’s satisfaction with the possibility to control the access of day- and sunlight. Respondents who can manually control the sun shading turn out to be statistically significantly more satisfied than respondents who cannot ($t(386)=6.80$, $p<.001$). This results agree with the finding of Galaciu & Veitch (2006) that automatic shading control systems are more accepted when a degree of manual control is provided.

Respondents of building 1 and 2 whose offices have sun shading and respondents of buildings 3 and 5 to 8 who can manually control the sun shading, subsequently, were asked what their reasons are to close the sun shading by a multiple-choice question (n=399). The results are displayed in table 7.14. The most important reason is that sun shading reduces the experience of discomfort glare. A total of 30% of the respondents (also) closes the sun shading for thermal comfort reasons.

The results confirm the findings of Lindsay and Littlefair (1992) and O’Brien et al. (2012) that shades are generally controlled manually in order to improve the visual conditions, rather than the thermal conditions.

Table 7.14: Ranking of reasons to close the sun shading (n=399)

Reason to close the sun shading	Percentage
1. To prevent light shining annoyingly into my eyes	59%
2. To prevent annoying reflections on my computer screen	45%
3. To block the heat of solar radiation	30%
4. Other	14%
5. Because then people will no longer be able to look inside	4%
6. Because the computer screen will be too dark otherwise	3%

The respondents who answered that they can control the sun shading were also asked about their reasons to open the sun shading (n=334). Those results can be found in table 7.15. The majority of the respondents open the sun shading in order to increase the access of day- and sunlight. About half of the respondents indicate that they (also) open the sun shading in order to look outside. Respondents who answered 'other' had to specify their answer. For both questions the main reason to answer 'other' appeared to be that the sun shading is never closed or opened by the respondent (resp. 20 and 18 respondents). Other reasons to close the sun shading are 'because a colleague asks for it' and 'for prevention of burglary at night'.

Table 7.15: Ranking of reasons to open the sun shading (n=334)

Reason to open the sun shading	Percentage
1. To increase the access of day- and sunlight	76%
2. To look outside	49%
3. Other	10%

Finally, respondents of building 2 who's offices has sun shading, and respondents of buildings 3 and 5 to 8 who can manually control the sun shading, got a question about the possible to keep having an outside view when the sun shading is closed (n=348). Figure 7.14 shows the results of this question. It is remarkable that respondents working in the same building give different answers. Respondents having access to the same type of sun shading, apparently, have a different perception of when it is possible to keep having an outside view when the sun shading is closed.

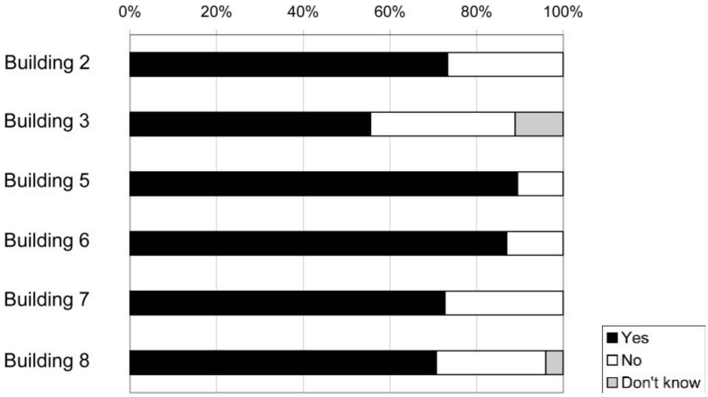


Figure 7.14: Possibility to look outside when the sun shading is closed per building

In order to test if respondents who answered that they cannot look outside when the sun shading is closed are as satisfied with the possibility to control the access of day- and sunlight as respondents who can do this, a t-test is performed on the results. Respondents who cannot look outside turn out to be statistically significantly less satisfied with the possibility to control the access of day- and sunlight ($t(128)=5.69$, $p<.001$).

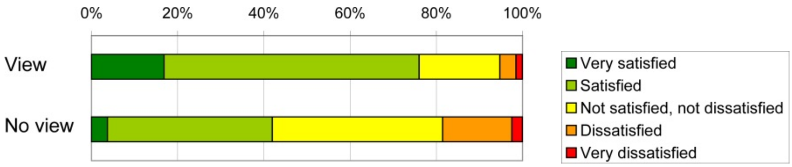


Figure 7.15: Satisfaction with the possibility to control the access of day- and sunlight, a distinction is made between respondents who can look outside when the sun shading is closed and respondents who cannot

The results of this paragraph show that if manually control possibilities are available respondents are more satisfied with the sun shading. Most respondents close the sun shading devices for visual comfort reasons. The second most important reason to close the sun shading is to improve the thermal comfort in their office room. The sun shading is opened mainly in order to increase the access of day- and sunlight. The possibility to look outside is the second most important reason to open the sun shading. Finally, respondents who indicated that they cannot look outside when the sun shading is closed turn out to be statistically significantly less satisfied with the possibility to control the access of day- and sunlight than respondents who can look outside.

7.2. Assessment of the View Quality

This paragraph discusses the answers on several questions about the assessment of the of the outside view from the workplace. The first part is about the rating of view quality. Secondly, the results are discussed of a question about the perception of the view from the workplace. The third part is about season and weather, and the fourth part about view content and obstructions. Finally, the influence of the view variables on the assessment of view quality is explored by hierarchical multiple regression analysis.

Background information about the questions and their answering codes can be found in text box 7.4. Variables are listed according to their codes. These codes have a letter and one or two numbers. The letter stands for one of the four parts of the questionnaire and the numbers for the question and, if relevant, the sub question (Appendix B).

Text box 7.4: Questions about the assessment of view quality

The questionnaire asked the respondents to rate the quality of the view from their workplaces on a 11-point rating scale ranging from (0) very bad view to (10) very good view. By a semantic differential question with six bipolar pairs of adjectives the respondents were asked to rate their perception of the view, e.g. with regard to the diversity.

The respondents of buildings 1 to 7 were also asked if the view in summer is more, equally, or less pleasant than the view in winter (n=298). Respondents of building 8 did not get this question. All respondents in the main study were asked how well they can see what weather it is from their workplaces. The answers range from (1) good to (4) not at all.

A seven item Yes/No question asked the respondents what topics they can see through the window. For the topics that could be seen, the respondents were asked to rate the pleasantness of what they see and what their opinion is about the distance to these topics. The answers of the first question range from (1) very pleasant to (5) very unpleasant and the answers of the second question range from (1) far too close to (5) far too distant. Finally, the results of a question about objects obstructing the view are discussed. For four different items respondents had to answer if they (almost) entirely, somewhat, or not at all were blocking their view through the window.

Table 7.16: View variables

Rating of view quality		
D10	Assessment of view quality	0 = Very bad view to 10 = Very good view
Impression (or perception) of the view from the workplace		
D1-1	Diversity of view	1 = Diverse to 5 = Monotonous
D1-2	Limitation of view	1 = Finite to 5 = Infinite
D1-3	Distraction of view	1 = Distracting to 5 = Not distracting
D1-4	Quietness of view	1 = Quiet to 5 = Busy
D1-5	Openness of view	1 = Open to 5 = Closed
D1-6	Pleasantness of view	1 = Pleasant to 5 = Unpleasant
Season and weather		
D2	View in summer compared to view in winter	1 = More pleasant, 2 = Equally pleasant, 3 = Less pleasant
D3	Possibility to see the weather	1 = Good, to 4 = Not at all
View content and obstruction		
B8, B9	Obstructions of the view	One variable for each obstruction: Plants, Computer screen, Furniture, Blinds, Other 1 = Yes (almost) entirely blocked, 2 = Yes, somewhat blocked, 0 = No
D6-1	Possibility to see the ground	1 = Yes, 0 = No
D6-2	Possibility to see buildings	Idem
D6-3	Possibility to see water	Idem
D6-4	Possibility to see green	Idem
D6-5	Possibility to see people	Idem
D6-6	Possibility to see traffic	Idem
D6-1	Pleasantness to see the ground	1 = Very pleasant, to 5 = Very unpleasant
D6-2	Pleasantness to see buildings	Idem
D6-3	Pleasantness to see water	Idem
D6-4	Pleasantness to see green	Idem
D6-5	Pleasantness to see people	Idem
D6-6	Pleasantness to see traffic	Idem

7.2.1. Rating of view quality

The graph in figure 7.16 displays how respondents in the main study have rated the quality of the outside view from their workplaces (n=558, M=6,3, SD=1,8). The mean rating per building can be found in table 7.17. To examine whether the respondents coming from each building are evenly satisfied with their view the results are subjected to One-way between groups ANOVA. A statistically significant difference between the results of the different buildings is found (F(7,540)=3.3, p< .01). Post-hoc comparisons, using the Contrast option Deviation, show that the mean results of buildings 2 and 8 deviate significantly from the mean of the entire dataset (Table 7.17).

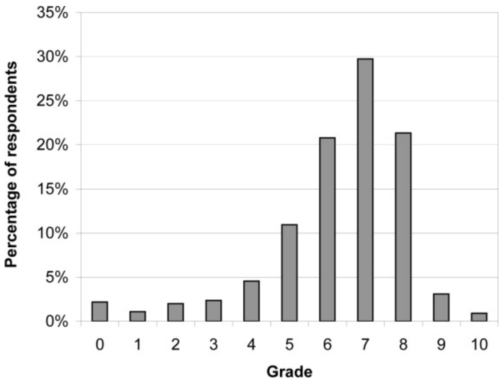


Figure 7.16: Rating of view quality (all building).

Table 7.17: Results per building on rating view quality

Building	Mean	Std. deviation	Deviation from grand mean	Significance
Building 1	6.3	1.7	-.18	.53
Building 2	7.3	1.7	.81	.000
Building 3	6.0	1.5	-.54	.09
Building 4	6.6	1.5	.18	.72
Building 5	6.7	1.0	.07	.62
Building 6	6.3	1.6	-.24	.24
Building 7	6.9	1.4	.35	.21
Building 8	6.0	2.1	-.46	.000

In building 2 the mean rating of the view quality is statistically significantly higher than in the other buildings. In building 2 the view from the northern side of the building is very different from the view from the southern side of the building. Most respondents have a workplace at the northern side of the building, which has the most beautiful view. It is a wide view of a river, green and in the far distance the city center of Rotterdam. The view from the other side shows a parking lot, trees and other buildings. Respondents might appreciated their view from the northern side even more, because the view from the other side has a much lower view quality.

The mean rating of the outside views from building 8 is slightly lower than the mean rating of the outside views from the other buildings. The reason could be that many respondents can see a part of their own office building, although the number of people who have this kind of view cannot be obtained from the results. In chapter 4, viewing buildings at a close distance appeared to have a negative influence on perceived view quality, so people having this kind of view might be dissatisfied. In building 4 also many respondents see a part of their own building, but the façade probably has a higher view quality than the façade of building 8. Building 4 is a historical building with a complex facade and building 8 a modern buildings with a simple facade. Both are well-maintained, so according to findings of Herzog and Gale (1996) the view of building 4 is likely to be more preferred.

Another reason that the mean view quality rating from building 8 is slightly lower could be that the outside views from the different office rooms is very different. From some offices in building 8 the view is very wide, with plenty of natural green, so these views are likely to have a high view quality rating. Maybe the availability of this view type could lead to more dissatisfaction amongst the respondents who do not have a room with a high view quality.

7.2.2. Impression of the view from the workplace

The results of a question on the perception of the view shows that most views are considered to be quiet and not to be distracting. The perceived amount of diversity, limitation, quietness and pleasantness of the views differs. The influence of the items on the assessment of view quality will be examined in paragraph 7.2.5.

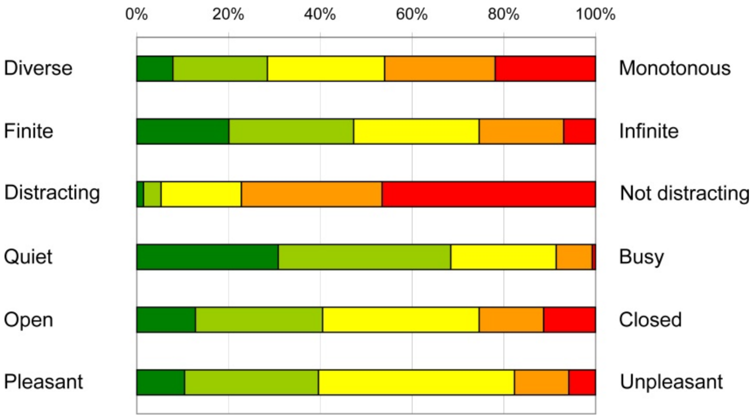


Figure 7.17: Impression of the view

7.2.3. Season and weather

The respondents of buildings 1 to 7 were asked to compare the pleasantness of the view in summer to the view in winter (n=298). A total of 60% of the respondents think that the view in winter is equally pleasant, and 36 % think that the view in summer is more pleasant (Figure 7.18). The result suggests that respondents who were surveyed in summer might have given a higher rating for the view quality, than respondents who were surveyed in autumn or winter. No statistically significant difference was found, however, on the T-test between the assessment of view quality and the season ($t(297)=1.13$, $p=.26$).

The results of the literature study in chapter 4 and the pilot study discussed in chapter 5 show that the possibility to see what weather it is, is an important benefit from windows. Having access to a window and outside view, however, does not necessarily mean that it is possible to see what weather it is, for example because the outside view is very limited. Respondents in the main study are therefore asked how well they can see what weather it is from their workplaces. A total of 81% answered that the visibility of the weather is good and only two respondents answered that they cannot see it at all (Figure 7.19).

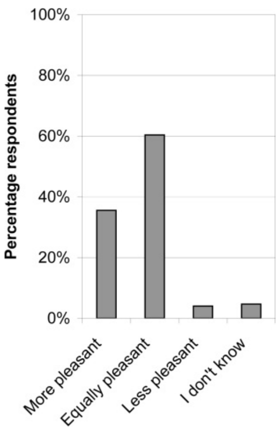


Figure 7.18: View in summer compared to view in winter

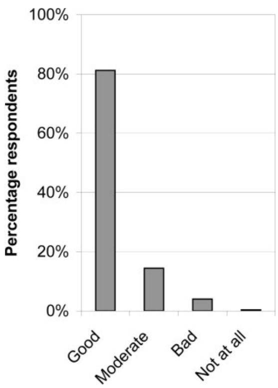


Figure 7.19: Visibility of the weather

7.2.4. View content and obstructions

Most respondents in the main study can see the sky and buildings from their office window and the majority can also see natural elements (Figure 7.20). The ground, people and traffic can be seen by about half of the respondents, and water can be seen by only 14% of the respondents.

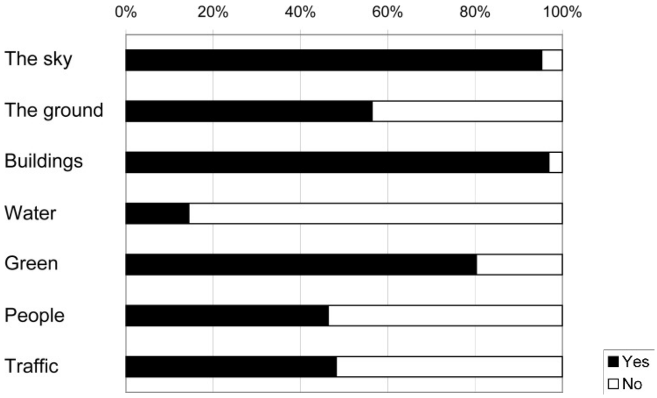


Figure 7.20: Topics which could be seen by the respondents through the window

For the topics that could be seen, the respondents were asked to rate the pleasantness of what they see (Table 7.18, Figure 7.21) and what their opinion is about the distance to these topics (Figure 7.22). The results show that the respondents find most topics in the outside view pleasant to see, and that they are generally satisfied with the distance between their workplaces and the view topics. Overall, seeing green and the sky is found more pleasant than seeing buildings, which is similar to the results of the pilot study (Chapter 5).

The mean pleasantness of seeing water is similar to the mean pleasantness of seeing green and the sky (Table 7.18, Figure 7.21). Many more respondents than in the pilot study find the water in their outside view pleasant or very pleasant to see. The results from the main study confirm the finding from the literature (Chapter 4) that people generally like to see water. Apparently, the still and dirty water seen from the surveyed building in the pilot study was an exception.

Similar results are found for the pleasantness to see traffic as for the pleasantness to see buildings (Table 7.18, Figure 7.21). Both topics are found to be at a too close distance by a part of the respondents. One of the literature findings was that buildings at a close distance from the window are likely to have a negative influence on satisfaction with the outside view. It seems that the same is true for traffic.

Table 7.18: Pleasantness of the topics which could be seen by the respondents, means and standard deviations

Topic	Mean	Std. deviation	Number (n)
The sky	1.7	0.67	522
Green	1.7	0.65	440
Water	1.8	0.72	79
People	2.1	0.71	254
The ground	2.2	0.73	309
Traffic	2.6	0.79	264
Buildings	2.6	0.77	530

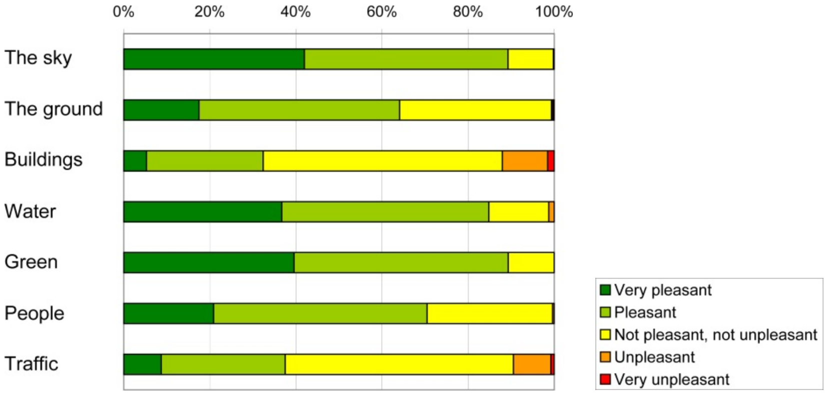


Figure 7.21: Pleasantness of the topics that could be seen by the respondents

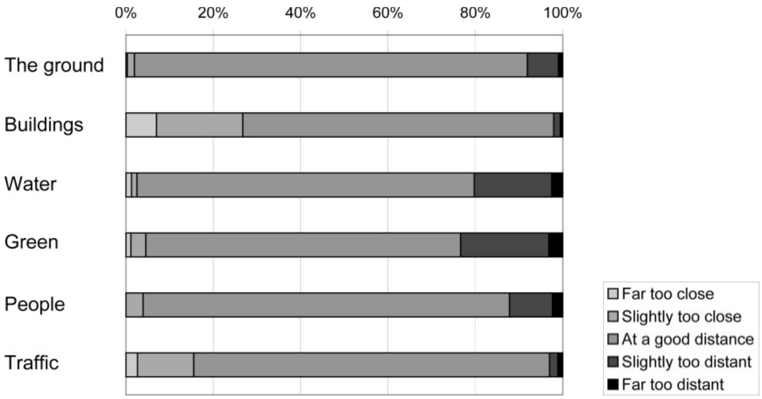


Figure 7.22: Opinion about distance to the topics that can be seen by the respondents

Figure 7.23 shows what obstructions are blocking the view through the windows. The sun shading is the main cause that views are obstructed and the computer screen is the second most cause.

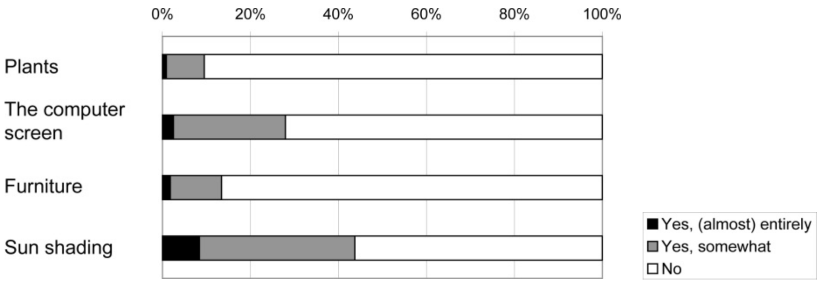


Figure 7.23: Perceived obstructions

7.2.5. The influence of the view variables on the assessment of view quality

The influence of all view variables from the survey research on the perceived view quality is explored by a hierarchical multiple regression analysis. Information about the variables which are entered in the multiple regression analysis can be found in text box 7.5.

Text box 7.5: Variables entered in the multiple regression analysis

Table 7.19 shows which variables are entered in the multiple regression analysis. Dummy variables are made for the variables building, floor and orientation of the workplace towards the window. For each building, floor and orientation of the workplaces a dummy variable is made with answers coded (1) yes or (0) no. Per variable, all dummy variables except one are entered in the multiple regression analysis.

Dichotomous variables are made for satisfaction with the size of the windows and for the distance of the workplace to the window. The respondents who answered that the windows in their workroom are too small or too big are considered to be unsatisfied with the size of the windows and the respondents who thought that the size of the windows is good are considered to be satisfied with the size of the windows. Furthermore, a distinction is made between respondent having a workplace within two meters of the window and respondents having a workplace further than two meters from the window.

The variable assessment of view quality (D10) is entered as dependent variable, building and floor are entered as intervening variables in block 1, and the view variables are entered as independent variables in block 2 of the multiple regression analysis. In this way the impact of the view variables is explored after correction for the impact of intervening variables building and floor.

Table 7.19: Variables for hierarchical multiple regression analysis

Dependent variable		
D10	Assessment of view quality	0 = Very bad view to 10 = Very good view
Intervening variables (Block 1)		
-	Building	One variable -1 for each building 1 = Yes, 0 = No
B 1	Floor	One variable -1 for each floor 1 = Yes, 0 = No
Independent variables (Block 2)		
-	Season	1 = Summer, 0 = Winter
B4	Distance to window	1 = More than 2m, 0 = 0-2m
B5	Orientation workplace to window	One variable -1 for each orientation of the workplace 1 = Yes, 0 = No
B8, B9	Obstructions of view	One variable for each obstruction 1 = Yes, 0 = No
B10	Satisfaction with size of windows	1 = Unsatisfied, 0 = Satisfied
D1-1	Diversity of view	1 = Diverse to 5 = Monotonous
D1-2	Limitation of view	1 = Finite to 5 = Infinite
D1-3	Distraction of view	1 = Distracting to 5 = Not distracting
D1-4	Quietness of view	1 = Quiet to 5 = Busy
D1-5	Openness of view	1 = Open to 5 = Closed
D1-6	Pleasantness of view	1 = Pleasant to 5 = Unpleasant
D3	Possibility to see the weather	1 = Good to 4 = Not at all
D4	Possibility to see the sky	1 = Yes, 0 = No
D6-1	Possibility to see the ground	Idem
D6-2	Possibility to see buildings	Idem
D6-3	Possibility to see water	Idem
D6-4	Possibility to see green	Idem
D6-5	Possibility to see people	Idem
D6-6	Possibility to see traffic	Idem

A “forward”, a “backward” and an “enter” selection procedure are performed in order to search for the most reliable combination of statistically significant predictors. In the final model only the statistically significant predictors are included in order to obtain a parsimonious model.

The final model is displayed in table 7.20. The higher the outcome of the regression function, the higher the view quality. The outcome ranges from (0) very bad view to (10) very good view. This means that variables with a positive b-value have a ‘positive’ effect on view quality and vice versa, meaning that the higher the scale score of that variable, the higher the view quality. The range of the scores per variable can be found in table 7.19. The variables *building* and *floor* are not included in the model, because they are not statistically significant.

Table 7.20: Results of multiple regression analysis on view quality[1]

		Unstandardized Coefficients			
		b	Std. Error	t	Sig.
	(Constant)	8.06	.40	20.41	.000
B5-1	Orientation workplace to window - window behind respondent	-.38	.17	-2.24	.03
D1-1	Diversity of view	-.25	.06	-4.15	.000
D1-2	Limitation of view	.16	.06	2.84	.000
D1-5	Openness of view	-.13	.07	-2.03	.04
D1-6	Pleasantness of view	-.47	.08	-6.00	.000
D3	Possibility to see the weather	-.49	.10	-4.67	.000
D6-4	Possibility to see green	.92	.15	6.19	.000
D6-6	Possibility to see traffic	.50	.11	4.52	.000

1. n=548, r=.77, r^2=.59

The variable with the highest effect on view quality is the *possibility to see green* (t=6.19). The view quality increases with 0.92 if green is visible from the window. It is followed by *pleasantness of the view* (t=-6.00), *possibility to see the weather* (t=-4.67), and *possibility to see traffic* (t=4.52). The effect of the possibility to see weather should not be misinterpreted. It is a variable on a 4-point scale, and the lower the outcome, the better the weather can be seen. The b-value for this variable is negative, which, in this case, means that the worse the weather can be seen, the lower the rating of view quality. This result agrees with the finding from the pilot study that one of the most important functions of a view is the possibility to see what weather is (Chapter 5).

Orientation of the workplace to the window is also found to effect view quality. Respondents having a workplace with the window(s) located behind them give a lower view quality rating, than respondents who have a workplace in front of them, or at the left or right side. Those respondents have to turn around to look through the window, so they have less access to an outside view.

The other three variables influencing view quality are *diversity, limitation,* and *openness of the view*. The more diverse and open and the less limited the view is, the higher the view quality rating.

Variables for which no significant effect was found are *distance between the workplace and the nearest window, obstructions of the view, satisfaction with the size of the windows, distraction,* and *quietness.* In this study it seems to be rather the view content, than the size of the view which affects the view quality rating. The reason could be that all respondents have sufficiently access to an outside view.

The *possibility to see the sky, ground, buildings, water* and *people* are also not found to affect the assessment of view quality. It is remarkable that being able to see traffic has a positive effect on the assessment of view quality, while the other items related to the content of the outside view do not have a statistically significant effect. In the previous paragraph traffic appeared to be one of the least pleasant topics that respondents could see from their workplace. The outcome of the regression analysis is probably the result of a particular combination of predictors by which a certain part of the variance in the view quality could be predicted by the possibility to see traffic after the influence of the other predictors was accounted for. The reason that the possibility to see the sky, buildings and water are not found to be statistically significant predictors of view quality is probably because almost all respondents answered that they are able to see the sky and buildings and very few could see water.

7.3. Rating of Pictures Representing Different View Types

In each building the survey ended with a picture question in order to explore what the view preference are of the respondents. After the pilot study the question was changed, in order to obtain new information about view preferences from the main study. After examining the results of buildings 1 and 2 the decision was made to change the question again for buildings 3 to 8.

7.3.1. Buildings 1 and 2

The questionnaire of buildings 1 and 2 contained a question with twelve pictures which represent twelve different outside views (Figure 2.24). The respondents were asked to order these pictures from (1) most pleasant to (12) least pleasant. When the outcome per respondent was examined, the number of pictures in the final question appeared to be too high. Several respondents answered the question by giving the pictures the same rank order as the order in which they were displayed to them. Picture 1 got rank order 1, picture 2 got rank order 2 and so on. This might indicate that, after filling out a long questionnaire about the workplace, answering the picture question is too complicated and takes too much time. This was confirmed by the remarks of two respondents. One respondent wrote that it took too long to answer this question, and someone else made the comment that there were too many pictures.

It was decided to change the picture question, before the questionnaire was distributed to buildings 3 to 8. No further analysis is performed on the picture question of buildings 1 and 2.

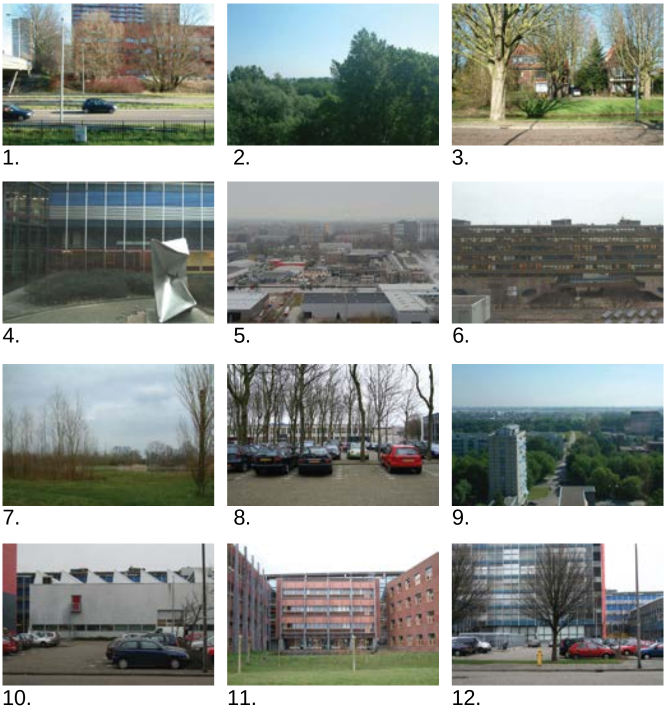


Figure 7.24: Picture question in questionnaires of building 1 and 2

7.3.2. Buildings 3 to 8

The questionnaire of buildings 3 to 8 showed the respondents six pictures and asked them how much they would like them to be the outside view from their workplace, by giving them a rating between (0) very bad view to 10 (very good view). In each building a different set of six pictures was assessed by the respondents. The total number of pictures used for this question is twenty-three. Figure 7.26 displays the rank order of the picture with the mean rating rounded off to a whole number. In appendix C more information can be found about the number of respondents that rated the pictures and the outcome.

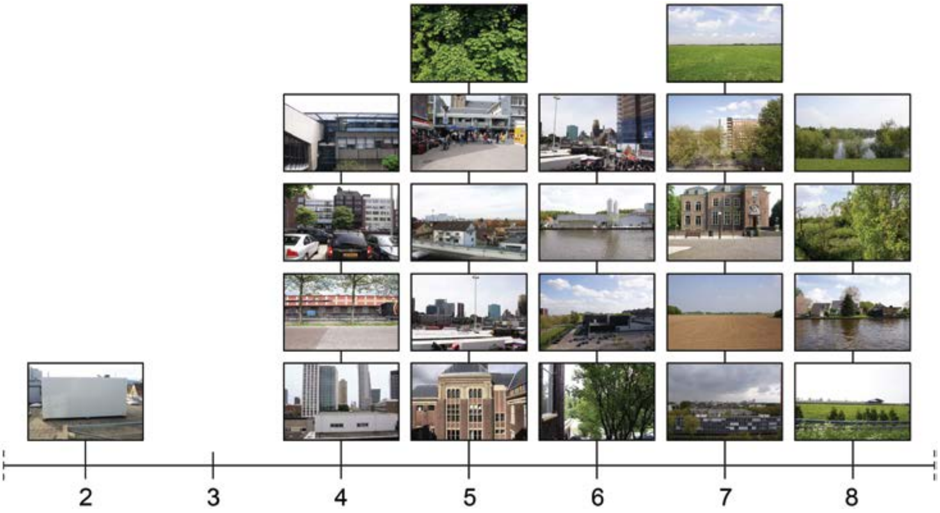


Figure 7.26: Ranking of the pictures from most pleasant to least pleasant

The results again show that natural green is an important element that affects the rating of view quality. Views which are dominated by nature generally get a higher rating than views with little or no natural green. Two pictures contain natural green which is limiting the view, because the natural green is at a close distance of the window and blocking the view of the sky and/or distant objects. These views got a relative low rating, which agrees with the conclusion of Meerdink et al. (1988) that views totally filled by vegetation are not appreciated.

Overall, pictures containing three layers, i.e. the sky, distant city or landscape, and the ground, also got higher ratings than pictures which lack one or two of these layers. It confirms the findings from the literature that the most interesting view is a distant view with three horizontal layers (Chapter 4).

Views containing water also get higher ratings that similar views which do not contain any water. This agrees with the literature results in chapter 4 that water increases preference ratings and the finding from paragraph 7.2.4 that the office workers find water pleasant to see.

One view shows nearby cars. This view has a low preference rating. In paragraph 7.2.4. traffic was found to be one of the least pleasant topic that respondents could see from their workplace. It seems that nearby cars have a negative influence on view quality rating.

Views dominated by buildings get different view quality ratings. According to the literature building distance, maintenance, complexity and building age affect preference ratings (Chapter 4).The results of the picture question indicate that building distance might not be directly related to the view preference rating. It are the pictures of older buildings with a brick façade which are preferred over the pictures of younger buildings. According to Herzog and Gale (1996) this is the case when the buildings are well maintained. Complexity could also play a role in the preference rating. Herzog and Shier (2000) found a positive influence of complexity on building preference and this seems to be confirmed by the picture question, although other variables seem to have had a more significant role.

The multiple regression analysis in paragraph 7.2.5. showed that diversity, openness and limitation are predictors of view quality ratings. The results of the picture question indicate that these are not the most dominant variables with respect to the preference rating of the pictures. To what extent the landscape assessment variables mentioned in chapter 2 affect view quality ratings is also not clear. It seems that view quality cannot be predicted by these variables solely, but that it is the combination of these variables that influence view preference ratings.

7.4. Key Findings

7.4.1. Satisfaction with the workplace, lighting, and view

A summary is given of the questionnaire results on satisfaction with several aspects of the workplace, lighting and view.

- Overall the respondents in the field study are satisfied with their workplace. Most workplaces are in the direct neighborhood of a window. The results indicate that if sufficiently access to a window and outside view are available, workplace distances of more than two meter from a window are acceptable.
- The results show that window sizes of more than 30% of the wall between floor and ceiling are preferable, which agrees with the findings from the literature (Chapter 2).
- Similar to the results of the pilot study, respondents in the main study generally are more satisfied with the lighting and view from their workplaces, than with the temperature and the ventilation. The percentages of respondents who are satisfied or unsatisfied seem to be representative for office buildings in the Netherlands (Van der Voordt and De Been, 2010).
- Satisfaction with the amount of daylight is found to depend on the orientation of the workplaces towards the window and on the season. Respondents with a window located right of their workplaces are statistically significantly less satisfied with the amount of daylight than the respondents who have a workplace with another orientation. Furthermore, respondents who filled out the questionnaire in summer are statistically significantly more satisfied with the amount of daylight than the respondents who filled out de questionnaire in autumn or winter. In summer daylight levels are higher which could be the reason that respondents who filled out the questionnaire in summer are more satisfied. However, different results can also be found because in summer buildings with different characteristics were surveyed than in winter.
- The chance that office workers will experience glare from daylight is higher in offices which receive higher amounts of direct sunlight. Furthermore, office workers who have a window in front of their workplace experience significantly more glare by daylight shining into their eyes than office workers who have a window right or left of their workplace. Office workers with a window behind them experience significantly less glare by daylight shining into their eyes.
- Respondents are found to be more satisfied with the sun shading when they can manually control the sun shading. This results agree with the finding of Galaciu & Veitch (2006) that automatic shading control systems are more accepted when a degree of manual control is provided.

- Most respondents close the sun shading devices for visual comfort reasons. The second most important reason to close the sun shading is to improve the thermal comfort in the office rooms. The results confirm the findings of Lindsay and Littlefair (1992) and O'Brien et al. (2012) that shades are generally controlled manually in order to improve the visual conditions, rather than the thermal conditions.
- The sun shading is opened mainly in order to increase the access of day- and sunlight. The possibility to look outside is the second most important reason to open the sun shading.
- Respondents who indicated that they cannot look outside when the sun shading is closed turn out to be statistically significantly less satisfied with the possibility to control the access of day- and sunlight than respondents who can look outside. However, respondents having access to the same type of sun shading do not agree if it is possible to look outside when the sun shading is closed.

The results of this chapter do not show how different variables are related. Because similar results are found for satisfaction with the lighting and satisfaction with the amount of daylight, these variables might be related. The pilot study in Chapter 5, on the other hand, indicates that satisfaction with the lighting might be related to satisfaction with the lighting control. In order to get more insight in the statistical relationship between the different variables, in Chapter 8 the results are subjected to some statistical tests.

7.4.2. Factors that affect the assessment of view quality

The assessment of the views from the workplaces and the rating of pictures that represent different views lead to the following conclusions:

- Most respondents in the main study are satisfied with the outside view from their offices.
- The availability of natural green in the view is found to be the most important variable affecting the rating of view quality, which agrees with previous research (Chapters 4 and 5). The results of the multiple regression analysis show that views which contain natural green, on average get a .92 higher score on a scale from 0 (Very bad view) to 10 (Very good view) than views with no natural green. Pictures of views which are dominated by nature also got a higher preference rating than views with little or no natural green. Views with vegetation which is blocking the view, however, get a lower preference rating than views which do not contain any obstructing objects, which agrees with the findings from the literature (Chapter 4, Meerdink et al., 1988)
- The results of the main study confirm the finding from the literature study that people not only like to see nature, but also to see the sky and water. Buildings and

traffic can be less pleasant to see. The results suggest that this is the case when buildings and traffic are at close distance of the window.

- The multiple regression analysis shows, in contrary to the previous finding, that the *possibility to see traffic* has a positive effect on the view quality rating. As this result was not found univarietly, the outcome is probably the result of a particular combination of predictors by which a certain part of the variance in the view quality could be predicted by the possibility to see traffic after the influence of the other predictors was accounted for.
- Other variables which are found to have a positive effect on the view quality rating are *possibility to see what weather it is,* which was found to be the most important functions of a view in the pilot study (Chapter 5), and the *pleasantness of the view*. Furthermore, the more *diverse* and *open* and the less *limited* the view is, the higher the view quality rating.
- Finally, view quality ratings are higher when the window is located right, left, or in front of the respondent, than when the window is behind the respondents. The accessibility of the outside view apparently also influences the view quality rating.

If view quality has an effect on the perceived light quality is explored in chapter 8. In chapter 9 the influence of light and view quality on workplace quality is examined.

7.5. References

Ariës, M.B.C., Human Lighting Demands: Healthy Lighting in an Office Environment, Eindhoven: Technical University of Eindhoven, Faculty of Architecture, Building and Planning, 2005

Field, A., Discovering Statistics Using SPSS, London: Taylor & Francis, 2003

Galasiu, A.D., Veitch, J.A., Occupant preferences and satisfaction with the luminous environment and control systems in daylit offices: a literature review, Energy and Buildings, Vol. 38, No. 7, 2006, p. 728-742

Herzog, T.R., Gale, T.A., Preference for urban buildings as a function of age and nature context, Environment and Behavior, Vol. 28, No. 1, 1996, p. 44-72

Herzog, T.R., Shier, R.L., Complexity, Age, and Building Preference, Environment and Behavior, vol. 32, No. 4, 2000, p. 557-575

Lindsay, C.T.R., Littlefair, P.J., Occupant use of venetian blinds in offices, (Building Research Establishment, contract PD233/92), BRE Garston Library, Watford, UK, 1992

Meerdink, G., Rozendaal, E.C., Witteveen, C.J.E., Daglicht en uitzicht in kantoorgebouwen, DGMR, ISBP, 1988

O'Brien, W., Kapsis, K., Athienitis, A.K., Manually-operated window shade patterns in office buildings: A critical review, Building and Environment, 2012

Van den Ham, E.R., Haartsen, T.J., Utilization of daylight in offices: Monitoring in a sample of ten buildings, Proceedings 3rd International Building Physics Conference, Montreal, 2006, p. 801-807

Van der Voordt, D.M.M, De Been, I., Werkomgeving: Breinbreker of tevredenheidsgenerator, p. 67-86 in Bakker, I., De Breinwerker, Naarden: Uitgeverij FMN, 2010

Chapter 8

How Light and View Quality are Related

After exploring the results of the different variables from the questionnaire in chapter 7, in this chapter the relationship is studied between the items which are about the visual perception of the workplace.

First, the underlying structure of the variables is explored by principle component analysis (PCA), which is a type of factor analysis (Text box 8.1). The analysis is done on the results of the entire dataset. Based on the results factors are constructed, which are subjected to several statistical tests. In order explore if there are statistically significant differences between the results obtained from the different buildings or different groups, two types of statistical tests are performed: the between groups ANOVA and independent sample t-test (Text box 8.2). Pearson's correlations are calculated to explore the relationships between the factors from the PCA, between individual variables, and between factors and individual variables (Text box 8.2).

The procedure is repeated for the results of building 8. The questionnaire of building 8 contains more variables than the questionnaires of the other buildings. These variables are include in the statistical tests in order to explore if different results will be found.

The research questions are:

- How can the questionnaire variables related to light and view be combined in a factor for light and a factor for view quality?
- How are perceived light and perceived view quality related?

Chapter outline

Text box 8.1: Procedure principle component analysis

In this chapter a number of items that are theoretically assumed to measure visual quality are subjected to PCA in order to develop a scale that measures light and view quality. In fact, the data used for the PCA is not meeting the criteria for PCA because the data is on an ordinal scale. The range from 1 to 5 with an interval of 1 is limited. The distribution of the data, furthermore, is not meeting the criteria for normality. Therefore, the results of the analysis should be interpreted carefully. On the other hand, criteria for the sample size, multicollinearity, homogeneity of variance, and number of residual are met (Field, 2009, p. 627- 685), which adds to the reliability of the outcome.

It is not possible to perform the PCA, without taking into consideration that the data is collected from eight different buildings, with each one occupying a different organization. A different outcome of the PCA might be found for the different buildings, because background variables, which are not studied in this thesis, may play a role in the assessment of the building occupants. The datasets of buildings 1 to 7 are rather small and therefore it is not possible to perform a PCA on the data of each building separately. In order to test if differences will occur between the results of the small samples and the far biggest sample, the decision is made to split the dataset into two parts, i.e. results of building 1 to 7 and results of buildings 8. The two datasets have a similar size and results of the PCAs of both datasets are compared. If the results are similar, the PCA is repeated for the entire dataset.

The expectation is, based on the literature study, that there will be a correlation between daylight and view variables. For this reason an oblique rotation is chosen instead of an orthogonal rotation (Oblimin, instead of Varimax) (Field, 2009, p. 664-670). The scree plot is examined and Kaiser’s criterion calculated in order to determine what number of factors should be selected. To meet Kaiser’s criterion the factor has to have an eigenvalue >1 (Field, 2009, p. 640, 641).

The reliability of the factors is calculated by Chronbach’s alpha. The outcome of the test should be at least .70 (Nunnally, 1978). Only the items with a factor loading of at least .30 are used for the interpretation of the factors.

For further analysis scale scores are calculated per respondent by summing the scores on the individual items included in the factors. For this reason, the raw scores of the items with a negative loading on the factor are reversed. Because the factor loadings of the various variables have about the same size and because the precise factor loadings differ between the different buildings, the choice is made not to weight the items according to their factor loading (DiStefano et al., 2009).

Text box 8.2: Comparison of groups and variables

The data of different groups or categories are compared by one-way analysis of variance (ANOVA) for three or more independent groups and independent samples t-test for two independent groups.

Between-groups ANOVAs are performed to examine whether there are differences in the mean responses obtained from the eight different buildings, and from the different floors. The same procedure is followed as described in Chapter 7.

T-tests are done to compare the mean results of the two office types in building 8 and to compare the results of respondents with a workplace near the atrium and respondents with a workplace near the outside wall.

Furthermore, Pearson's correlations are calculated to explore the relationships between the factors from the PCA, between individual variables, and between factors and individual variables. The results are interpreted according to Field, 2008, p. 173:

- $r = .1$ is a small effect
- $r = .3$ is medium effect
- $r = .5$ is large effect

8.1. Construction of a Factor for Light and a Factor for View Quality

In order to explore if the variables related to the lighting in the offices and the outside view can be combined in one factor for light and one for view quality, all variables that are theoretically assumed to measure visual quality and which answers are on a 5-point Likert-scale are subjected to Principle Component Analysis (PCA).

Not all questionnaire data is on a 5-point Likert-scale. Some of the questionnaire results are summarized in two new variables which are included in the PCA (Text box 8.3). Furthermore, the raw scores of the variable *view quality* are rescaled. In this way all items have the same weight in the PCA.[5]

Text box 8.3: Construction of variables

Two new variables are constructed which are included in the PCA (table 8.1).

Table 8.1: New variables which are constructed for the PCA

New variables composed by three questionnaire variables		
C4	Satisfaction with light level	1 = Satisfied, to 5 = Dissatisfied
D4, D6	Number of visible topics in the view	1 = Seven topics, to 5 = Zero topics

The first variable is called *satisfaction with light level*. It combines the results of three items about respectively light level at the desk, light level in the entire room, and light level at the computer screen. The answers on these questions are coded 0 (satisfied), 1 (slightly too much/little light) or 2 (far too much/little light). The answers are added and then rescaled, in order to let the new variable range from 1 to 5.

The second variable is called *number of visible topics in the view*. In the questionnaire, there are seven items about the content of the view on a dichotomous scale. In the former chapter it was found that the respondents generally like what they see, which suggests that the higher the number of topics in the view, the higher the view quality. Therefore a new variable is constructed by calculating per respondent the number of topics that could be seen. The outcome ranges from 0 to 7, which means that the answers have to be rescaled, in order to let the variables range from 1 to 5.

[5] It won't affect the outcome of the PCA, but later on in the research, when the results of all items included in a factor are added to determine the factor score, they need to be measured on the same scale. If the variables would not be rescaled one variable would have more influence on the factor score than another, because the maximum outcome could be heigher.

The dataset is split into two parts, the results of buildings 3 to 7 and the results of building 8, in order to explore if the same results are found for both datasets. An agreement between the results indicates that the results are reliable. Buildings 1 and 2 are excluded from the analysis, because the questionnaire of these buildings did not contain the variables *discomfort by daylight shining into the eyes* (C3-3) and *discomfort by daylight reflecting in the computer screen* (C3-4).

A three factor solution is found to give the best possible result. Kaisers' criterion indicates a six-factor solution, but then three factors (dataset of buildings 3-7) or four factors (dataset of building 8) would have less than four items with a factor loading of at least .60, which indicates that the particular variable is less reliable. The three factor solution gives similar results for both dataset (Appendix D), for this reason, the analysis is repeated for the two datasets combined. The outcome of this analysis is displayed in the Pattern Matrix in tables 8.2.

Per dataset, the reliability of the factors is calculated by Chronbach's alpha. Different solutions are tried, by adding or removing one or two variables. The best possible solution, with the highest Chronbach's alphas, is given in tables 8.3 and 8.4. Table 8.3 shows which items are included in the factors and table 8.4 the outcome of the reliability analysis. The factors are named VQ (View quality), LQ-1 (Perception light), and LQ-2 (Discomfort by daylight).

The reliability of the factors VQ and LQ-1 is higher than .70 and therefore sufficient (Nunnally, 1978). The reliability of factor LQ-2 is insufficient. The overall Chronbach's alpha level of .68 is slightly too low. In order to explore if differences occur between the different buildings, the Chronbach's alpha level per building is calculated (Table 8.5).

Because two variables included in the factor were missing in the questionnaire of building 1 and 2, these buildings are not included in the analysis. The Chronbach's alphas found for the datasets from buildings 3, 5 and 6 is much lower than .07. The decision is made to exclude this factor from further analysis.

In order to perform further analysis on the factors VQ and LQ-1 the scale scores per respondent are calculated. This is done by summing the scores on the individual items included in the factors VQ and LQ-1. The scores of factor VQ range from (7) high view quality to (35) low view quality and the scores of factor LQ-1 from (5) high light quality to (25) low light quality.

Factor scores are also calculated for the respondents of buildings 1 and 2, because the missing variables in the questionnaire of buildings 1 and 2, were not included in the factors LQ-1 and VQ.

Table 8.2: Pattern Matrix with factor loadings, buildings 3-8

Variables		Component		
		1	2	3
D10	Assessment of view quality	-.86		
D1-6	Pleasantness of view	.84		
D1-5	Openness of view	.83		
D1-1	Diversity of view	.80		
D1-2	Limitation of view	-.76		
C1-6	Satisfaction with view from window	.65	.33	
D4, D6	Number of visible topics in the view	-.59		
D1-3	Distraction of view	.30		
C1-1	Satisfaction with lighting		.74	
B12-3	Uniformity of lighting of office space		.69	
C1-5	Satisfaction with amount of daylight		.67	
B12-2	Lightness of office space		.66	.46
C3-1	Discomfort by artificial light shining into the eyes		-.53	
C3-2	Discomfort by artificial light reflecting in the computer screen		-.47	
C13	Satisfaction with control of day- and sunlight penetration		.44	
C7	Satisfaction with control of (artificial) lighting		.33	
D1-4	Quietness of view			
C3-4	Discomfort by daylight reflecting in the computer screen			.76
C2-3	Discomfort by heat from sunlight			.71
C3-3	Discomfort by daylight shining into the eyes			.68
C4	Satisfaction with light level		.44	-.52

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.
Rotation converged in 9 iterations.

Table 8.3: Visual comfort factors, buildings 3-8

FACTOR VQ – VIEW QUALITY		
C1-6	Satisfaction with view from window	1 = Very satisfied, to 5 = Very dissatisfied
D1-1	Diversity of view	1 = Diverse, to 5 = Monotonous
D1-2	Limitation of view	1 = Infinite, to 5 = Finite
D1-5	Openness of view	1 = Open, to 5 = Closed
D1-6	Pleasantness of view	1 = Pleasant, to 5 = Unpleasant
D10	Assessment of view quality	1 = Good view, to 5 = Bad view
D4, D6	Number of visible topics in the view	1 = Seven topics, to 5 = Zero topics
FACTOR LQ-1 – PERCEPTION LIGHT		
B12-2	Lightness of office space	1 = Light, to 5 = Dark
B12-3	Uniformity of lighting of office space	1 = Evenly lit, to 5 = Unevenly lit
C1-1	Satisfaction with lighting	1 = Very satisfied, to 5 = Very dissatisfied
C1-5	Satisfaction with amount of daylight	Idem
C13	Satisfaction with control of day- and sunlight penetration	Idem
FACTOR LQ-2 – DISCOMFORT BY DAYLIGHT		
C2-3	Discomfort by heat from sunlight	1 = Never, to 5 = Always
C3-3	Discomfort by daylight shining into the eyes	Idem
C3-4	Discomfort by daylight reflecting in the computer screen	Idem
C4	Satisfaction with light level	1 = Satisfied, to 5 = Dissatisfied

Table 8.4: Chronbach's alpha's for visual comfort factors, buildings 3-8

Category	Factor		
	VQ	LQ-1	LQ-2
Building 3 - Building 7	.86	.71	.68
Building 8	.90	.79	.66
All Buildings	.88	.74	.68

Table 8.5: Chronbach's alpha's for visual comfort factors, buildings 3-8

Category	Factor
	LQ-2
Building 3	.46
Building 4	.78
Building 5	.29
Building 6	.51
Building 7	.74
Building 8	.66

8.2. Light and View Quality per Building, Floor and Office Type

After calculating the scale scores per respondent, statistical analysis are performed to explore if statistically significant differences are found between the results of the different buildings or different groups. A one-way ANOVA on the factor LQ-1 shows that there is a statistically significant difference between the outcome of the different buildings ($F(7,542)=6.07$, $p<.001$). The lower the outcome of factor LQ-1, the higher the light quality. In other words, for buildings with a positive Contrast Estimate a lower perceived light quality is found than for the entire dataset and vice versa. The perceived light quality of building 4 turn out to be significantly lower and the perceived light quality of building 5 significantly higher than the mean of all buildings (Table 8.6).

Table 8.6: Deviation Contrast Results, factor LQ-1, entire dataset

Building	Mean	Std. deviation	Deviation from grand mean	Significance
Building 1	12.37	3.44	1.11	.03
Building 2	10.53	2.36	-.72	.18
Building 3	11.30	2.42	.04	.94
Building 4	12.93	3.64	1.67	.000
Building 5	8.53	2.39	-2.73	.000
Building 6	11.01	2.49	-.24	.52
Building 7	11.42	3.00	.16	.74
Building 8	11.96	3.45	.70	.01

In chapter 7, no statistically significant difference was found for the individual items related to the lighting in building 4. It is not clear why a significantly lower outcome was found for the factor LQ-1, but in building 4 respondents were also statistically significantly less satisfied with their workplace in general. The windows are found to be too big by some respondents, although they were not less satisfied with the amount of daylight.

The respondent of building 5 are not only found to be statistically more satisfied with the factor LQ-1, but they were also found to be statistically significantly more satisfied with the lighting in general and with the amount of daylight (Paragraph 7.1). In this building window sizes are big and daylight levels are high. The offices are cellular offices with general lighting which can be controlled per office.

Analysis of the results of the factor LQ-1 did not show a statistically significant difference for the different floors at which the responents have their workplace ($F(6,543)=1.86$, $p=.09$). A t-test shows that, in case of building 8, respondents working in an open-plan office give a slightly less positive assessment of the light quality, than the respondents working in cellular offices ($t(237)=2.18$, $p<.03$). No statistically significant difference is found between respondents in building 8 with a workplace near the atrium and respondents with a workplace near the outside wall ($t(237)=-1.23$, $p=.22$).

An one-way ANOVA on the factor VQ shows that there is also a statistically significant difference between the different buildings with regard to the assessment of view quality ($F(7,535)=4.29$, $p<.001$). The lower the outcome of factor VQ, the higher the view quality, therefore a positive Contrast Estimate means a lower perceived view quality and vice versa.

The perceived view quality of building 8 is statistically significantly lower than the perceived view quality of the other buildings (Table 8.7). In Chapter 7 respondents of building 8 also gave a signficiant lower rating for the view quality. An explanation of the possible reasons is given in paragraph 7.2.1.

Table 8.7: Deviation Contrast Results, factor VQ, entire dataset

Building	Mean	Std. deviation	Deviation from grand mean	Significance
Building 1	17.77	3.24	1.18	.12
Building 2	15.13	4.78	-1.45	.06
Building 3	18.23	4.31	1.65	.05
Building 4	16.06	4.49	-.52	.34
Building 5	14.85	3.13	-1.73	.09
Building 6	15.85	5.44	-.73	.21
Building 7	16.66	3.81	.07	.92
Building 8	18.11	5.46	1.53	.000

A statistically significant difference is also found for the different floors at which the respondents are working ($F(6,536)= 9.14$, $p<.001$). The respondents with a workplace on the 2nd or 4th floor give a significantly lower assessment, and respondents with a workplace on the 6th floor give a significantly higher assessment of the view quality (Table 8.8). The results do not show a trend, for instance that the view from higher floors is more pleasant, because the view from higher floors is wider. The different outcome of floors 2, 4 and 6 might be caused by differences between the views from the different buildings, because the questionnaire was not distributed to the same floors in each building (chapter 6, table 6.2). Moreover, in building 8 the office type was not the same at the different floors. The questionnaire was filled out by office workers at floors 2, 3, 4, and 6. A t-test explores if results of the different office types in building 8 show a statistically significantly different outcome. It turns out that for the cellular offices (floors 3 and 6) a significantly lower value for factor VQ is found than for the open-plan offices (floors 2 and 4), which means that the rating of view quality is more positive ($t(233)=-3.97$, $p<.001$). The reason is not known, but it is likely that this outcome has an effect on the different outcome found for the different floors.

Table 8.8: Deviation Contrast Results, factor VQ, entire dataset

Floor	Mean	Std. deviation	Deviation from grand mean	Significance
Floor 1	15.29	4.47	-.98	.17
Floor 2	17.81	5.08	1.53	.000
Floor 3	17.42	5.13	1.14	.03
Floor 4	18.73	4.38	2.46	.000
Floor 5	16.57	4.85	.29	.69
Floor 6	13.89	4.19	-2.38	.000
Floor 7 and 11	14.20	5.18	-2.07	.03

Respondents in building 8 with a workplace near the atrium turn out to give a significantly lower assessment of the view quality than respondents with a workplace near the outside wall ($t(233)=8.55$, $p<.001$). This agrees with the findings in chapter 7 that the the more open and the less limited the view is, the higher the view quality rating.

The results of this paragraph show that many different features of the different office buildings affect the outcome of the factors LQ-1 and VQ. The reason that a significantly different outcome is found for different buildings and different floors in a building is not always clear. It is hard to explain why different results are found for different floors or for different office types.

8.3. *Additional Analysis of the Results of Building 8*

As explained in chapter 6 the questionnaire of building 8 contains more questions than the questionnaire of the other buildings. Two more questions are asked about satisfaction with the lighting in the office space (Text box 8.4).

Text box 8.4: Extra variables building 8

The questionnaire of building 8 contains two more items, which are included in the principle component analysis. The items show how satisfied the respondents are with the color of the artificial lighting and the daylight, which is measured on a scale from (1) very satisfied to (5) very dissatisfied.

Table 8.9: Added variables from the questionnaire of building 8

Satisfaction with the lighting		
C*	Satisfaction with color of artificial lighting	1 = Satisfied, to 5 = Dissatisfied
C*	Satisfaction with color of daylight	Idem

The Pattern Matrix in tables 8.10 shows that, when these variables are included in the Principle Component Analysis, they load on the second factor. Similar to the results of the entire dataset (minus buildings 1 and 2) the second factor represents perception of the lighting. Besides the two added variables from the questionnaire of building 8, the same variables load on the second factor as in the PCA of the entire dataset (Table 8.2). However, the variable *satisfaction with light level* had a stronger load on the third factor in the results of the entire dataset. The third factor, similarly to the results of the entire dataset, respresents discomfort by daylight. The first factor represents perception with the view and the same variables load on this factor as in the PCA of the entire dataset.

The reliability of the second factor found for building 8 is explored by calculating Chronbach's alpha. Again, different solutions are tried, by adding or removing one or two variables. The best possible solution, with the highest Chronbach's alpha levels is displayed in table 8.11.

Table 8.11 shows that there are five more items included in the factor LQ-8 (Light quality building 8) than in the factor LQ-1. Three variables were also included in the analysis of the entire set, but did not improve the reliability of the factor LQ-1. In the case of building 8, however, these variables, together with the two new variables, cause an increase in the Chronbach's alpha level from .79 (Table 8.4) to .83.

For further analysis, the scale scores per respondent are calculated by summing the scores on the individual items included in factor LQ-8. The answers range from (10) high light quality to (50) low light quality. The factor will be used for further analysis, in order to examine if similar results will be obtained for LQ-8 as for LQ-1, the best possible composition of the light factor found for the entire dataset.

Table 8.10: Pattern Matrix with factor loadings, additional results building 8

Variables		Component		
		1	2	3
D10	Assessment of view quality	-.86		
D1-5	Openness of view	.85		
D1-6	Pleasantness of view	.84		
D1-1	Diversity of view	.80		
D1-2	Limitation of view	-.75		
D4, D6	Number of visible topics in the view	-.67		
C1-6	Satisfaction with view from window	.66	.34	
D1-3	Distraction of view	.33		
C1-1	Satisfaction with lighting		.77	
C1-5	Satisfaction with amount of daylight		.75	
B12-2	Lightness of office space		.69	.37
C*	Satisfaction with color of artificial lighting		.69	
B12-3	Uniformity of lighting of office space		.67	
C*	Satisfaction with color of daylight		.60	
C4	Satisfaction with light level		.60	-.35
C13	Satisfaction with control of day- and sunlight penetration		.55	
C3-1	Discomfort by artificial light shining into the eyes		-.48	
C3-2	Discomfort by artificial light reflecting in the computer screen		-.47	.46
C7	Satisfaction with control of (artificial) lighting		.31	
D1-4	Quietness of view			
C3-4	Discomfort by daylight reflecting in the computer screen			.77
C3-3	Discomfort by daylight shining into the eyes			.70
C2-3	Discomfort by heat from sunlight			.62

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.
Rotation converged in 11 iterations.

Table 8.11: Light factor, additional results building 8

FACTOR LQ-8 – LIGHT QUALITY BUILDING 8		
B12-2	Lightness of office space	1 = Light, to 5 = Dark
B12-3	Uniformity of lighting of office space	1 = Evenly lit, to 5 = Unevenly lit
C1-1	Satisfaction with lighting	1 = Very satisfied, to 5 = Very dissatisfied
C1-5	Satisfaction with amount of daylight	Idem
C3-1	Discomfort by artificial light shining into the eyes	1 = Never, to 5 = Always
C3-2	Discomfort by artificial light reflecting in the computer screen	Idem
C4	Satisfaction with light level	1 = Very satisfied, to 5 = Very dissatisfied
C*	Satisfaction with color of artificial lighting	Idem
C*	Satisfaction with color of daylight	Idem
C13	Satisfaction with control of day- and sunlight penetration	Idem

8.4. Correlation Between Light Quality and View Quality

In this paragraph the correlation between the light and view factors is examined by calculating Pearson's product moment correlations. In the literature was found that the chance that people perceive glare from windows is affected by the quality of the outside view (Chapter 1 and 3; Kim et al., 2011; Tuaycharoen & Tregenza, 2007). Both have an impact on visual comfort and, therefore, the hypothesis is that there will be a significant correlation between the light and view factors.

The correlation between factors LQ-1 and VQ has a moderate strength for the entire dataset (n=535, r=.36, p<.001). When the dataset is split into two, similar results are found for the dataset of buildings 1-7 as for the dataset of building 8 (Table 8.12). The correlation between the factors LQ-8 and VQ, surprisingly, is considerably lower than the correlation between LQ-1 and VQ in building 8 (Table 8.13). In the remainder of this paragraph the cause of this difference is explored.

Table 8.12: Correlations between the light and view factor per data-set

Variable	Data	LQ-1		
		All builidngs	Buildings 1-7	Building 8
VQ	Pearson Correlation	.36	.41	.31
	Significance	.000	.000	.000
	Number	535	300	235

Table 8.13: Correlation between the light factor of building 8 and the view factor

Variable	Data	LQ-8
VQ	Pearson Correlation	.15
	Significance	.02
	Number	234

As explained in paragraph 8.3 the factor LQ-8 is composed by more different items than the factor LQ-1. Some of the items are about the daylighting in the office and other items about the artificial lighting or a combination of both. In order to test if the individual items of the light factors correlate differently with the perceived view quality, correlations between eight individual light variables (Table 8.14) and the factor VQ are calculated for the entire dataset (Table 8.15).

Table 8.14: Light variables

Variable		
B12-2	Lightness of office space	1 = Light, to 5 = Dark
B12-3	Uniformity of lighting of office space	1 = Evenly lit, to 5 = Unevenly lit
C1-1	Satisfaction with lighting	1 = Very satisfied, to 5 = Very dissatisfied
C1-5	Satisfaction with amount of daylight	Idem
C3-1	Discomfort by artificial light shining into the eyes	1 = Always, to 5 = Never
C3-2	Discomfort by artificial light reflecting in the computer screen	Idem
C4	Satisfaction with light level	1 = Satisfied, to 5 = Dissatisfied
C13	Satisfaction with control of day- and sunlight penetration	1 = Very satisfied, to 5 = Very dissatisfied

Table 8.15: Correlations between view factor and light variables

Variable	Pearson Correlation	Significance (2-tailed)	Number
B12-2	.35	.000	543
B12-3	.19	.000	543
C1-1	.13	.002	543
C1-5	.41	.000	543
C3-1	-.02	.59	538
C3-2	-.09	.04	539
C4	-.03	.54	543
C13	.17	.000	535

The factor VQ has a median strong correlation with the items *satisfaction with the amount of daylight* (C1-5) and *lightness of the office space* (B12-2). The correlation between the factor VQ and *uniformity of the lighting* (B12-3), *satisfaction with the lighting* (C1-1), *discomfort by artificial lighting reflecting in the computer screen* (C3-2), and *satisfaction with the control of day- and sunlight penetration* (C13) is much lower. No statistically significant correlation was found between the factor VQ and *discomfort by artificial lighting shining into the eyes* (C3-1), and *satisfaction with the light level* (C4).

The data of the discomfort variables is very skewed, which might have an affect on the outcome. However, the results clearly show that the factor LQ-1 only contains items which are statistically significantly correlated to the factor VQ and the factor LQ-8 contains items which are not statistically significantly correlated to the factor VQ.

The expectation is that overall daylight items have a stronger correlation with the perceived view quality, than the artificial lighting items. For some items it is not clear if the outcome is mainly affected by the daylighting or by the artificial lighting. In order to explore which items are related to the amount of daylighting and which items to the artificial lighting, the correlations between six of the individual light variables is calculated (Table 8.16).

There are only two light variables which are not statistically significantly correlated, i.e. *lightness of the office space* (B12-2) and *satisfaction with light level* (C4). All other items are statistically significantly correlated and the variables with the strongest correlation are *satisfaction with the amount of daylight* (C1-5) and *lightness of the office space* (B12-2). These variables previously appeared to have the strongest correlation with the factor VQ. The variable *satisfaction with the lighting* (C1-1) has a medium strong correlation with all other variables and seems to represent the overall light perception. The results of the PCA shows that this item also has the strongest loading on the light factor (Paragraph 8.1. and 8.3.).

Table 8.16: Correlations between individual light variables

Variable	Data	B12-2	B12-3	C1-1	C1-5	C4	C13
B12-2	Pearson Correlation	1.00	.47	.40	.55	.06	.21
	Significance		.000	.000	.000	.14	.000
	Number	558	558	558	558	558	550
B12-3	Pearson Correlation	.47	1.00	.42	.37	.29	.23
	Significance	.000		.000	.000	.000	.000
	Number	558	558	558	558	558	550
C1-1	Pearson Correlation	.40	.42	1.00	.45	.42	.31
	Significance	.000	.000		.000	.000	.000
	Number	558	558	558	558	558	550
C1-5	Pearson Correlation	.55	.37	.45	1.00	.25	.38
	Significance	.000	.000	.000		.000	.000
	Number	558	558	558	558	558	550
C4	Pearson Correlation	.06	.29	.42	.25	1.00	.19
	Significance	.14	.000	.000	.000		.000
	Number	558	558	558	558	558	550
C13	Pearson Correlation	.21	.23	.31	.38	.19	1.00
	Significance	.000	.000	.000	.000	.000	
	Number	550	550	550	550	550	550

In table 8.17 and figure 8.1 an interpretation is given of the light category in which items fall and of the correlation between the categories. Some items specifically ask about day- or artificial lighting. The categorization of the other variables is deduced from the calculated Pearson's correlations in table 8.16.

The first five items are included in the factor LQ-1 and the factor LQ-8 includes all items from the table. It seems that the weight of the factor LQ-1 is more towards impression of the daylight access, and the weight of the factor LQ-8 towards impression of the artificial lighting.

Table 8.17: Variables related to different light quality topics

Satisfaction with the artificial and daylighting		
C1-1	Satisfaction with lighting	1 = Very satisfied to 5 = Very dissatisfied
Daylight variables		
B12-2	Lightness of office space	1 = Light, to 5 = Dark
C1-5	Satisfaction with amount of daylight	1 = Very satisfied, to 5 = Very dissatisfied
C13	Satisfaction with control of day- and sunlight penetration	Idem
Artificial light variables		
B12-3	Uniformity of lighting of office space	1 = Evenly lit to 5 = Unevenly lit
C4	Satisfaction with light level	1 = Satisfied to 5 = Dissatisfied
Discomfort by artificial lighting		
C3-1	Discomfort by artificial light shining into the eyes	1 = Always to 5 = Never
C3-2	Discomfort by artificial light reflecting in the computer screen	Idem

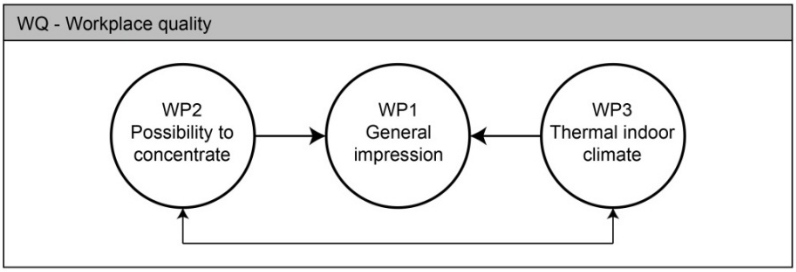


Figure 8.1: Scheme of correlations between light and view variables

8.5. Key Findings

By principle component analysis (PCA) light and view factors are derived from the entire dataset and from the dataset of building 8:

- For the entire dataset, a three factor solution is found to give the best possible result. The first two factors, one which presents perceived view and one which presents perceived light quality, are subjected to several statistical tests.
- The questionnaire of building 8 includes two more questions about perception of the lighting, than the questionnaires of the other buildings. When these variables are included in the principle component analysis, they load on the second factor, i.e. the light factor. The best possible solution is a two factor solution with five more items included in the light factor. This factor is used for further analysis of the results of building 8.

Statistical analysis of the differences between the results obtained from the different buildings or different groups has resulted in the following key findings:

- The perceived light quality of building 4 turns out to be statistically significantly lower than the mean of all buildings. In building 4 respondents were also found to be statistically significantly less satisfied with their workplace in general, although they are not found to be less satisfied with the amount of daylight (Chapter 7).
- The perceived light quality of building 5 is found to be statistically significantly higher than the mean of all buildings. The respondents of building 5 were also statistically significantly more satisfied with the lighting in general and with the amount of daylight (Paragraph 7.1). In this building window sizes are big and daylight levels are high.
- The perceived view quality of building 8 is statistically significantly lower than the perceived view quality of the other buildings, which agrees with the outcome of the rating of view quality in chapter 8. In building 8 respondents who work in a cellular office gave a higher rating for view quality than respondents who work in open-plan offices, which could be one of the reasons that also a statistically significant difference is found for the different floors in the entire dataset.
- Respondents in building 8 with a workplace near the atrium gave a statistically significantly lower assessment of the view quality than respondents with a workplace near the outside wall. This agrees with the findings in chapter 7 that the the more open and the less limited the view is, the higher the view quality rating.

In the literature was found that the chance that people perceive glare from windows is affected by the quality of the outside view (Chapter 1 and 4). Therefore, correlations are calculated between the light and view factors and between the view factors and individual lighting variables. The key findings are:

- The correlation between light and view factor of the entire dataset has a moderate strength for the entire dataset. The correlation between the light factor of building

8 and the view factor is considerably lower. The reason that a stronger correlation is found between the light factor of the entire dataset and the view factor is probably because daylight items are more strongly correlated to view quality then variables which only represent the artificial lighting. It seems that the weight of the light factor of the entire dataset is more towards impression of the daylight access, and the weight of the light factor of building 8 towards impression of the artificial lighting.

If light and view quality have a statistically significant effect on the assessment of workplace quality is explored in chapter 9.

8.6. References

DiStefano, C., Zhy, M., Mîndrilă, D., Understanding and using factor scores: Considerations for the applied researcher, Practical Assessment, Research & Evaluation, Vol. 12, No. 20, 2009

Field, A., Discovering Statistics Using SPSS, London: Taylor & Francis, 2003

Nunnally, J.C., Psychometric theory, 2nd edition, New York: McGraw-Hill, 1978

Kim, J.T., Shin, J.Y., Yun, G.Y., Prediction of discomfort glare from windows: Influence of the subjective evaluation of window views, Indoor and Built Environment, Vol. 21, No. 1, 2011, p. 92-97

Tuaycharoen, N., Tregenza, P.R., View and discomfort glare from windows, Lighting Research and Technology, Vol. 39, No. 2, 2007, p. 185-200

Chapter 9

The Influence of Light and View on Perceived Workplace Quality

In this last chapter about the main study the influence of daylight and view quality on the perceived workplace quality is explored. A factor measuring light quality and a factor measuring view quality are constructed in chapter 8. In this chapter a similar procedure is followed in order to study if factors can be constructed that measure workplace quality.

The underlying structure of the variables from the questionnaire which are related to the workplace, but not to visual comfort, is explored by principle component analysis (PCA text box 9.1). The analysis is done on the results of the entire dataset. Based on the results of the PCA three factors are constructed. Pearson's correlations are calculated to explore the relationships between the factors. Subsequently, one factor is constructed that measures workplace quality. Two types of statistical tests are performed to explore if statistically significant results of this factor differ statistically significantly between the different buildings or groups: the between groups ANOVA and independent sample t-test (Text box 9.2). After constructing a factor for workplace quality, the impact of light and view quality on workplace quality is explored by hierarchical multiple regression analysis (Text box 9.3).

The procedure is repeated for the results of building 8, which contains more variables than the questionnaires of the other buildings. These variables are include in the statistical tests in order to find out if it will lead to different results.

The chapter deals with the following research questions:

- How can the questionnaire variables related to the perception of the workplace, but not related to the visual quality be combined in one factor for workplace quality?
- Does perceived light and view quality influence the perception of workplace quality?

Chapter outline

Text box 9.1: Procedure principle component analysis

To develop a scale that measures workplace quality, a number of items measured on a five-point Likert-scale, that are theoretically assumed to measure work quality, but not visual quality are subjected to PCA. For the same reason as described in chapter 8, text box 8.1, the results should be interpreted very carefully. The dataset is split into two parts, i.e. results of buildings 1-7 and results of building 8. If the results are similar, the PCA is repeated for the entire dataset. The selected rotation method is Varimax rotation (Field, 2009, p. 664-670), because factors are not expected to be related.

The number of factors that is selected for further analysis is based on Kaiser's criterion (eigenvalue > 1, Field, 2009, p. 640, 641). The reliability of the factors is calculated by Chronbach's alpha. The outcome of the test should be at least .70 (Nunnally, 1978). Only the items with a factor loading of at least .30 are used for the interpretation of the factors. Scale scores are calculated per respondent by summing the scores on the individual items included in the factor, following the same procedure as described in chapter 8, textbox 8.1.

Pearson's correlations are calculated to explore the relationship between the factors. Based on an interpretation of the results by the researcher, the decision is made to combine the results of the three factors into one factor which is used for further analysis.

Text box 9.3: Procedure hierarchical multiple regression analysis

The influence of light- and view quality on the assessment of workplace quality is explored by hierarchical multiple regression analysis. The same procedure is followed as described in chapter 7, text box 7.2.

By choosing hierarchical multiple regression analysis the impact of the independent variables is explored after correction for the impact of the intervening or socio-demographic variables. A "forward", a "backward" and an "enter" selection procedure are performed in order to search for the most reliable combination of statistically significant predictors. In the final model only the statistically significant predictors are included in order to obtain a parsimonious model. The outcome of the analysis shows to what extent perceived light and view quality are statistically significant predictors of perceived workplace quality.

9.1. Construction of a Factor for Workplace Quality

9.1.1. Reduction of the number of variables for workplace quality

In order to reduce the number of variables for further analysis all items on a 5-point Likert-scale, which are related to workplace perception, but not to visual comfort, are subjected to PCA (Principle Component Analysis). For both datasets a three factor solution is found based on the Kaiser's criterion (eigenvalue > 1, Appendix E). Because the results are similar, the analysis is repeated for the entire dataset of all buildings. The rotated component matrix in table 9.1 gives the factor loadings above .30. The total variance explained is 63%.

Table 9.1: Rotated Component Matrix with factor loadings, all buildings, 3 factors

Variables		Component		
		1	2	3
B12-6	Pleasantness of office space	.79	.30	
B12-1	Comfort of office space	.76		.31
B12-5	Spaciousness of office space	.75		
B13	Satisfaction with workplace	.62	.40	
C2-1	Discomfort by noise		-.87	
C1-4	Satisfaction with privacy		.79	
B12-4	Quietness of office space	.37	.73	
C1-2	Satisfaction with temperature			.83
C1-3	Satisfaction with ventilation			.75
C2-3	Discomfort by heat from sunlight			-.64
C2-2	Discomfort by draught			-.55

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 5 iterations.

Per dataset, the reliability of the factors is calculated by Chronbach's alpha. Table 9.2 shows which items are included in the factors and table 9.3 the outcome of the reliability analysis. The factors are named WP1 (General impresssion workplace), WP2 (Possibility to concentrate), and WP3 (Thermal indoor climate). The reliability of factors WP1 and WP2 is rather good. The reliability of WP3 is just more than .70 for the entire dataset and therefore considered to be acceptable (Nunnally, 1978).

Table 9.2: Workplace factors, all buildings

FACTOR WP1 - GENERAL IMPRESSION WORKPLACE		
B12-1	Comfort of office space	1 = Comfortable, to 5 = Uncomfortable
B12-5	Spaciousness of office space	1 = Spacious, to 5 = Cramped
B12-6	Pleasantness of office space	1 = Pleasant, to 5 = Unpleasant
B13	Satisfaction with workplace	1 = Very satisfied, to 5 = Very dissatisfied
FACTOR WP2 - POSSIBILITY TO CONCENTRATE		
B12-4	Quietness of office space	1 = Quiet, to 5 = Busy
C1-4	Satisfaction with privacy	1= Very satisfied, to 5= Very dissatisfied
C2-1	Discomfort by noise	1 = Never, to 5 = Always
FACTOR WP3 – THERMAL INDOOR CLIMATE		
C1-2	Satisfaction with temperature	1 = Very satisfied, to 5 = Very dissatisfied
C1-3	Satisfaction with ventilation	Idem
C2-2	Discomfort by draught	1 = Never, to 5 = Always
C2-3	Discomfort by heat from sunlight	Idem

Table 9.3: Chronbach's alpha's for workplace factors

Category	Factor		
	WP1	WP2	WP3
Building 1 - Building 7	.78	.76	.68
Building 8	.84	.82	.75
All Buildings .	.81	.79	.72

The scale scores per respondent are calculated by summing the scores on the individual items included in the factors. The factor WP1 ranges from (4) positive impression of the workplace to (20) negative impression of the workplace. The factor WP2 ranges from (3) high possibility to concentrate to (15) low possibility to concentrate. The factor WP3 ranges from (4) good thermal indoor climate to (20) bad thermal indoor climate.

Pearson's correlations are calculated to explore the relationship between the factors (Table 9.4). A large correlation is found between factors WP1 and WP2 and between WP1 and WP3. A medium correlation is found between factors WP2 and WP3.

Table 9.4: Correlations between factors, all buildings

Variable	Data	WP1	WP2	WP3
WP1	Pearson Correlation	1.00	.54	.45
	Significance		.000	.000
	Number	558	557	554
WP2	Pearson Correlation	.54	1.00	.26
	Significance	.000		.000
	Number	557	557	553
WP3	Pearson Correlation	.45	.26	1.00
	Significance	.000	.000	
	Number	554	553	554

Because correlations between the factors are statistically significant and the results of the PCA show that some items have a substantial loading on more than one factor (Table 9.1), in the next paragraph the possibility will be explored to construct one factor for workplace quality for further analysis.

9.1.2. One factor for workplace quality

In order, to find one factor for workplace quality the PCA is repeated, forcing a one factor solution. Again, the results of the two datasets, i.e. building 1-7 and building 8, are almost the same (Appendix E) and the analysis is repeated for the entire dataset. The Component Matrix shows that all items except one have a factor loading of at least .30 (Table 9.5). The total variance explained has dropped to 39%, but is still acceptable.

Table 9.5: Component Matrix with , all buildings, 1 factor

Variables		Component
		1
B12-6	Pleasantness of office space	.81
B12-1	Comfort of office space	.76
B13	Satisfaction with workplace	.75
B12-4	Quietness of office space	.66
C1-4	Satisfaction with privacy	.65
C1-3	Satisfaction with ventilation	.59
C2-1	Discomfort by noise	-.57
C1-2	Satisfaction with temperature	.56
B12-5	Spaciousness of office space	.54
C2-2	Discomfort by draught	-.49
C2-3	Discomfort by heat from sunlight	

Extraction Method: Principal Component Analysis.

Table 9.6 gives an overview of the variables included in the factor, which will be called WQ (Workplace Quality). The results of the reliability analysis shows that Chronbach's alpha's are .80 or higher (Table 9.7). This means that the reliability of the factor is strong, which makes the factor suitable for further analysis on the relation between visual comfort and workplace quality.

Table 9.6: Workplace factor, all buildings

FACTOR WQ – WORKPLACE QUALITY		
B12-1	Comfort of office space	1 = Comfortable, to 5 = Uncomfortable
B12-4	Quietness of office space	1 = Quiet, to 5 = Busy
B12-5	Spaciousness of office space	1 = Spacious, to 5 = Cramped
B12-6	Pleasantness of office space	1 = Pleasant, to 5 = Unpleasant
B13	Satisfaction with workplace	1 = Very satisfied, to 5 = Very dissatisfied
C1-2	Satisfaction with temperature	Idem
C1-3	Satisfaction with ventilation	Idem
C1-4	Satisfaction with privacy	Idem
C2-1	Discomfort by noise	1 = Never, to 5 = Always
C2-2	Discomfort by draught	Idem

Table 9.7: Chronbach's alpha's for workplace factor

Category	Factor
	WQ
Building 1 - Building 7	.80
Building 8	.87
All Buildings	.84

The scale scores per respondent are calculated by summing the scores on the individual items included in the factor WQ. The factor ranges from (10) high workplace quality to (50) low workplace quality.

9.2. The Influence of Light and View on Perceived Workplace Quality

The influence of the light and view quality on workplace quality is investigated by hierarchical multiple regression analysis. Information about the variables entered in the multiple regression analysis and the procedure can be found in text box 9.4.

Text box 9.4: Variables entered in the multiple regression analysis

The variables which are entered in the multiple regression analysis are displayed in table 9.8. The factor WQ is entered as dependent variable, intervening variables are entered in block 1, and the factors LQ-1 and VQ are entered as independent variables in block 2. In this way the impact of the light and view factor is explored after correction for the impact of the socio-demographic variables.

Table 9.8: Variables for regression analysis, all buildings

Dependent variable		
WQ	Workplace quality	10 = High quality, to 50 = Low quality
Intervening variables (Block 1)		
A1	Age	Continuous
A2	Gender	1 = Male, 0 = Female
A3	Glasses	1 = Yes (always or sometimes), 0 = No
A4	Contact lenses	1 = Yes (always or sometimes), 0 = No
A5	Eye disorder or disease	1 = Yes, 0 = No
-	Building	One variable -1 for each building 1 = Yes, 0 = No
-	Season	1 = Summer, 0 = Winter
B1	Floor	One variable -1 for each floor 1 = Yes, 0 = No
B4	Distance to window	1 = More than 2m, 0 = 0-2m
B5	Orientation workplace to window	One variable -1 for each orientation 1 = Yes, 0 = No
B21	Number of people that share the office space	Continuous
Independent variables (Block 2)		
LQ-1	Perception light	5 = Low quality, to 25 = High quality
VQ	View quality	7 = Low quality, to 35 = High quality

There are two types of intervening variables: personal and environmental parameters (Chapter 5, figure 5.1). The personal variables have a code starting with a A and the environmental parameters have a code starting with a B. Two variables, i.e. building and season, do not have a code, because they are not obtained from the questionnaire results, but are constructed by the researcher

Dummy variables are made for the variables building, floor, and orientation workplace to window. For each building, floor and orientation of the workplaces a dummy variable is made with answers coded (1) yes or (0) no.

Per variable, all dummy variables except one are entered in the multiple regression analysis.

Dichotomous variables are made for the distance of the workplace to the window, season, glasses, and contact lenses. A distinction is made between respondent having a workplace within two meters of the window and respondents having a workplace further than two meters from the window, between the questionnaire results which are obtained during the summer and during the winter and between respondents who always or sometimes and respondent who never wear glasses or contactlensens.

The final model is displayed in Table 9.9. The higher the outcome of the regression function, the lower the workplace quality. The outcome ranges from (10) high quality to (50) low quality. This means that variables with a positive b-value have a 'negative' effect on view quality and vice versa, meaning that the higher the scale score of that variable, the lower the workplace quality. The range of the scores per variable can be found in table 9.8.

Table 9.9: Results of multiple regression analysis, all buildings[1]

		Unstandardized Coefficients			
		b	Std. Error	t	Sig.
	(Constant)	11.45	.88	12.96	.000
A2	Gender	1.64	.49	3.34	.000
-	Building 6	2.38	.70	3.42	.000
-	Building 2	3.55	.99	3.57	.000
B1-5	Floor 6	2.50	.72	3.46	.000
B21	Number of people that share the office space	.16	.02	8.81	.000
LQ-1	Perception light[3]	1.01[3]	.07	14.75	.000

1. n=545, r=.62, r^2=.38

It turns out that the factor LQ-1 has a considerable effect on the outcome of factor WQ. Without the factor LQ-1 in the final model the total variance explained is 14% (r=.37, n=545). When the factor LQ-1 is included the total variance explained increases to 38% (r=.62, n=545). The factor VQ does not have a statistically significant effect on the outcome of factor WQ and is therefore not included in the final model.

Intervening variables with a statistically significant influence on WQ are *gender, building 2, building 6, floor 6, and number of people that share the office space*. Men appear to give significantly lower ratings of workplace quality than woman. No reason is found why the workplace quality of buildings 2 and 6 is significantly lower. In chapter 7 office workers in these buildings were not found to be less satisfied with their workplace. Why floor 6 has a statistically significant effect on WQ is also not known.

In the previous chapter a higher mean view quality was found for floor 6 than for the other floors. In building 8 floors 3 and 6 contain cellular offices and floors 2 and 4 open-plan offices. However, it is not known if this affects the outcome of the factor WQ.

A finding which could be explained is that the higher the number of people working in one room, the lower the assessment of workplace quality. This finding agrees with the result of Ariës study (2010) which shows that the more people are present in an office room, the more discomfort is reported. If the number of people in an office is high, this could make it harder to concentrate. Furthermore, people have less individual control over their work environment.

9.3. Additional Analysis of the Results of Building 8

As explained in chapter 6 the questionnaire of building 8 contains more questions than the questionnaire of the other buildings. Five more questions are asked about satisfaction with the workplace (Text box 9.5).

Text box 9.5: Extra variables building 8

The questionnaire of building 8 contains five more items, which are included in the principle component analysis. The items show how satisfied the respondents are with several aspects of their workplace, which is measured on a scale from (1) very satisfied to (5) very dissatisfied.

Table 9.10: Added variables from the questionnaire of building 8

Workplace variables		
B*	Satisfaction with the possibility to concentrate	1 = Very satisfied, to 5 = Very dissatisfied
B*	Satisfaction with the openness and transparency of the work environment	Idem
B*	Satisfaction with the ambience and appearance of the interior	Idem
B*	Satisfaction with the possibility for communication and social interaction	Idem
C*	Satisfaction with color of the interior	Idem

When these variables are added to the list of variables which are subjected to the two Principle Component Analyses, similar results are found, as for the original dataset (Table 9.11). The results of the three factor solution show that the added variables load significantly on the first or second factor. The variables represent the factors they load on very well. Therefore, the interpretation of the factors is not changed.

Table 9.11: Rotated Component Matrix with factor loadings, building 8, 3 factors

Variables		Component		
		1	2	3
B*	Satisfaction with the ambience and appearance of the interior	.85		
B*	Satisfaction with the openness and transparency of the work environment	.78		
C*	Satisfaction with color of the interior	.76		
B12-5	Spaciousness of office space	.63		
B*	Satisfaction with the possibility for communication and social interaction	.61		
B13	Satisfaction with workplace	.60	.48	
B12-6	Pleasantness of office space	.59	.47	.31
B12-1	Comfort of office space	.57	.41	.36
C2-1	Discomfort by noise		-.87	
B*	Satisfaction with the possibility to concentrate		.84	
B12-4	Quietness of office space		.83	
C1-4	Satisfaction with privacy		.80	
C1-2	Satisfaction with temperature			.85
C1-3	Satisfaction with ventilation			.76
C2-3	Discomfort by heat from sunlight			-.65
C2-2	Discomfort by draught		-.30	-.60

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 5 iterations.

The one factor solution also gives similar results (Table 9.12). With the added variables, Chronbach’s alpha of the factor WQ increases for building 8 from .87 to .90.

Table 9.12: Component Matrix with factor loadings, all buildings, 1 factor

Variables		Component
		1
B12-6	Pleasantness of office space	.81
B12-1	Comfort of office space	.78
B13	Satisfaction with workplace	.78
B*	Satisfaction with the possibility to concentrate	.73
B*	Satisfaction with the openness and transparency of the work environment	.69
D1-4	Satisfaction with privacy	.67
B12-4	Quietness of office space	.66
D1-3	Satisfaction with ventilation	.64
B*	Satisfaction with the ambience and appearance of the interior	.64
B12-5	Spaciousness of office space	.62
B*	Satisfaction with the possibility for communication and social interaction	.54
D2-1	Discomfort by noise	-.53
D1-2	Satisfaction with temperature	.49
C*	Satisfaction with color of the interior	.49
D2-2	Discomfort by draught	-.47
D2-3	Discomfort by heat from sunlight	-.32

Extraction Method: Principal Component Analysis.

The factor with the added variables will be named WQ-8 and be used for further analysis. Scale scores range from (16) high workplace quality to (80) low workplace quality (Table 9.13).

The regression analysis of the former paragraph is repeated for the factors of building 8, in order to explore if a different composition of the factors affects the outcome of the analysis, and to test the influence of few more intervening variables. Information about the variables entered in the multiple regression analysis and the procedure can be found in text box 9.6.

Table 9.13: Workplace factor building 8

FACTOR WQ-8 – WORKPLACE QUALITY		
B12-1	Comfort of office space	1 = Comfortable to 5 = Uncomfortable
B12-4	Quietness of office space	1 = Quiet to 5 = Busy
B12-5	Spaciousness of office space	1 = Spacious to 5 = Cramped
B12-6	Pleasantness of office space	1 = Pleasant to 5 = Unpleasant
B13	Satisfaction with workplace	1 = Very satisfied to 5 = Very dissatisfied
B*	Satisfaction with the possibility to concentrate	1 = Very satisfied to 5 = Very dissatisfied
B*	Satisfaction with the openness and transparency of the work environment	1 = Very satisfied to 5 = Very dissatisfied
B*	Satisfaction with the ambience and appearance of the interior	1 = Very satisfied to 5 = Very dissatisfied
B*	Satisfaction with the possibility for communication and social interaction	1 = Very satisfied to 5 = Very dissatisfied
C1-2	Satisfaction with temperature	1= Very satisfied to 5 = Very dissatisfied
C1-3	Satisfaction with ventilation	1= Very satisfied to 5= Very dissatisfied
C1-4	Satisfaction with privacy	1= Very satisfied to 5= Very dissatisfied
C2-1	Discomfort by noise	1 = Never to 5 = Always
C2-2	Discomfort by draught	1 = Never to 5 = Always
C2-3	Discomfort by heat from sunlight	1 = Never to 5 = Always
C*	Satisfaction with color of the interior	1 = Very satisfied to 5 = Very dissatisfied

Text box 9.6: Variables entered in the multiple regression analysis

The variables which are entered in the multiple regression analysis are displayed in table 9.14. The factor WQ-8 is entered as dependent variable, intervening variables are entered in block 1, and the factors LQ-8 and VQ are entered as independent variables in block 2. In this way the impact of the light and view factor is explored after correction for the impact of the socio-demographic variables.

There are two types of intervening variables: personal and environmental parameters (Chapter 5, figure 5.1). The personal variables have a code starting with a A and the enviornmental parameters have a code starting with a B. Two variables, i.e. building and season, do not have a code, because they are not obtained from the questionnaire results, but are constructed by the researcher

Dummy variables are made for the variables building, floor, orientation workplace to window, and office type in the same way as described the text box 9.4. Dichotomous variables are made for the distance of the workplace to the window, season, and atrium.

A distinction is made between respondent having a workplace within two meters of the window and respondents having a workplace further than two meters from the window, between the questionnaire results which are obtained during the summer and during the winter and between respondents who have a workplace near the atrium and respondents who have a workplace near the outside façade.

Table 9.14: Variables for regression analysis, building 8

Dependent variable		
WQ-8	Workplace quality	16 = High quality, to 80 = Low quality
Intervening variables (Block 1)		
A1	Age	Continuous
A2	Gender	1 = Male, 0 = Female
A3	Glasses	1 = Yes (always or sometimes), 0 = No
A4	Contact lenses	1 = Yes (always or sometimes), 0 = No
A5	Eye disorder or disease	1 = Yes, 0 = No
-	Season	1 = Summer, 0 = Winter
B1	Floor	One variable -1 for each building 1 = Yes, 0 = No
B*	Office type	One variable -1 for each building 1 = Yes, 0 = No
B2	Orientation room	One variable -1 for each building 1 = Yes, 0 = No
B*	Workplace besides atrium	1 = Yes, 0 = No
B4	Distance to window	1 = More than 2m, 0 = 0-2m
B5	Orientation workplace to window	One variable -1 for each orientation 1 = Yes, 0 = No
B21	Number of people that share the office space	Continuous
Independent variables (Block 2)		
LQ-8	Light quality building 8	10 = Low quality, to 50 = High quality
VQ	View quality	7 = Low quality, to 35 = High quality

The final model is displayed in Table 9.15. The higher the outcome of the regression function, the lower the workplace quality. The outcome ranges from (16) high quality to (80) low quality. This means that variables with a positive b-value have a 'negative' effect on view quality and vice versa, meaning that the higher the scale score of that variable, the lower the workplace quality. The range of the scores per variable can be found in table 9.14.

Table 9.15: Results of multiple regression analysis, all buildings[1]

		Unstandardized Coefficients		t	Sig.
		b	Std. Error		
	(Constant)	6.94	3.73	1.86	.06
A1	Age	.14	.05	2.67	.01
B1-5	Floor 6	6.38	1.54	4.15	.000
B*	Workplace besides atrium	-3.77	1.28	-2.96	.000
B21	Number of people that share the office space	.22	.04	5.91	.000
LQ-8	Light quality building 8	.89[3]	.10	8.98	.000
VQ	View quality	.29[3]	.11	2.58	.01

1. n=233, r=.65, r^2=.42

In the model of building 8 both the light and view factor have a statistically significant influence on the outcome of factor WQ, while in the former chapter view quality had no statistically significant effect on the workplace quality.Without the factors LQ-8 and VQ in the final model the total variance explained is 16% (r=.40, n=233). When the factors LQ-8 and VQ are included the total variance explained increases to 42% (r=.65, n=545).

The most likely reason that the factors LQ-8 and VQ are both significant predictors of workplace quality is that the correlation between the factors is much weaker than the correlation between the factors LQ-1 and VQ (Paragraph 8.4). The factor LQ-8 includes more items that are related to the artificial lighting in the workplace than the factor LQ-1, and these items have little or no correlation with view quality. It seems that when the light factor mainly includes daylight variables it has a similar, but stronger effect on the factor WQ as the factor VQ. In that case, the factor VQ does not add any new information. The conclusion can be drawn that it depends on the composition of the light factor if view quality is a statistically significant predictor of workplace quality.

The intervening variables *floor 6* and *number of people that share the office space* again are found to influence the outcome of WQ. In the model of building 8 the intervening variable *gender* does not have a statistically significant effect, but the variable *age* does. The higher the age of the respondents, the lower the perceived workplace quality. Respondents with a workplace near the atrium in building 8 give a more positive assessment of workplace quality, than the respondents with a workplace near the outside wall, while they previously were found to be less satisfied with their view (Chapter 8). Although the factor VQ is found to be a significant predictor of workplace quality, other variables are likely to have a stronger effect.

9.4. Interpretation of the Results

Based on the results of the analysis described in paragraphs 8.4 and 9.3, a scheme is constructed which shows an intepreation of the underlying structure of the questionnaire variables (Figure 9.1).

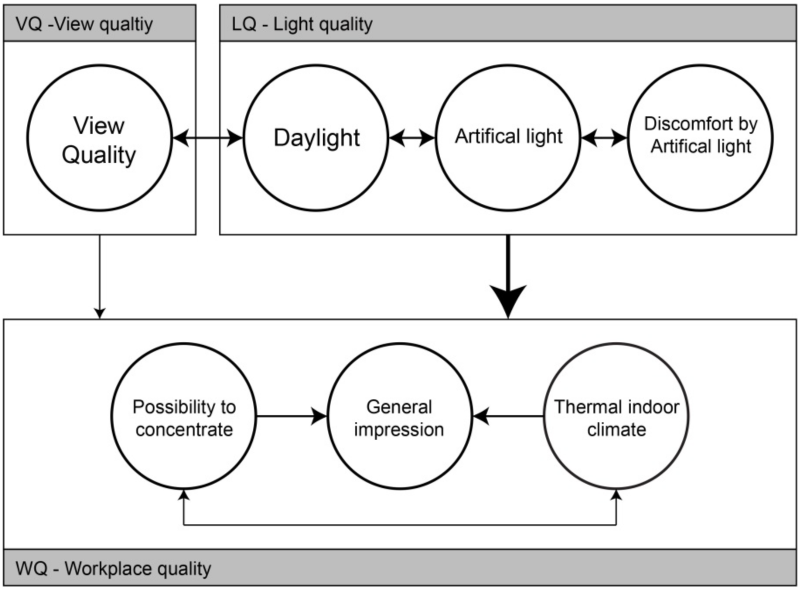


Figure 9.1: Scheme of correlations between light, view and workplace quality

A statistically significant correlation is found between variables related to daylight and artificial lighting. These can be combined in one factor that measures perceived light quality. The outside view variables from the questionnaire can be combined in one factor for view quality. Variables which a related to daylight have a much stronger correlation with outside view variables than the variables which only respresent perception of the artificial lighting.

In the questionnaire three sets of items are found to be related to workplace quality, but not to the visual quality of the workplace: general impression of the workplace, possibility to concentrate, and thermal indoor climate. These items can be combined in one factor that measures perceived workplace quality

The perceived light quality is found to be a statistically significant predictor of the perceived workplace quality. It seems that view quality also has a significant effect on workplace quality, but the correlation between perceived daylight and view variables is that strong that this effect could be measured by the daylight variables solely.

9.5. Key Findings

By principle component analysis three factors are derived from the questionnaire results which are related to workplace quality: general impression of the workplace, possibility to concentrate, and thermal indoor climate. Correlations between the factors are high, therefore, the decision was made to combine the data of the three factors in one factor for workplace quality. This factor is used to study if perceived light and view quality influence the perception of workplace quality. The key findings of the analysis are:

- The multiple regression analysis on the entire dataset shows that perceived light quality has a considerable effect on the perceived workplace quality. The factor which was constructed to represent view quality (Chapter 8), however, does not have a statistically significant effect.
- In the model of building 8, both perceived light quality and perceived view quality have a statistically significant influence on the perceived workplace quality. The most likely reason is that the correlation between the factors is much weaker than the correlation between the factors which are composed for the entire dataset (Paragraph 8.4).

If view quality is a statistically significant predictor of perceived workplace quality seems to depend on the composition of the light factor. It seems that when the light factor mainly includes daylight variables it has a similar, but stronger effect on the perceived workplace quality. In that case, the factor view quality does not add any new information and therefore no statistically significant effect is found.

- Intervening variables with a statistically significant influence on the perceived workplace quality are, amongst others, gender and the number of people that share an office space. Men are found to give a statistically significantly less positive assessment of workplace quality than women. Furthermore, the higher the number of colleagues working in one room, the lower is the assessment of workplace quality. Small rooms, therefore, seem to be more appreciated than big open-offices.
- Respondents with a workplace near the atrium in building 8 give a more positive assessment of workplace quality, than the respondents with a workplace near the outside wall, while they were found to be less satisfied with the view (Chapter 7).

9.6. References

Ariës, M.B.C., Veitch, J.A., Newsham, G.R., Windows, view, and office characteristics predict physical and psychological discomfort, Journal of Environmental Psychology, Vol. 30, No. 4, 2010, p. 533-541

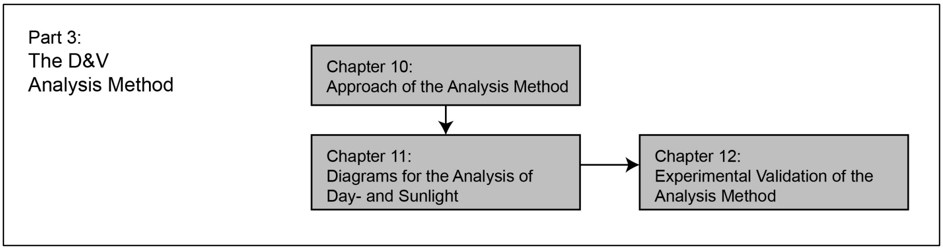
Field, A., Discovering Statistics Using SPSS, London: Taylor & Francis, 2003

Nunnally, J.C., Psychometric theory, 2nd edition, New York: McGraw-Hill, 1978

Part 3

The D&V Analysis Method

The results of parts 1 and 2 are used to develop a new method for the analysis of the daylight and view quality of windows, the D&V analysis method, which is explained and validated in Part 3. It combines several existing methods for the analysis of daylight quality with a new assessment method for view quality. The accuracy and applicability of the method is explored by computer simulations and a scale model research. Part 3 consists of three chapters, chapters 10, 11 and 12.



The research questions of chapter 10 are:

- Which requirements does a new method for the analysis of daylight and view quality have to meet, in order to make it possible to analyse daylight and view quality simultaneously?
- How can the outside view and access of daylight be measured, visualized and assessed in an objective and comprehensible way?

The research questions of chapter 11 are:

- How can existing diagrams for the analysis the access of day- and sunlight be implemented in the new analysis method for daylight and view quality?
- How accurate are dot and sunpath diagrams compared to calculations with daylight simulation software?

The research questions of chapter 12 are:

- To what extent can the dot diagrams of the D&V analysis method be used to predict what the measured and perceived light level will be in an indoor space?
- To what extend can the sunpath diagrams of the D&V analysis method be used to predict when glare problems might occur?
- How accurate is the new assessment method for view quality?

Chapter 10

Approach of the Analysis Method

The final objective of the PhD research is to develop a method which can be used to analyse simultaneously the daylight and view quality of window openings. This method should be a helpful tool for designers to optimize the design of daylight openings, and for researchers to study the influence of light and view on visual comfort. In order to make the method objective, comprehensible and attractive for both designers and researchers, the following research questions are asked:

- Which requirements does a new method for the analysis of daylight and view quality have to meet, in order to make it possible to analyse daylight and view quality simultaneously?
- How can the outside view and access of daylight be measured, visualized and assessed in an objective and comprehensible way?

This research questions have led to the approach of the D&V (Daylight and View) analysis method described in the second paragraph of this chapter.

Following the approach, there are several possibilities to record the outside view through a window. Three different ways are explained and illustrated in chapters 10.2 to 10.4. Subsequently, paragraphs 10.5 and 10.6 explain how light and view quality are assessed with the new analysis method.

Chapter outline

10.1. Projection of the View and the Daylighting

Before the daylight and view quality of a window can be assessed, the outside view and light levels have to be visualized and/or measured in an objective way. One way to visualize the view is by making a projection of the window and what can be seen through the window on a two dimensional surface, for instance a sheet of paper. This projection can be made according to different projections functions, i.e. stereographic projection, equidistant projection, or gnomic projection (Chapter 3 of this thesis; Hopkinson et al., 1966, Chapter 20).

The function that is chosen in this research is the 180 degree equidistant projection, because it is rather simple and it includes the entire human visual field. The projection shows what can be seen from a viewpoint inside a space into a certain viewing direction. This is illustrated in figure 10.1, where point P is the view point from which the projection is made, point F is the position of an object in the view and F' is the projection of F on a vertical plane. The general equation of the equidistant projection is:

$$r_{eq} = C \cdot \sigma \qquad (10.1)$$

where r_{eq} is the distance between viewpoint P and the projection of point F, σ is the angle between the line through P and F and the viewing direction, and C is a constant.

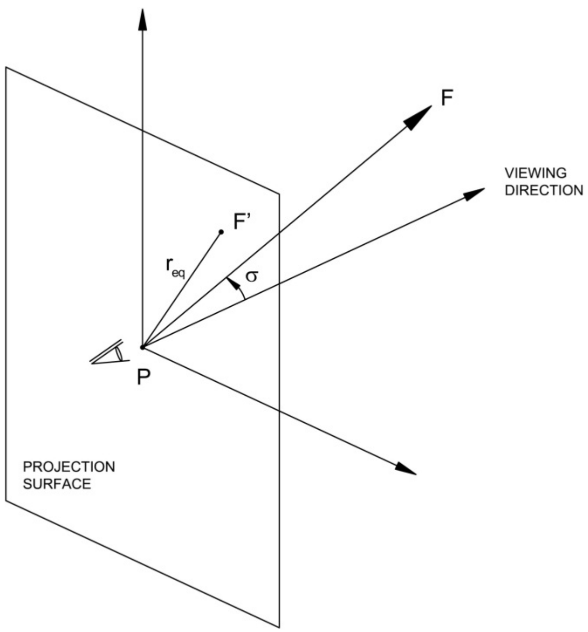


Figure 10.1: Projection of the window and view outwards (C=0,5)

Because the relationship between the angle σ and the distance r_{eq} is linear, it is easy to determine what the position of an object in the outside view should have in the projection and vice versa. The projection can be displayed in a polar diagram with angles σ and τ (Figure 10.2).

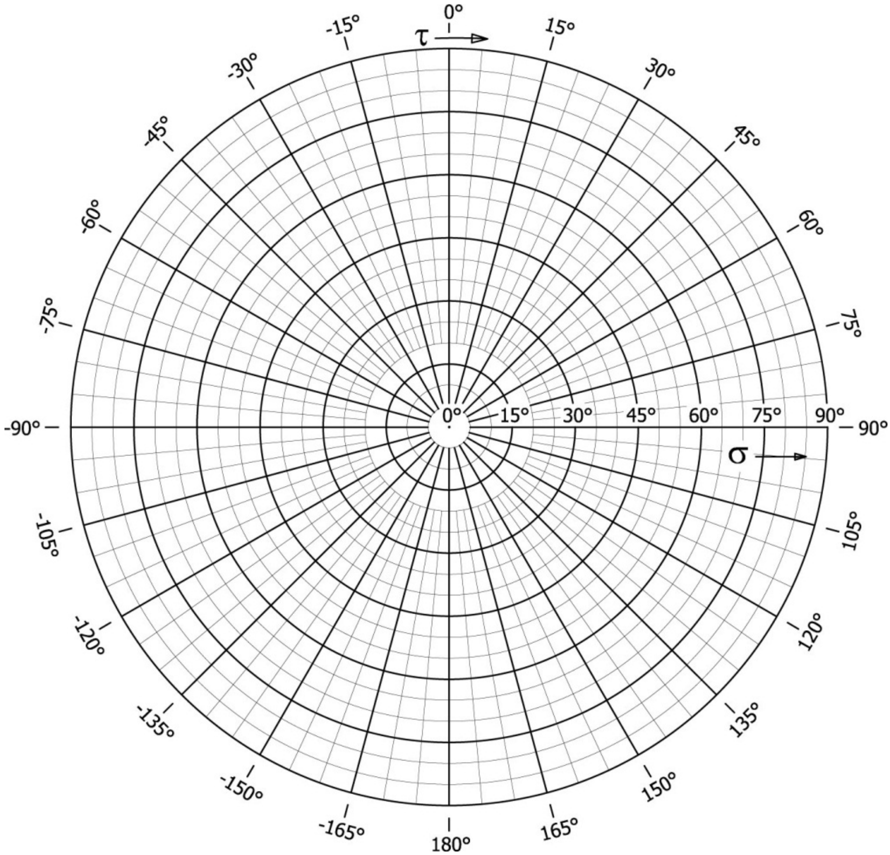


Figure 10.2: Polar diagram of the equidistant projection

The coordinate system in figure 10.3 shows angles σ and τ of an object F in the real world. Again, σ is the angle between the line through P and F and the viewing direction. The angle τ is the angle between the vertical axis and the projection of object F in the vertical plane perpendicular to the viewing direction. Point P is the center of the diagram and the viewing direction starts in point P and is perpendicular to the diagram.

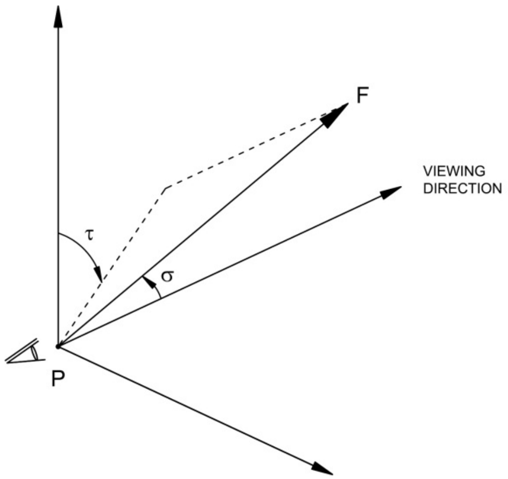


Figure 10.3: Coordinate system with angles σ (sigma) and τ (tau)

There are several ways to make the projection of the windows and view through the windows, which will be explained in the following paragraphs:

1. The hand drawn projection
2. Projection made with a computer model
3. Projection made with a camera with fisheye lens

10.2. The Basic Diagram for the Hand-Drawn Projection

If the projection of the windows and outside view is drawn by hand, first the coordinates of the windows and all objects that are visible through the windows have to be determined. This can be done by calculating the σ and τ angles of all objects in the view and by drawing them in the polar diagram of the equidistant projection (Figure 10.2). By following this approach, however, a lot of angles have to be calculated. In order to make it easier to draw the projection by hand, a second diagram is created with angles β alongside the horizontal axis and γ alongside the vertical axis (Figure 10.4). This diagram will be called basic diagram for the hand-drawn projection.

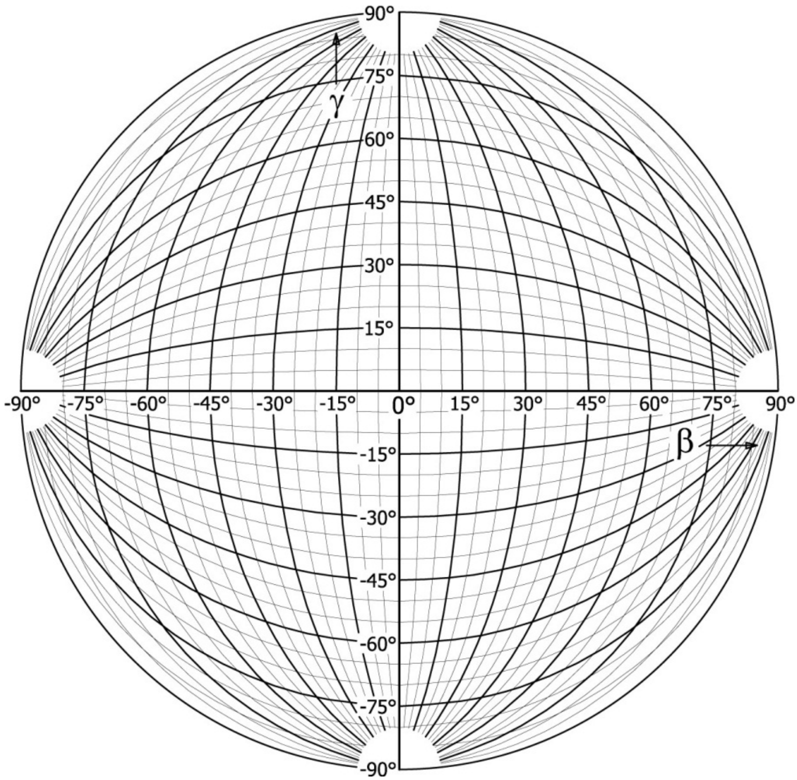


Figure 10.4: Basic diagram for the hand-drawn projection

The coordinate system in figure 10.5 shows how angles β and γ of an object F in the real world are determined. The angle β is the angle between the viewing direction and the projection of the line through P and F in the horizontal plane. The angle γ is the angle between the viewing direction and the projection of the line through P and F in the vertical plane parallel to the viewing direction. After calculating angles β and γ, the objects seen from point P can be drawn in the basic diagram for the hand-drawn projection. If a line in the real world is a straight vertical line, the line will have one value for the angle β and will follow the curve of β in the diagram. If a line in the real world is a straight horizontal line, it will have only one value for angle γ. The line will follow the curve of γ in the diagram.

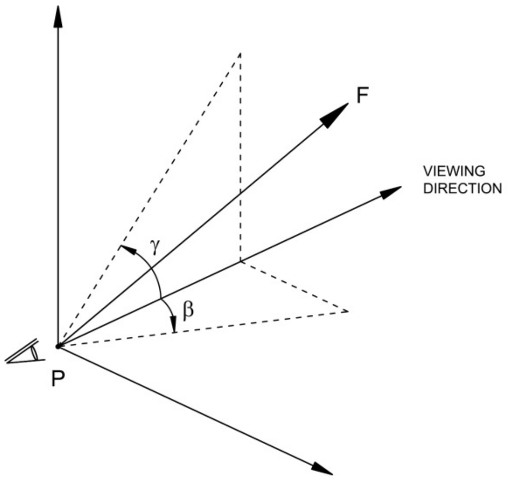


Figure 10.5: Coordinate system with angles β (beta) and γ (gamma)

Text box 10.1: Background information on the construction of the basic diagram for the hand-drawn projection

The basic diagram for the hand-drawn projection is made by connecting coordinates with a constant β or γ. Basically, the diagrams are drawn in the same way as the polar diagram in paragraph 10.1. Therefore, coordinates σ and τ are calculated for a series of points with a constant β or γ value. Firstly, the angles τ are derived from angles β and γ by the equation:

$$\tau = f(\beta,\gamma) = \arctan\left(\frac{\tan\beta}{\tan\gamma}\right) \tag{10.2}$$

Subsequently, the angles σ are derived from β and γ by the equation:

$$\sigma = f(\beta,\tau) = \arctan\left(\frac{\tan\beta}{\tan\tau}\right) \tag{10.3}$$

After calculating angles σ and τ, the basic diagram is drawn according to the equidistant projection function in the former paragraph.

10.2.1. Example of a Hand-Drawn Projection

In order to test the approach of the D&V analysis method, hand drawn projections are made of the outside views from two rooms in a test model. The test model consist of three buildings. The first building is 15 x 18 x 9 meter. It has three floors and each floor contains one room of 6 x 4.5 x 3 meter. The outside façade of each room has a window opening of 4 x 1 meter at 1 meter above the floor. Through the windows, the other two buildings can be seen. The size of these buildings is 10 x 21 x 6 meter and 15 x 9 x 15 meter.

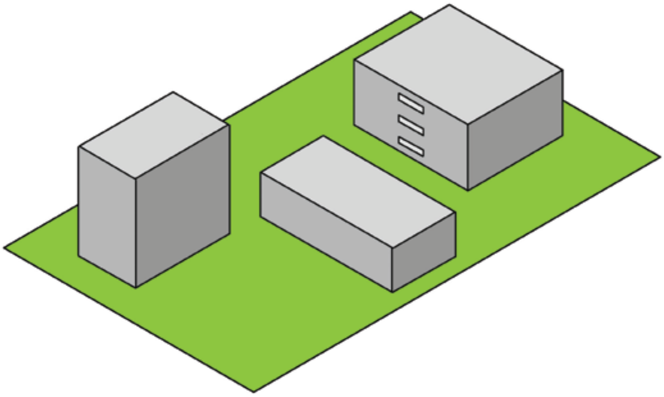


Figure 10.6: The test model

Following the procedure of the hand-drawn projection, projections are made from two view points at the first and two view points at the third floor of the test model. They are located at 1 and 3 meter from the façade, in the middle of the room, and at 1.5 meter above the floor (Figure 10.7).

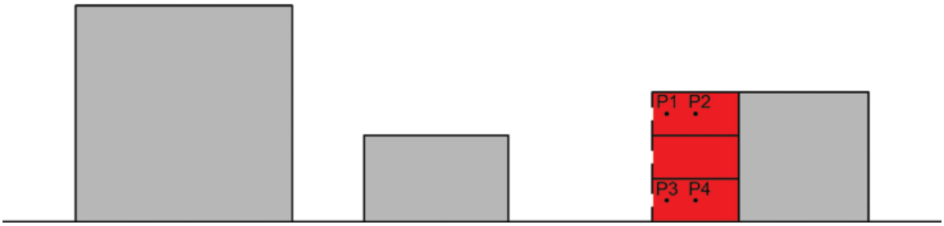


Figure 10.7: Cross-section of the test model with the four viewpoints P1 to P4

For each viewpoint, the angles β en γ are calculated of the window frame and the opposite buildings which can be seen through the window. Subsequently, the projections are drawn in the basic diagram of the hand-drawn projection. The resulting projections in figure 10.8 clearly show the differences between the views from the different floors. The further the distance of the viewpoint from the window, the more limited is the outside view.

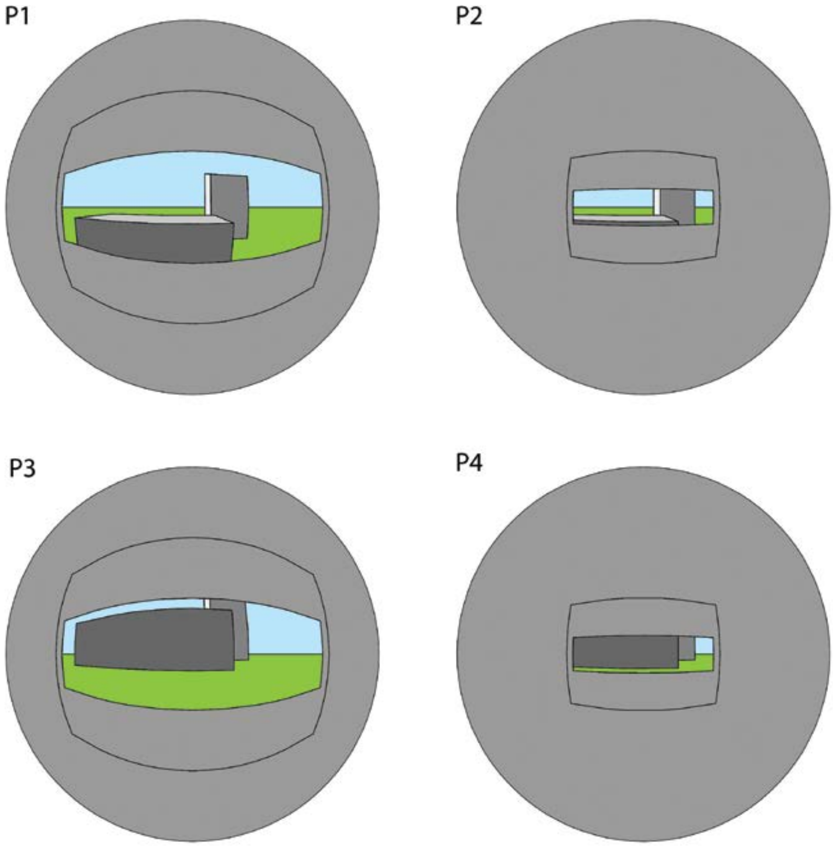


Figure 10.8: Example of hand-drawn projections from viewpoints P1 to P4 inside the test model

10.3. Projection Made with a Computer Model

The second way to make the projection of the windows and the outside view is by making fisheye renderings of a computer model. This study uses the computer program Desktop Radiance 2.0 BETA, which is a plug-in in AutoCad 2000. The steps that need to be taken to make a fisheye rendering with this program are described in text box 10.2. Because the fisheye renderings are made according to the function of the equidistant projection, the results will look similar to hand-drawn projections made with the basic diagram. The equidistant diagrams developed throughout this research, therefore, can be used for both the hand-drawn projection as well as for the projections made with Desktop Radiance 2.0 BETA.

Text box 10.2: Procedure to make a projection with Desktop Radiance 2.0 BETA

In order to make a projection with Desktop Radiance 2.0 BETA, first a three-dimensional model is made in AutoCad 2000 of the building that is going to be examined. Rooms from which projections will be made need to be constructed, as well as the windows in the outer walls of these rooms. Then the opposite buildings and other objects within the view from the window are constructed. Material properties have to be added to all planes in the model in order to make them visible in the rendering.

The next step is to determine the camera positions with Desktop Radiance and to start the simulation with a standard perspective. When the simulation starts, first, the Simulation Manager pops up and the simulation parameters can be defined. Subsequently, an image of the rendering is made.

The tool Winrview can be used to change the camera settings. When the software has finished rendering the Winrview screen automatically appears. The view which is chosen is 'angular view' (vta) and the angles (vh and vv) are defined. The values should both be set on 180º, in order to make a full 180º degree rendering. The software immediately shows how the image will change when the perspective is changed. The settings are saved in a RIF file and a View file (*. vf).

The final step is to make the actual rendering, which can be saved as a picture. In the Simulation Manager a copy is made of the original image with a standard perspective. The view is selected that just was defined in Winrview. Now the Batch mode should be selected and subsequently the actual 180º rendering with a high resolution, is made.

10.2.2. Example of a Projection Made with a Computer Model

This paragraph shows projections made with Desktop Radiance 2.0 beta from the test model described in paragraph 10.2.1. Firstly, a three dimensional representation of the test model is made in AutoCad 2000. Subsequently, renderings are made from the four viewpoints in the test model with Desktop Radiance 2.0 BETA by following the procedure described in text box 10.2. The input parameters are displayed in table 10.1. The results are shown in figure 10.9.

As expected, the same views are found as in figure 10.8. The pictures show that when a computer model is used, the applied material properties and the lighting of the model affect the appearance of the images

Table 10.1: Input parameters of the test model in Desktop Radiance 2.0 BETA

Variable		Input
Location		Berkeley
Date and time		21 March, 12:00h
Sky		CIE overcast sky
Material properties	Interior	RAL7030_Stone_Grey (56.08% reflectance)
	Exterior	RAL7013_Brown_Grey (26.15% reflectance)
Simulation parameters	Lighting	Light Variability is set High Ambient Bounce is 6
	Geometric Detail	Geometric Detail is set High
	Rendering	Rendering Quality is set High

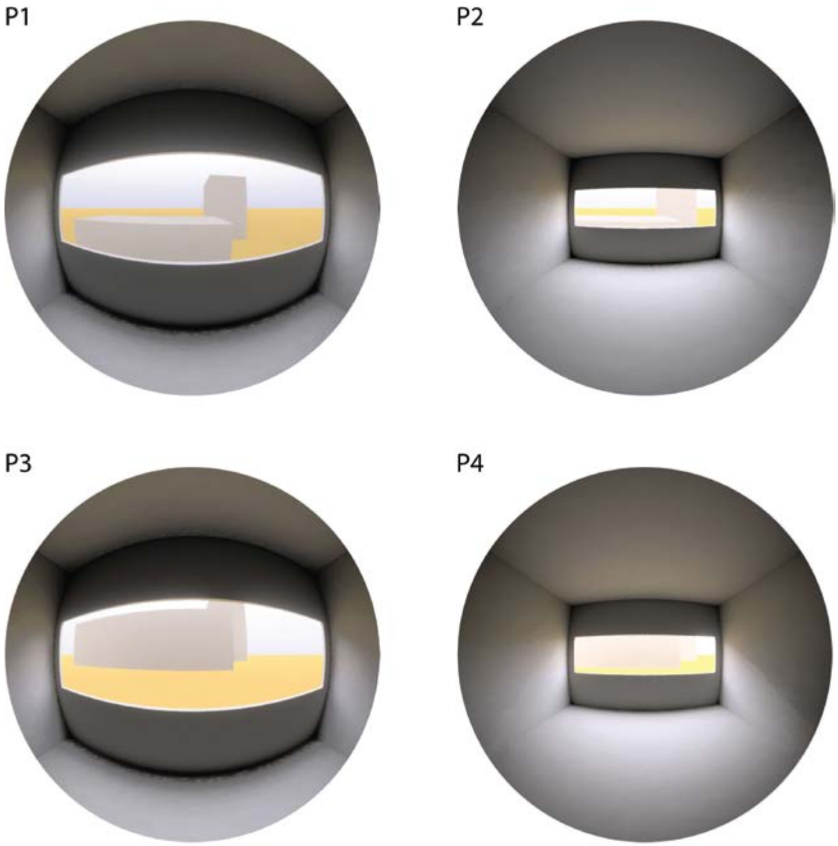


Figure 10.9: Example of projections made with a computer model from viewpoints P1 to P4 inside the test model

10.4. Projection Made with a Camera with Fisheye Lens

If someone wants to explore the daylight access into and view from an existing building, the projections of the windows and outside view can also be made with a camera with fisheye lens. In this research a luminance camera is used with complementary software of TechnoTeam. The camera is called LMK Mobile Advanced, which consists of the CANON EOS 350D camera and Sigma 8mm Circular Fisheye lens. The camera and lens are purchased and calibrated in 2008.

The pictures made with the LMK Mobile Advanced are not equidistant projections, so the results will slightly deviate from projections made with the hand-drawn projection method or Desktop Radiance 2.0 Beta. The equidistant diagrams developed throughout this research are therefore not applicable to the pictures made with the luminance camera. This is why for each diagram made in this research, a second exemplary is made which is converted to the equation of the pictures taken with the luminance camera (Text box 10.3, appendix H).

Text box 10.3: Background information on the construction of diagrams for the LMK Mobile Advanced

According to the information delivered together with the camera, the Sigma fisheye lens makes pictures with a size of about 168° horizontally and 104° vertically, so it is not a full 180° projection. However, full 180° diagrams are made, which can be used in combination with the pictures which are taken with the luminance camera. The angles σ and τ are calculated in the same way as for the other diagrams.

Subsequently, the position of angles σ in the diagram are calculated according to the equation belonging to the LMK Mobile Advanced and Sigma fisheye lens (Techno Team, Tobias Porsch, 27-05-2009):

$$r_{LMK} = \frac{pixel}{1000} = -2.0245\left(\frac{\sigma}{100}\right)^6 + 5.144\left(\frac{\sigma}{100}\right)^5 - 5.195\left(\frac{\sigma}{100}\right)^4 + 2.4767\left(\frac{\sigma}{100}\right)^3 - 0.652\left(\frac{\sigma}{100}\right)^2 + 1.193\left(\frac{\sigma}{100}\right) \quad (10.4)$$

Where r_{LMK} is the distance between viewpoint P and the projection of point F, and σ is the angle between the line through P and F and the viewing direction in the real world

The polar diagram and basic diagram of the LMK Mobile Advanced are displayed in figures 10.10 and 10.11. Examples of pictures made with the luminance camera and fisheye lens can be found in chapter 12 and complementary appendix K. In chapter 12 a scale model research is described, which is performed in order to validate the D&V analysis method.

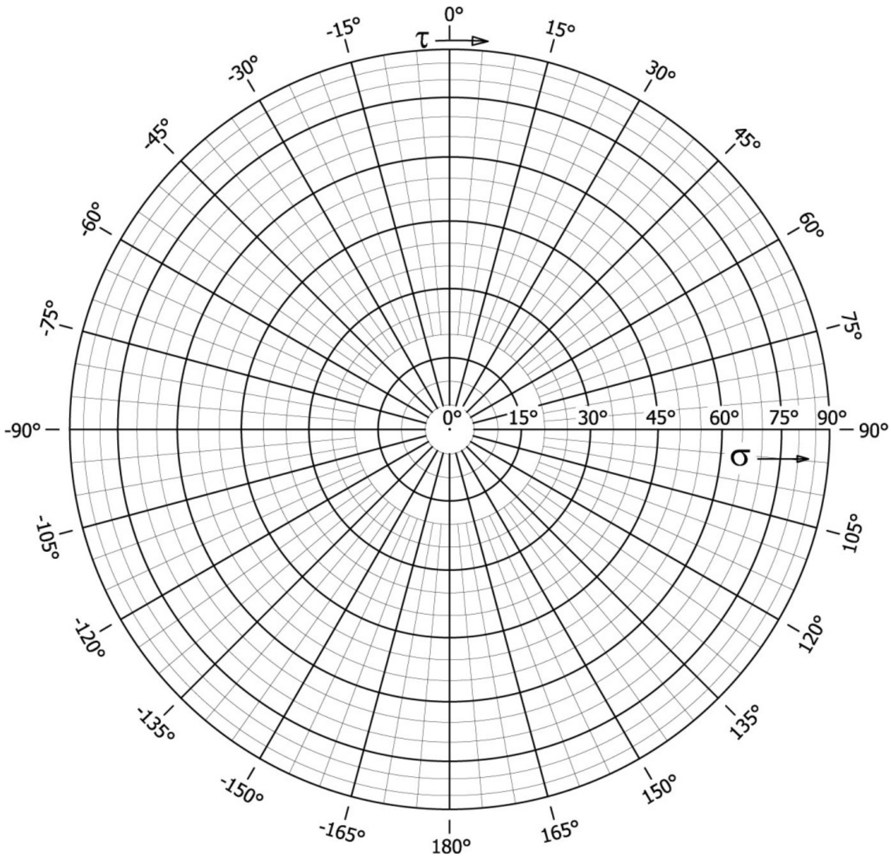


Figure 10.10: Polar diagram of LMK Mobile Advanced

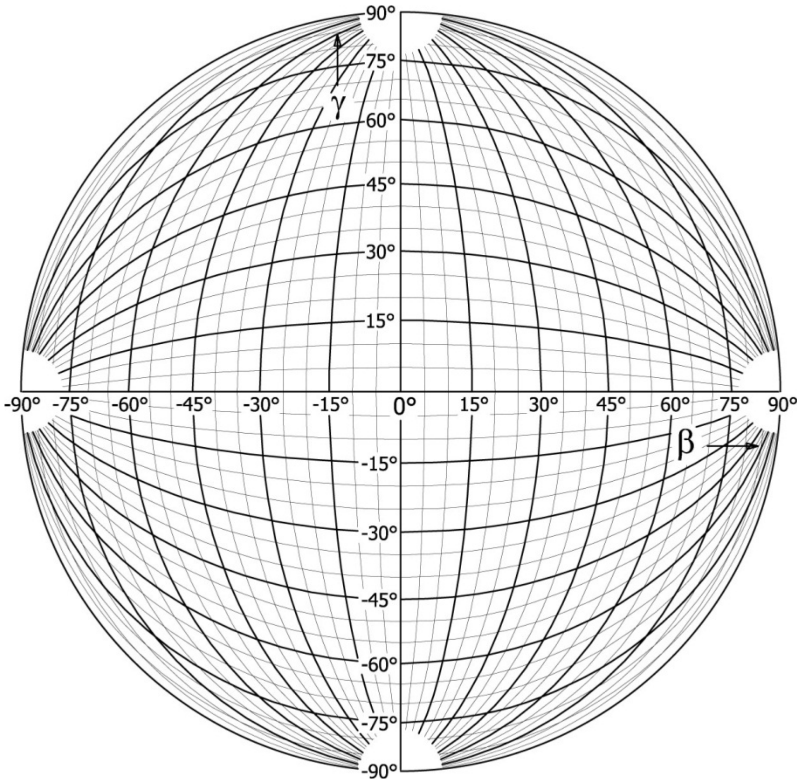


Figure 10:11: Basic diagram of LMK Mobile Advanced

10.5. Assessment of Daylight Quality

After the projections are made of the windows and the view through the windows, subsequently, the access of daylight can be analysed. This can be done in several ways.

Firstly, the access of day- and sunlight can be explored with daylight diagrams. Dot and sunpath diagrams are constructed for the new analysis method, which are based on existing diagrams. The new diagrams show an equidistant vertical projection of the sky dome, which makes the diagrams applicable to the D&V analysis method. By placing the dot diagrams on the projection of the windows and outside view the access of direct daylight from the overcast sky becomes visible. Similarly, the sunpath diagrams show what period of the year direct sunlight may fall into the room. The daylight diagrams are displayed in chapter 11, which also describes their construction and use and explores their accuracy.

It is also possible to perform more detailed analysis on the light quality in the projection. The luminance distribution in the projection can be calculated with light simulation software like (Desktop) Radiance and, if the projections are made from an existing building, it is also possible to measure luminance levels in the projection with a luminance camera. Subsequently, the chance on glare can be calculated with one of the methods for daylight glare described in chapter 3.4, or by calculating luminance ratios in the projection. This can be done in the entire 180 degree projection, but it is also possible to do this within a specified area, for instance the human visual field which is displayed in figure 10.12. The ratio between the minimum and mean luminance level in the visual field shows if there is an unbalanced light distribution or darkness in parts of a room (De Bruin-Hordijk, 2011).

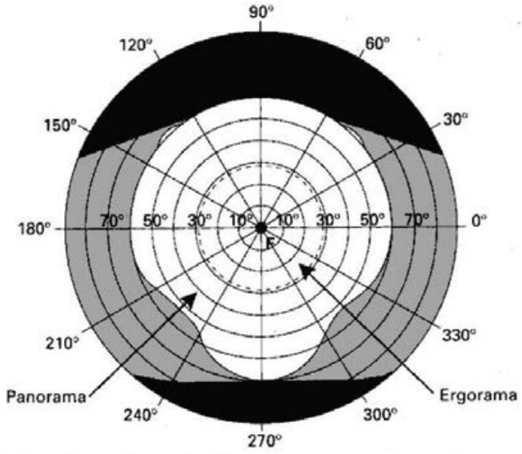


Figure 10.12: Human field of vision (IESNA, 1984), F is the central field (fovea)sper window and view

10.6. Assessment of View Quality

Because no methods were found in the literature which specifically are developed for the assessment of outside views, a new assessment method for view quality is made. The results of the literature study in chapter 4 and the field surveys in chapter 5 and 7 shows that many factors influence the perception of view quality. The most important ones are used to develop the new assessment method which consists of two different parts: the first part is a general method for the assessment of view quality (Paragraph 10.6.1.), and the second part is a method for the assessment of the view from a workplace (Paragraph 10.6.2.).

10.6.1. General method for the assessment of view quality

With the general method, the quality of the outside view from an indoor space can be assessed. From an indoor space, firstly, a projection is made of the windows and view through the windows at eye height. The viewing direction is perpendicular to the window and the distance to the window preferably 1.5 meter, because if the distance is larger the projection of the view will be very small, which makes it difficult to assess the view content. Subsequently, the influence of different variables on the quality of the projected view is determined by answering the multiple choice questions displayed in the flowchart (Figure 10.13).

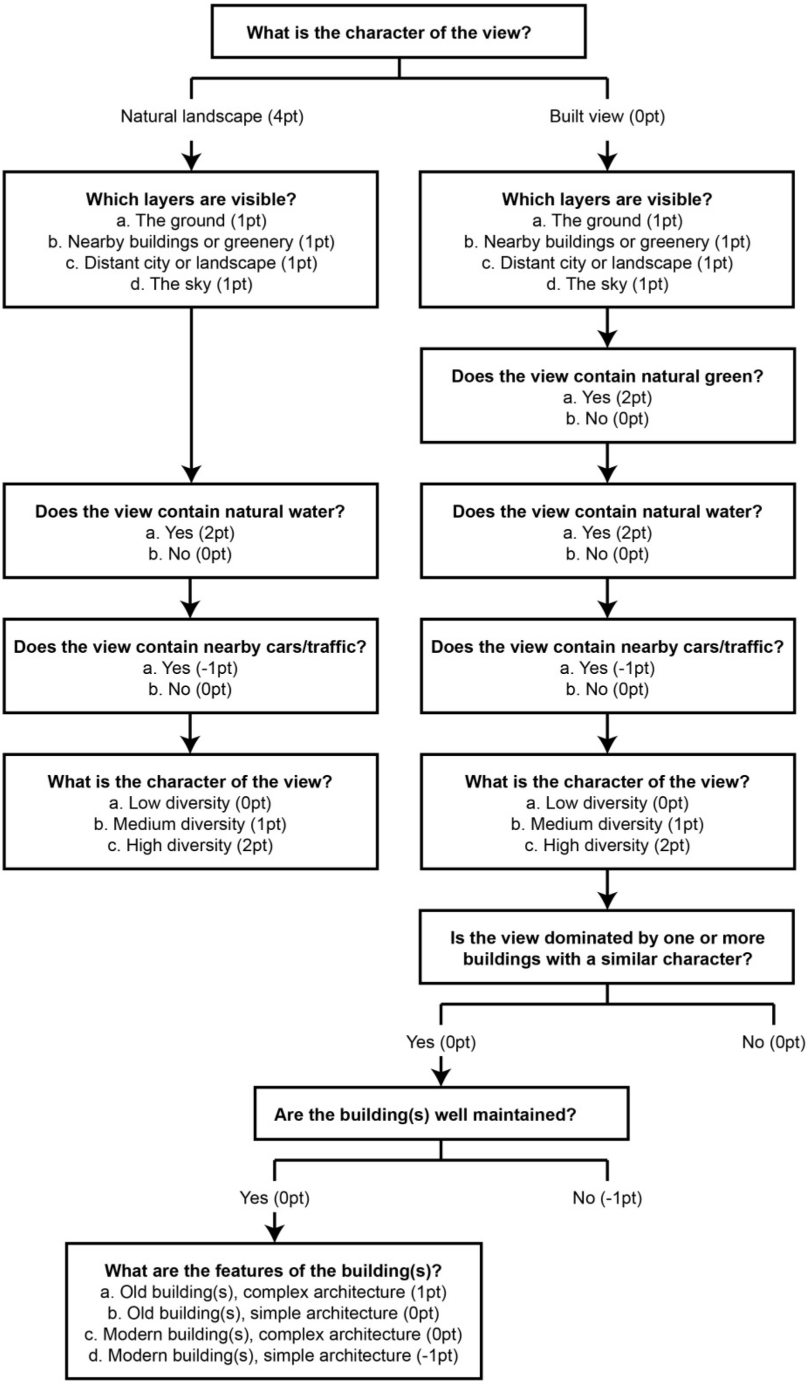


Figure 10.13: General method for the assessment of view quality

Each possible answer in the flow chart has a number of points, which depends on its predicted effect on the assessment of view quality compared to other factors. In part 1 and part 2 of this thesis, some variables were more consistently found to influence view quality than others. For this reason, some answers got more points than others. An explanation per question is given in table 10.2 The scores of the selected answers are added in order to calculate the view quality score. The calculated score ranges from 0pt (low view quality) to 12pt (high view quality).

Table 10.2: Clarification of the questions and answers of the assessment method

Question	Clarification
1. What is the character of the view? a. Natural landscape = 4pt b. Built view = 0pt	Natural views are preferred over built or urban views and natural green is found to influence the well-being of building occupants. Both the literature and the field study show that the preference for natural views over built or urban views is the most important parameter affecting view quality ratings (Chapter 4, 5 and 7). For this reason, the point factor for natural landscape is 4. However, the total view quality score of a landscape view is not necessarily higher. This depends on the other variables in the flow chart. The total view quality score of landscape views ranges from 4 to 12 points, and the total view quality score of built views ranges from 0 to 11 points.
2. Which layers are visible? a. The ground = 1pt b. Nearby buildings or greenery = 1pt c. Distant city or landscape = 1pt d. The sky = 1pt	The more layers are visible, the higher the information content of a view. The literature finding that views with different layers are preferred over single layer views, was confirmed by the results of the picture question in the main study (Chapter 4 and 7). The weight factor of each layer is one point. Distant city or landscape was found to be the most preferred layer in the literature (chapter 4), but when distant city or landscape is seen, other layers are also presumed to be seen, so the entire score on the question will be much higher than if the view is very limited. In this question is also enclosed the preference for wide and distant views and the preference to see what weather it is. The assumption is made that, generally, the more layers are visible the wider the view and the better the weather can be seen.

Question	Clarification
3. Does the view contain natural green? a. Yes = 2pt b. No = 0pt	This question should only be answered in case of a built or urban view. Views of natural landscapes got already 4 points in the first question. Built or urban views, however may also contain natural green. Because the preference for natural green is consistently found to have a strong positive effect on perceived view quality (Chapter 4, 5 and 7), urban views with naturel green get 2 points.
4. Does the view contain natural water? a. Yes = 2pt b. No = 0pt	The literature shows that people like to see water, for example a lake or a river (Chapter 4). Although in the pilot study water did not seem to be a significant factor, the main study confirmed that water contributes to the pleasantness of an outside view (Chapter 5, 7). Because in the literature the preference to see water was very consistent, views with water get 2 points.
5. Does the view contain nearby cars/traffic? a. Yes = -1pt b. No = 0pt	The results of the main study indicate that nearby cars or traffic have a negative effect on perceived view quality (Chapter 7), but that the effect is less strong than the effect of other variables. Therefore, 1 point should be subtracted from the view quality score if nearby cars or traffic are visible.
6. What is the character of the view? a. Low diversity = 0pt b. Medium diversity = 1pt c. High diversity = 2pt	The multiple regression analysis in chapter 7 shows that the diversity of a view has a significant effect on the rating of view quality. Furthermore, results of the factor analysis in chapter 8 show that the more different topics are visible, the higher the view quality rating. A distinction is made between three levels of diversity, and only views with very low or high diversity should get respectively 0 or 2 points.
7. Is the view dominated by one or more buildings with a similar character? a. Yes = 0pt → continue with next question b. No = 0pt → finish assessment of view quality	Past research indicated that some characteristics of buildings are likely to affect the rating of view quality. For this reason, if a view is dominated by one building or multiple buildings with a similar character, some questions will be asked about the characteristics of these buildings. By answering these questions the total view quality score will be max. 1 point higher, when the buildings are presumed to be very attractive to see and max. 2 points lower, when the buildings are presumed to be very unattractive to see.

Question	Clarification
8. Are the buildings well maintained? a. Yes = 0pt b. No = -1pt → finish assessment of view quality	Buildings which are well maintained are preferred over buildings which are poorly maintained (Chapter 4). The strength of this effect is not known and only if the buildings are very badly maintained 1 point should be subtracted from the view quality score.
9. What are the features of the nearby buildings? a. Old building(s), complex architecture = 1pt b. Old building(s), simple architecture = 0pt c. Modern building(s), complex architecture = 0pt d. Modern building(s), simple architecture = -1pt	Both the literature study and the field survey show that older buildings are generally preferred over modern buildings, unless the buildings are poorly maintained and/or complexity is low. Furthermore, buildings having a high degree of complexity are found to be generally preferred over buildings having a low degree of complexity (Chapter 4, 7). Buildings which are both old and complex are presumed to be most preferred and therefore the weight of this answer is 1 point. Modern buildings with a simple architecture are presumed to be least preferred and therefore the weight of this answer is -1 point.

In order to test the applicability of the method, view quality scores are calculated of the pictures used in the field study (Appendix F). The scores calculated with the new assessment method are compared to the mean view quality ratings from the main study.[6] The results are summarized in the graph in figure 10.14.

[6] The pictures are not made in accordance with the projection method, because no fisheye lens was available. It is possible to assess these pictures, but preferably pictures are made in accordance with the projection method. The advance of the equidistant projection is that it covers the entire visual field and it is a more objective manner of recording the view. If pictures are made with a normal lens, the part of the view that is seen in the picture depends on the features of the camera.

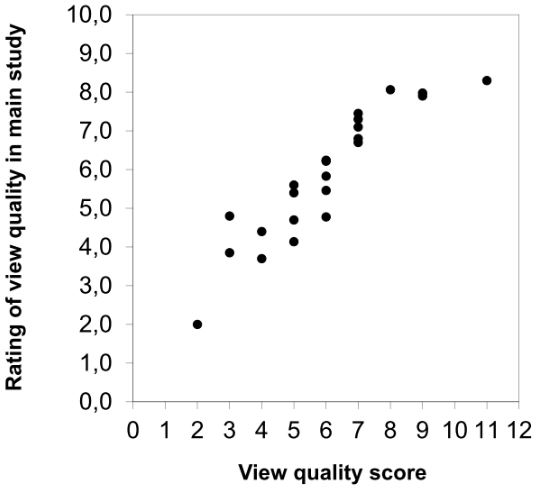


Figure 10.14: View quality of the pictures from the main study. The x-axis shows the view quality score calculated with the new assessment method and the y-axis the mean view quality rating from the main study.

Overall, the results show a similar rank order from high view quality to low view quality. The outcome of the new assessment method could be interpreted as followed:

$\geq$ 8pt High view quality
5-7pt Medium view quality
$\leq$ 4pt Low view quality

The general method for the assessment of view quality combines the approach of the psychophysical model and the psychological model describe in chapter 4 (paragraph 4.4.6). Questions 1 to 5 and 7 ask about the content of the view, questions 6, 8 and 9 are about the character of the view. The assessment partly relies on the opinion of the assessor. The expectation is, however, that view quality scores will not differ much between different assessors, because the subjective component is not too big. The method will particularly be useful for the comparison of different views.

10.6.2. Method for the assessment of the view from a workplace

For the assessment of the outside view from a workplace an additional procedure is made, in order to look into more detail how much access someone has to an outside view from a workplace. First a projection is made of the view from the workplace. This is done by making a projection of the windows and view through the windows at eye height in the direction of the computer screen. Subsequently, the availability to a view is assessed by answering the multiple choice questions displayed in the flowchart in figure 10.15.

The second question in the flow chart is about the size of the outside view. The percentage of the 180 degree projection which consists of a window opening can be calculated. This can be done, for instance, by placing the basic diagram on the projection of the view from the workplace and by dividing the number of cells which are filled by a window opening by the total number of cells in the diagram.

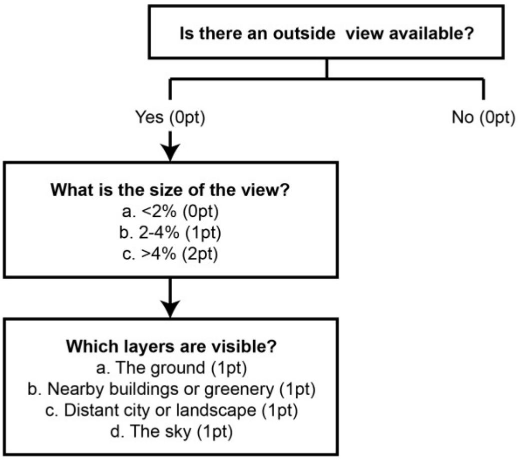


Figure 10.15: Method for the assessment of the outside view from a workplace

Similar to the method described in the previous paragraph, each answer in the flow chart has a number of points. The number of points which is given to an answer depends on its predicted effect on the availability of an outside view. An explanation per question is given in table 10.3.

After answering the questions, the scores of the selected answers are added. The outcome ranges from 0pt (no outside view) to 6pt (much outside view). The outcome could be interpreted as followed:

5-6pt Much outside view
3-4pt Medium outside view
1-2pt Little outside view
0pt No outside view

This is an estimation of the outcome, because the procedure in this paragraph has not yet been validated. The procedure is made, because the view from a workplace can be rather small and, therefore, it would be difficult to assess the content of the view from the workplace with the general method for the assessment of view quality. With the procedure described in this paragraph, one can determine if there is sufficiently access to an outside view from a workplace. Subsequently, the quality of the view can be determined by making a projection at 1.5 meter distance from the window and by following the procedure described in paragraph 10.6.1.

Table 10.3: Clarification of the questions and answers of the assessment method

Question	Clarification
1. Is there an outside view available? a. Yes = 0pt → continue with next question b. No = 0pt →finish assessment of the outside view from the workplace	If there is no outside view available, the score will be 0 points.
2. What is the size of the view? a. <2% = 0pt b. 2-4% = 1pt c. >4% = 2pt	In order to answer this question, the percentage of window openings in the 180% projection should be determined (see text box). Research in the US has shown that besides the availability of an outside view from a workplace, the size of the outside views also influences satisfaction with the view. Other research, however, has indicated that this is only the case if the view size is rather small (Chapter 4). The answers of this question and their rating are an estimation of the effect of view size on perceived view quality and has not yet been tested.
3. Which layers are visible? a. The ground = 1pt b. Nearby buildings or greenery = 1pt c. Distant city or landscape = 1pt d. The sky = 1pt	The more layers are visible, the higher the information content of a view. The literature finding that views with different layers are preferred over single layer views was confirmed by the results of the picture question in the main study (Chapter 4 and 7)

10.7. Key Findings

The approach of the new method for the analysis of the daylight access and view though windows, the D&V analysis method, is a basic theory of how the view and daylight access through a window can be recorded or measured in an objective way. Because the projection can be made in several ways, i.e. by a hand drawing, a computer model or with a camera with fisheye lens, the method can be used in different phases of a design or research process.

Existing methods for the analysis of daylight are implemented in the D&V analysis method, which makes it possible to examine the access of daylight through a window in multiple ways, without the need to construct a new model for each type of analysis. The access of daylight, for instance, can be examined with the dot and sunpath which are described in chapter 11. Furthermore, the luminance distribution in the projection can be measured with a luminance camera or calculated with light simulation software.

For the D&V analysis method, a new method for the assessment of view quality is developed, which consists of two different parts. The first part is a general method for the assessment of view quality and the second part is a method for the assessment of the view from a workplace. Both methods consist of a series of multiple choice questions. When these questions are answered the view quality score can be calculated.

In order to test the applicability of the general method for the assessment of view quality, mean view quality ratings of the pictures used in the main study are compared to the mean view scores calculated with the assessment method. Overall, the results show a similar rank order from high view quality to low view quality. The general method for the assessment of view quality combines the approach of the psychophysical model and the psychological model described in chapter 4 (paragraph 4.4.6). The assessment partly relies on the opinion of the assessor. The expectation is, however, that view quality scores will not differ much between different assessors, because the subjective component is not too big.

With the D&V analysis method the effect of different window designs on daylight access and view quality can be shown in an relatively easy and comprehensible way. This is illustrated by examples in this chapter and in chapters 11 and 12. In chapter 12 the applicability of the D&V analysis method is explored by a scale model research.

10.8. References

Hopkinson, R.G.; Petherbridge, P.; Longmore, J., Daylighting, London: Heinemann, 1966, Chapter 20

Illuminating Engineering Society of North America (IESNA), Lighting Handbook - Application and Reference Volume, New York: IESNA, 1984

De Bruin-Hordijk, G.J., Visual comfort for seniors, 4th VELUX Daylight Symposium, 4-5 May 2011, Lausanne, www.thedaylightsite.com.

Chapter 11

Diagrams for the Analysis of Day- and Sunlight

In this chapter the construction of the daylight diagrams is explained which are part of the D&V analysis method described in chapter 10. Two types of diagrams are made: dot diagrams and sunpath diagrams. They can be used to examine the access of day- and sunlight in an indoor space. In order to examine the accuracy of the diagram, results obtained with the diagrams are compared to results of computer calculations.

The aim is to answer two research questions:

- How can existing diagrams for the analysis of day- and sunlight be implemented in the new analysis method for daylight and view quality?
- How accurate are dot and sunpath diagrams compared to calculations with daylight simulation software?

Before the accuracy of the dot diagrams is explored, adaptations are made to the test model described in the previous chapter (paragraph 10.2). The hand-drawn projection method is used to make projections from the view points in the test model and, subsequently, the access of daylight is explored with the dot diagrams. The results are compared to calculations with Desktop Radiance 2.0 BETA and DIALux 4.0. Both programs are validated and widely used programs for light simulations (Chapter 3).

The accuracy of the sunpath diagrams is explored by comparing the diagrams with calculations of the luminance distribution in projections from the scale model with Desktop Radiance 2.0 BETA. Calculations are made for three different orientations of the test model, on different dates and times, under a clear sky. The position of the sun is deduced from the luminance pictures and compared to the sun's position according to the sun path diagrams.

Chapter outline

11.1. Development of the Dot Diagrams

For the analysis of the daylight access dot diagrams are made which can be used to calculate the sky factor or sky component in a measurement point. The diagrams show a vertical projection of the sky, represented as a dome around a measurement point, on a vertical surface (Figures 11.1-11.4).

Existing daylight diagrams are often projections of the sky dome or sun path on a horizontal surface (Chapter 3). The reason that for the new analysis a vertical orientation of the projection is chosen, is because the new analysis method is not only made for the visualization of day- and sunlight, but also for the visualization of window views. By choosing a vertical projection surface, the most important parts of the view will be displayed in the centre of the image.

The new dot diagrams are based on existing dot diagrams developed by the TH Delft Architecture and Civil Engineering (Chapter 3, Santen & Hansen, 1985). The original diagrams show a gnomonic projection of the sky dome on a vertical plane. These are transformed into equidistant projections, in order to allow the dots diagrams to be placed onto the projection of the window and the view through the window

Diagrams are made for two types of sky domes with a different luminance distribution: the uniform sky (figure 11.1 and 11.2) and the CIE overcast sky (figure 11.3 and 11.4). For each sky dome two diagrams are made, i.e. one for a measurement point on a horizontally orientated surface area and one for a measurement point on a vertically orientated surface area. The different orientations of the measurement points result in a different sky factor or sky component.

The position of the measurement point is exactly the same as the view point P, the point from which the projection of the windows and outside view is made. However, the orientation of the measurement point is not necessarily the same as the viewing direction. In case of the horizontally orientated measurement point the measurement point is 90 degree rotated and the normal axis does not correspond with the viewing direction, but faces upwards. The sky factor or sky component is calculated in the same way as with the original dot diagrams. The procedure is described in text box 11.1. Background information on the construction of the diagrams is given in text box 11.2.

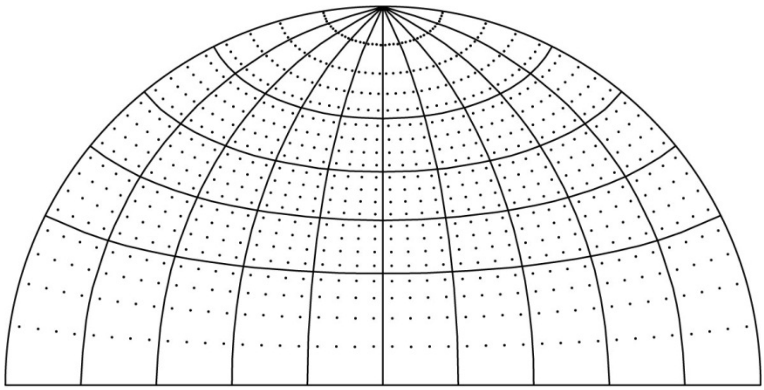


Figure 11.1: Dot diagram of uniform sky dome and horizontal point (SF = Σdots/1600)

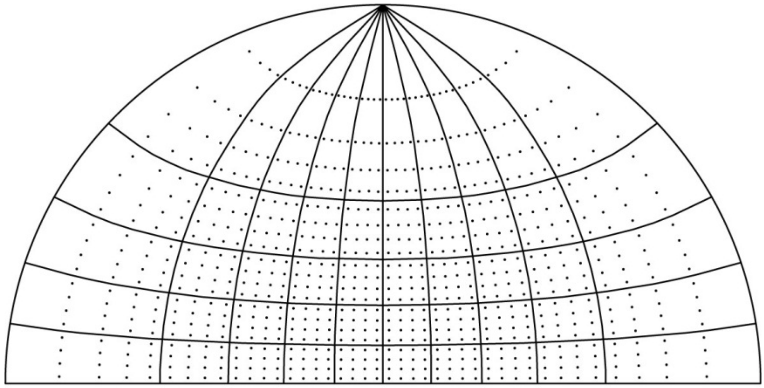


Figure 11.2: Dot diagram of uniform sky dome and vertical point (SF = Σdots/1600)

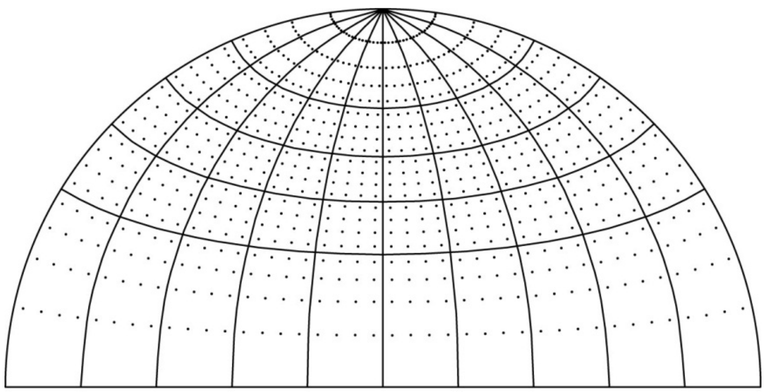


Figure 11.3: Dot diagrams of CIE overcast sky and horizontal point (SC = Σdots/1600)

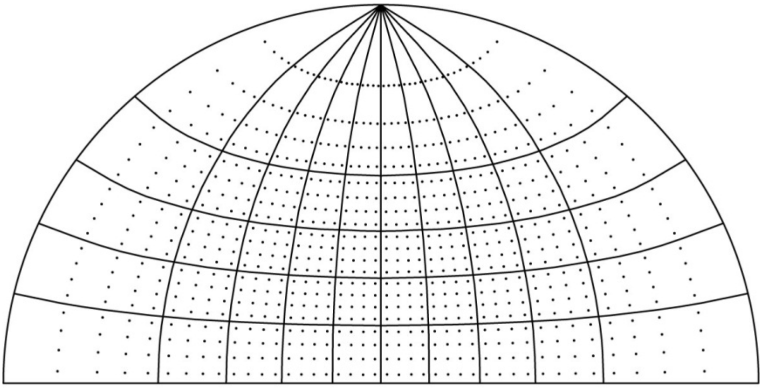


*Figure 11.4: Dot diagrams of CIE overcast sky and vertical point (SC = Σdots/800*0.396)*

Text box 11.1: Procedure to calculate the sky factor or sky component with the dot diagrams

The sky factor or sky component can be determined by placing the right dot diagram on the basic projection of the window and the view and counting the dots which are located in the visible part of the sky.

The sky factor, in case of the uniform sky, is calculated according to the following equation:

$$SF = \frac{E_{vs}}{E_{hor(ff)}} = \frac{\sum dots}{1600} \qquad (11.9)$$

where SF is the sky factor, E_{vs} is the illuminance of the visible part of the sky, and $E_{hor(ff)}$ is the horizontal illuminance in the free field (unobstructed horizontal illuminance).

The equation shows that the contribution of one dot in the diagram of the uniform sky to the illuminance in the measurement point is 1/1600*100% = 0.0625% of the illuminance measured in a horizontal measurement point in the free field. In other words, one dot equals to 0.0625% of the entire illuminance of the sky dome.

In case of the CIE overcast sky, the sky component in a horizontal measurement point is calculated in the same way as the sky factor. For the calculation of the sky component in a vertical measurement point, however, a different equation is used.

For a horizontal point M and CIE overcast sky applies:

$$SC = \frac{E_{vs}}{E_{hor(ff)}} = \frac{\sum dots}{1600} \qquad (11.10)$$

For a vertical point M and CIE overcast sky applies:

$$SC = \frac{E_{vs}}{E_{hor(ff)}} = \frac{\sum dots}{800} \cdot \frac{E_{vert(ff)}}{E_{hor(ff)}} = \frac{\sum dots}{800} \cdot 0.396 \qquad (11.11)$$

where SC is the sky component (of the daylight factor), E_{vs} is the illuminance of the visible part of the sky, $E_{hor(ff)}$ is the horizontal illuminance in the free field, and $E_{vert(ff)}$ is the vertical illuminance in the free field.

In case of the CIE sky and a horizontal measurement point, the contribution of one dot to the illuminance in the measurement point is also 0.0625% of the illuminance in the free field. In case of a vertical measurement point the contribution of one dot to the illuminance in the measurement point is 0.0495% of the illuminance in the free field.

Text box 11.2: Background information on the construction of the dot diagrams

The dot diagrams are made by drawing an equidistant projection of the sky in the polar diagram. The sky dome is divided into a number of surface areas, in such a way that each surface equally contributes to the illuminance in the measurement point. Each surface area is represented by a dot in the diagram.

Firstly, for each surface element of the sky dome dS_H the angles α and β are calculated. The angle α is the angle between the line through viewpoint P and surface area dS_H and the vertical axis and β is the angle between the viewing direction and the projection of the line through viewpoint P and dS_H in the horizontal plane.

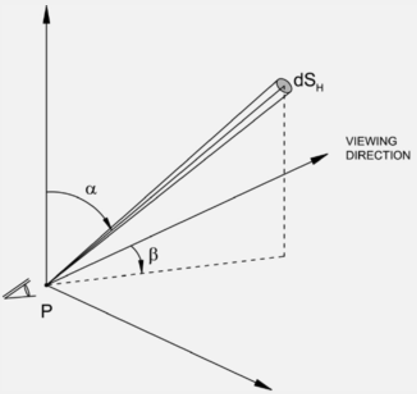


Figure 11.5: Coordinate system with angles α (alpha) and β (beta)

Dot diagrams are made for two different sky types. The luminance distribution of the uniform sky is the same in every part of the sky dome. The equation is:

$$L(\alpha,\beta) = L_0 \tag{11.1}$$

where L(α, β) is the luminance of a surface element of the sky dome and L_0 is the luminance of the sky dome.

The luminance of the CIE overcast sky is lowest at the horizon and increases closer to the zenith, the highest point of the sky dome, where the luminance is three times higher. The luminance distribution is:

$$L(\alpha,\beta) = L(\alpha) = L_z \frac{1+2\cos\alpha}{3} \tag{11.2}$$

where L_Z is the luminance at the zenith

The size of the surface areas depends on the type of sky and the orientation of surface element dS on which the measurement point P is located (Appendix G).

In case of the uniform sky the illuminance from the whole hemisphere on a horizontal surface area is:

$$E_{hor} = \pi L_0 \tag{11.3}$$

The luminance on a vertical surface area is:

$$E_{ver} = \frac{\pi L_0}{2} \tag{11.4}$$

In case of the CIE overcast sky the illuminance from the whole hemisphere on a horizontal surface area is:

$$E_{hor} = \frac{7\pi L_Z}{9} \tag{11.5}$$

The luminance on a vertical surface area is:

$$E_{ver} = \frac{L_Z}{18}(3\pi + 8) \tag{11.6}$$

These four equations are used to derive equations with which the coordinates of each surface and dot in the diagrams can be calculated. The derivation of the equations is given in appendix G.

Diagrams are created with 20 x 5 surface areas and in each area 4 x 4 dots. All dots together represent 80 x 20 surface areas and they are located in the centre of the surface area they represent.

After calculating angles α and β for each line and dot in the four diagrams, angles σ and τ are derived from α and β by the following two equations:

$$\sigma = f(\alpha, \beta) = \arccos(\sin\alpha \cdot \cos\beta) \tag{11.7}$$

$$\tau = f(\alpha, \beta) = \arccos(\tan\alpha \cdot \sin\beta) \tag{11.8}$$

After calculating angles σ and τ, the dot diagrams are drawn according to the equidistant projection function as described in chapter 10.

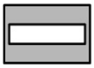
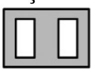
11.2. Accuracy of the Dot Diagrams

Results of daylight calculations with the dot diagrams are compared to daylight calculations with light simulation software in order to determine how accurate calculations with the dot diagrams are. Daylight calculations are made with Desktop Radiance 2.0 BETA and DIALux 4.7. An explanation of these programs can be found in chapter 3.

11.2.1. Adaptations to the test model

For the validation of the dot diagrams three variations of the façade of the test model are made. The first model has no façade, the second model one horizontal window opening and the third model two vertical window openings (Table 11.1).

Table 11.1: Three variations of the test model

Model	Description
No façade 	The rooms with the measurement points do not have a facade
Façade 1 	The façade of the room has window openings of 4 x 1 m, on 1 m above the floor of each room.
Façade 2 	The façade of the room has two window openings of 1 x 2 m, on 1 m above the floor of each room and 0.652 m from the side walls.

In the test model a total of six measurement points are defined; two on each floor, respectively on a distance of one and three meter from the façade (Figure 11.6). For each measurement point two calculations are made, namely for a horizontal and a vertical orientation of the measurement point. It means that in total 6 x 3 x 2 = 36 sky components are calculated with the dot diagrams, which are compared to the results of Desktop Radiance and DIALux.

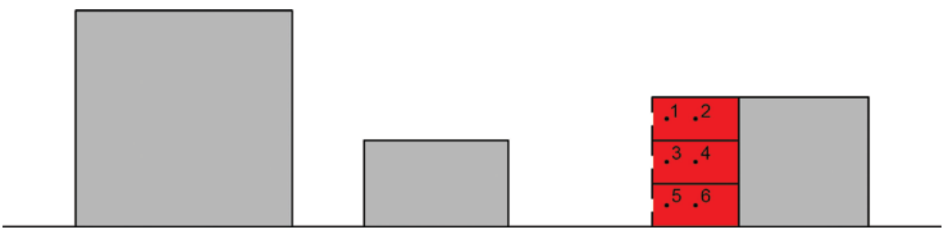


Figure 11.6: Cross-section of the test model with the six measurement points

11.2.2. Calculation of the sky components

First, for all three variations of the model, projections are made of the views from the six viewpoints. Both dot diagrams of the CIE overcast sky are placed onto the projection diagrams, in order to calculate the sky component in horizontally and a vertically orientated measurement points (Figure 11.7). An overview of all projections with the dot diagrams can be found in appendix I.

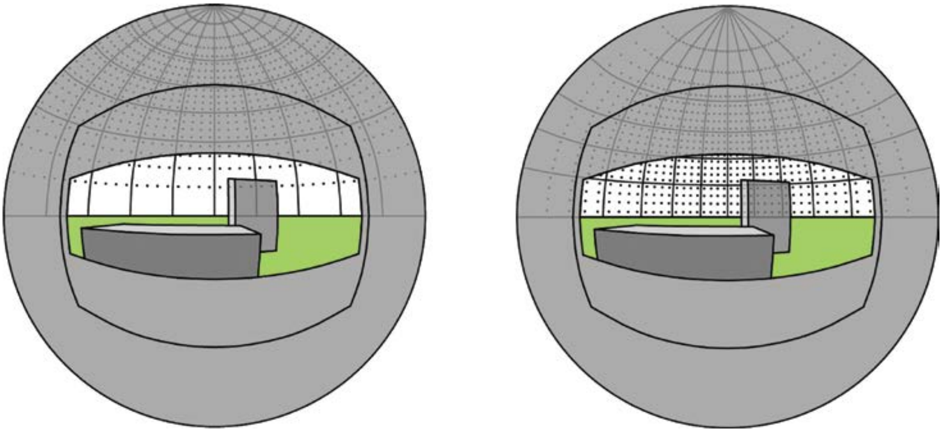


Figure 11.7: Calculation of the sky component in a horizontal and vertical measurement point of the test model. The projection displayed in this image is the projection from measurement point 1of the test model with façade 1.

For each projection the dots are counted which are in the visible part of the sky. Subsequently, the sky components are calculated by following the procedure described in paragraph 11.1. In case of a horizontal measurement point the total number of dots which are in the visible part of the sky is divided by 1600 and multiplied by 100%. In case of a vertical measurement point the number of dots is multiplied by 0,396/800*100%.

The resulting sky components are compared to the sky components calculated with the light simulation software. The procedure of these calculations can be found in text box 11.3.

Text box 11.3: Calculation of the sky components in Desktop Radiance and DIALux

In both Desktop Radiance and DIALux three files are made, with each file containing one of the variations of the test model. The outdoor planes of the buildings, the ground and the interior spaces have a reflection coefficient of 0%, so there will be no internal or external light reflections. The windows are unglazed. When the internal and external reflection coefficients are 0%, the daylight factor equals the sky component (Chapter 3).

In DIALux the sky components are calculated by calculating daylight factors. In Destkop Radiance the sky components are calculated in a different way, because Desktop Radiance does not calculate daylight factors correctly (Hellinga, 2006). A second file is made with an unobstructed horizontally orientated measurement point, in order to calculate the horizontal illuminance in the free field. The sky components are calculated by dividing the illuminance in the measurment points of the test model by the horizontal illuminance in the free field.

The standard calculation settings in Desktop Radiance do not give reliable results (Hellinga, 2006), therefore, some of the standard setting of the program are changed in order to make a more precise calculation. The simulation parameters used for the calculations are displayed in table 11.2.

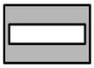
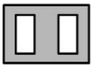
Table 11.2: Input parameters of the test model in Desktop Radiance 2.0 BETA

Variable		Input
Simulation parameters	Lighting	Light Variability is set High Ambient Bounce is 6
	Geometric Detail	Geometric Detail is set High
	Rendering	Rendering Quality is set High

11.2.3. Comparison of the calculated sky components

The results of the calculations are compared to each other in several ways. First of all, the average results per test model are examined (Table 11.3). The results show that with the dot diagrams lower values are found for the sky components, than with the light simulation software. The highest values are found with DIALux. It seems that the results of the dot diagrams do not deviate more from the results of Desktop Radiance than the results of DIALux.

Table 11.3: Average sky components in the three variations of the test model

Model	Dot diagram	Desktop Radiance	DIALux
No façade 	11.6%	12.1%	12.5%
Façade 1 	2.6%	2.7%	2.9%
Façade 2 	2.5%	2.6%	2.9%

In order to get more insight in the linear relationship between the results of the dot diagrams and the light simulation software, scatterplots are made (Figure 11.8 and 11.9) and correlations are calculated between the results of the dot diagrams, Desktop Radiance and DIALux (Table 11.4). The scatterplots include the results of all three variations of the test model. The horizontal axis shows the results of the dot diagrams, and the vertical axis shows the results of either Desktop Radiance or DIALux. The results of the three calculation methods are found to be highly correlated.

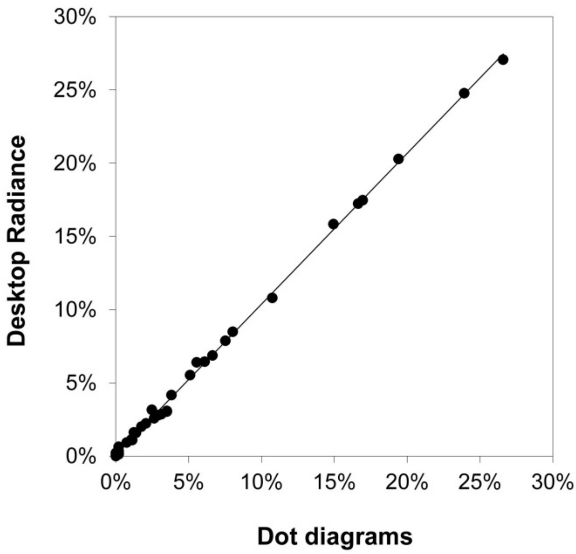


Figure 11.8: Scatter plot of the results of the dot diagrams and Desktop Radiance

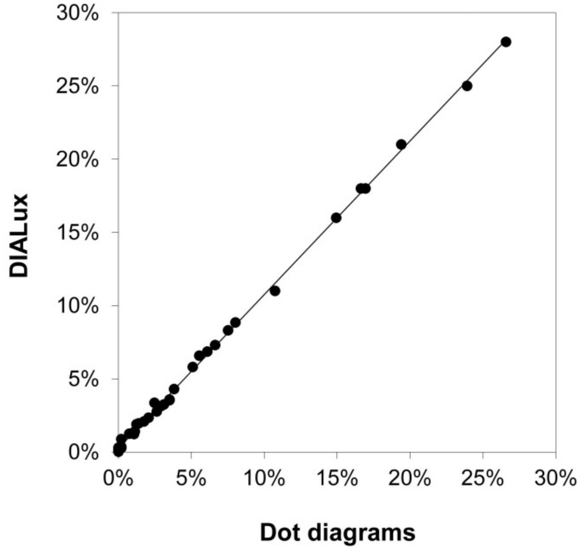


Figure 11.9: Scatter plot of the results of the dot diagrams and DIALux

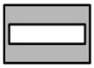
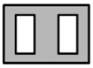
Table 11.4: Pearson's product-moment correlations

	Dot diagram	Desktop Radiance	DIALux
Dot diagram	1	0.9993	0.9994
Desktop Radiance	0.9993	1	0.9998
DIALux	0.9994	0.9998	1

Finally, the deviation of the results of the dot diagrams from the results of the light simulation software is calculated. The average results per test model are given in table 11.5 and an overview of the results of all measurement points is given in appendix I.

The highest absolute deviations are found for the results of the model without a façade, but the highest percent deviations for the results of the model with façade 1 and 2. It seems that if the sky component is low, the absolute deviation is likely to be low, but the percent deviation might be high, especially compared to the results of DIALux. The results of the dot diagrams do not deviate more from Desktop Radiance, than the results of DIALux. Since the correlation coefficients are very high, the conclusion is drawn that these variations are quite consistent. The deviations are mainly caused by the dot diagrams giving lower values and DIALux giving higher values than Desktop Radiance.

Table 11.5: Deviation of the results of the dot diagrams from the results of the computer models

Model	Absolute deviation of the dot diagrams from		Percent deviation of the dot diagrams from	
	Desktop Radiance	DIALux	Desktop Radiance	DIALux
No façade 	-0.6%	-0.9%	-7%	-11%
Façade 1 	-0.1%	-0.3%	-13%	-41%
Façade 2 	-0.1%	-0.4%	-14%	-33%

11.2.4. Accuracy of the dot diagrams

The absolute deviation of the dot diagrams' results from the results of the light simulation software DIALux and Desktop Radiance is rather small. However, the percent deviation can be quite big, especially when the results of the dot diagrams are compared to DIALux. Inside buildings, sky components of 1% or 2% are very common. Regulations prescribe a minimum daylight factor varying from 0.75% to 2.0% (Chapter 3). The results of the calculations show that meeting this criterion can depend on the calculation method which has been chosen.

It is not clear what the reason is that the dot diagrams give lower results than the light simulation software. With the dot diagrams the sky component is calculated by counting the dots which are in the visible part of the sky. One dot in the diagram of the CIE sky for a horizontal measurement point is 0.0645% of the illuminance of the entire sky dome and one dot in the diagram of the CIE sky for a vertical measurement point is 0.0495% of the illuminance of the entire sky dome. Each dot represents a surface area, which can be partly visible and partly invisible through the window. With the dot diagrams the researcher will always make an estimation of how much of the sky dome is visible. However, the value of one dot is very small and therefore mistakes by counting to few or too many dots cannot be the only cause of the differences found between the results of the dot diagrams and the light simulation software.

All considerations above lead to the conclusion that the deviation of the dot diagram's results from Desktop Radiance is acceptable, because there is a very strong correlations between the results of the dot diagrams and Desktop Radiance and similar absolute and percent deviations are found between the results of DIALux and Desktop Radiance. However, when someone is investigating if the minimum average sky component inside a space is 1%, he or she has to take into account that meeting this criterion or not can depend on which calculation method is selected. The dot diagrams give a more conservative estimation of the sky components than the light simulation software.

11.3. Development of the Sunpath Diagrams

Sunpath diagrams are developed for the new analysis method in order to detect what the sun's position will be throughout the year. The sunpath diagrams give information about the possible direct sunlight hours in the view point, the point from which the projection is made. This information might be useful to predict when glare problems might occur and when there will be a need for sunshading. Furthermore, the diagrams can be used to test if regulations are met, which prescribe a minimum number of uninterrupted sun hours at for instance the window sill (Chapter 2).

The new sun path diagrams are derived from existing diagrams, which show a projection of the sky dome on a horizontal surface area (Chapter 3). The new diagrams show a vertical, equidistant projection of the sun's path at different moments of the year and can be put onto the basic diagram of the D&V analysis method.

Both the latitude and geographical orientation affect the path of the sun in the diagram. In this research, sun path diagrams are made for 52º northern latitude, which is the mean latitude of the Netherlands, and for eight geographical orientations (Figures 11.10-11.18). However, diagrams can be made for every latitude and geographical orientation.

The geographical orientation which has to be chosen for the analysis of the sunhours in a view point depends on the viewing direction, the direction in which a projection is made. The straight lines show the different data and the dotted lines the true solar time. By choosing the diagram with the right orientation and putting it onto the basic diagram, the path of the sun along the window becomes visible.

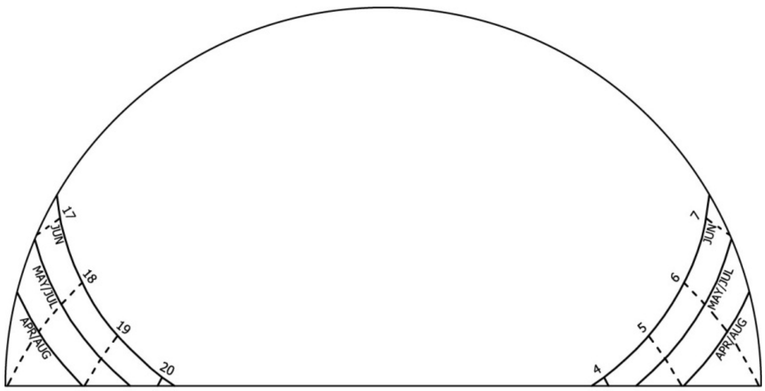


Figure 11.10: Sunpath diagram north

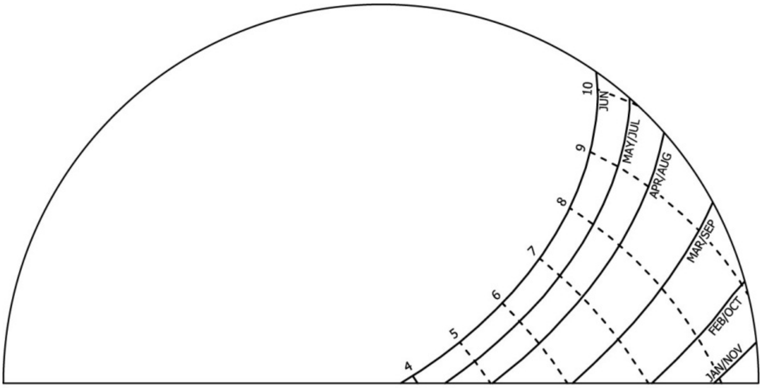


Figure 11.11: Sunpath diagram northeast

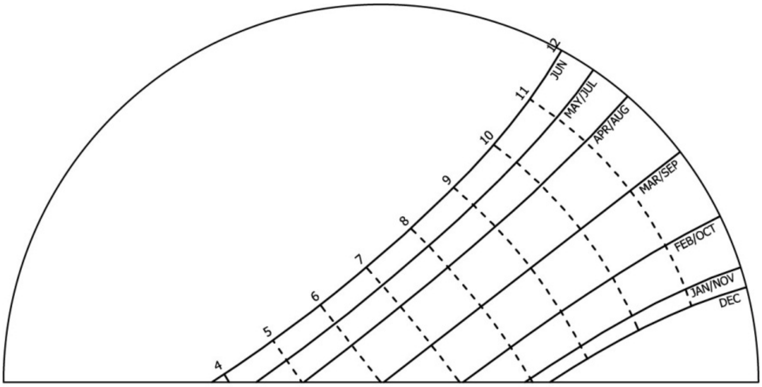


Figure 11.12: Sunpath diagram east

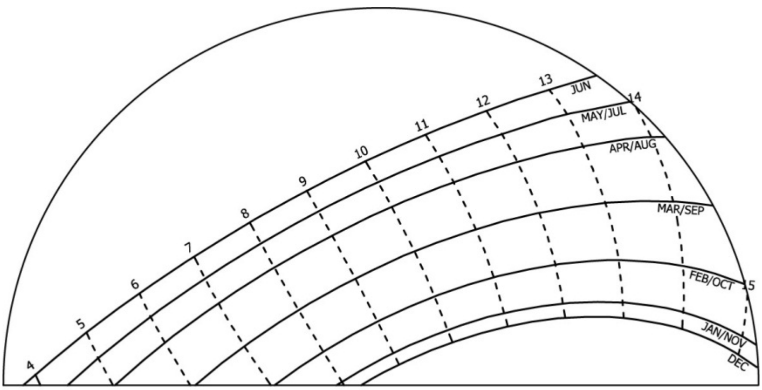


Figure 11.13: Sunpath diagram southeast

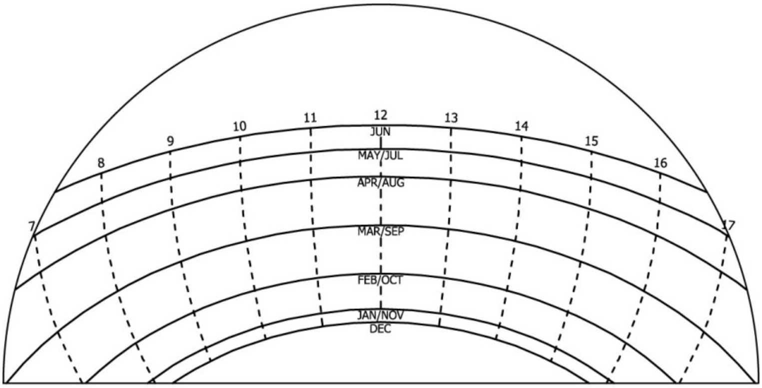


Figure 11.14: Sunpath diagram south

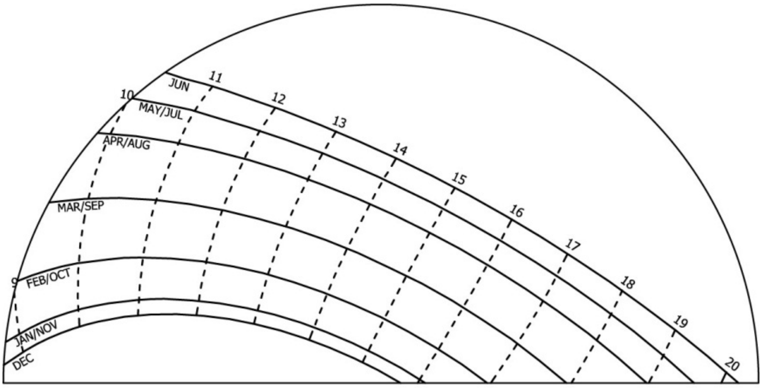


Figure 11.15: Sunpath diagram southwest

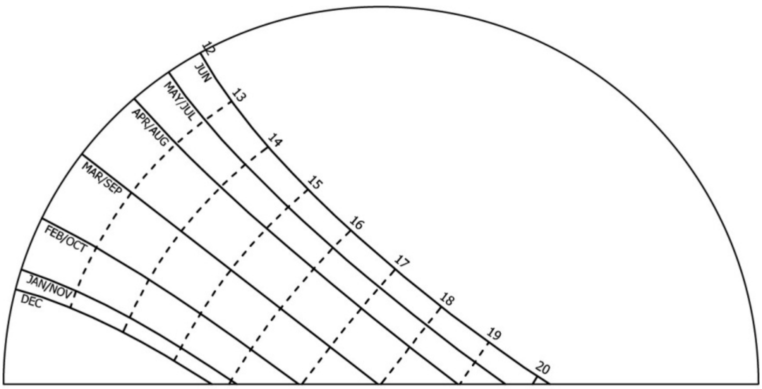


Figure 11.16: Sunpath diagram west

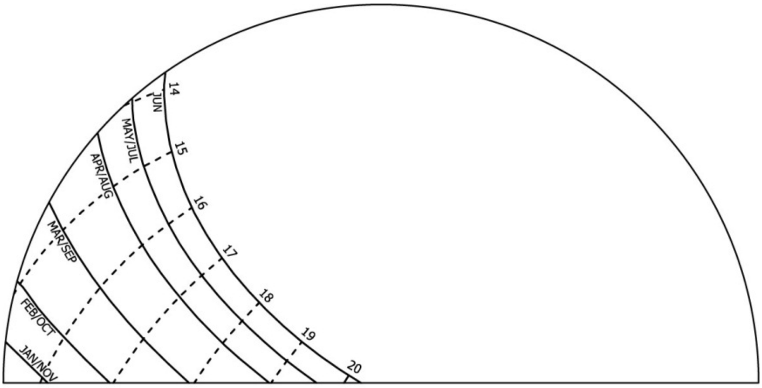


Figure 11.17: Sunpath diagram northwest

Text box 11.4: Background information on the construction of the sunpath diagrams

The construction of the sunpath diagrams consists of several steps. First the altitude and azimuth of the sun is calculated for each hour between sunrise and sunset on seven different dates (Table 11.6, Van der Voorden, 1979).

Table 11.6: Dates for which sun paths are calculated

Dates sunpath diagrams
22 December
20 January (equals 22 November)
19 February (equals 23 October)
21 March (equals 23 September)
20 April (equals 23 August)
21 May (equals 23 July)
21 June

The altitude and azimuth of the sun are calculated from two basic equations:

$$h = \arcsin\left(\sin\lambda \cdot \sin\delta - \cos\lambda \cdot \cos\delta \cdot \cos(H)\right) \tag{11.12}$$

$$a = \arcsin\left(\frac{\sin(H) \cdot \cos\delta}{\cos h}\right) \tag{11.13}$$

where h is the solar altitude (angle of elevation), a is the solar azimuth (bearing angle), λ the latitude of the locality, δ the solar declination, and H the hour angle of the sun from solar noon, all angles being measured in degrees (Van der Voorden, 1979, p.19; Hopkinson et al., 1996, p. 490).

The hour angle H and the solar declination δ give information about the direction of the solar radiation (Van der Voorden, 1979). The hour angle is calculated by the equation:

$$H = 15° \cdot t \tag{11.14}$$

where t equals the time in hours according to the true solar time.

On each date the solar declination has a constant value. This value can be calculated for the n^{th} day of the year with the equation (Van der Voorden, 1979):

$$\delta = 23{,}45° \cdot \sin\left(\frac{360°(284+n)}{365}\right) \tag{11.15}$$

After calculating the altitude and azimuth of the sun, the position of the sun in the sunpath diagrams can be calculated. First angles α and β, which also are also used for the construction of the dot charts, are derived from angles a and h. The angle β is dependent on the orientation of the diagram. As mentioned in the introduction diagrams are created for eight orientations: north, northeast, east, southeast, south, southwest, west, and northwest. For each orientation the derivation of angle β from the solar azimuth is given in table 11.7. The angle α is independent of the orientation of the diagram and can be calculated with the equation:

$$\alpha = 90° - h \qquad (11.16)$$

Table 11.7: Derivation of angle β from the solar azimuth

Orientation	Calculation of angle β	
North	$\beta = 180° - a$	When $a \geq 0$
	$\beta = 180° - a$	When $a < 0$
Northeast	$\beta = 135°$-a	When $a \geq -45°$
	$\beta = -255° - a$	When $a < -45°$
East	$\beta = 90° - a$	When $a \geq -90°$
	$\beta = -270° - a$	When $a < -90°$
Southeast	$\beta = 45° - a$	When $a \geq -135$
	$\beta = -315° - a$	When $a < -135$
South	$\beta = -a$	
Southwest	$\beta = 315° - a$	When $a \geq 135°$
	$\beta = -45° - a$	When $a < 135$
West	$\beta = 270° - a$	When $a \geq 90$
	$\beta = -90° - a$	When $a < 90$
Northwest	$\beta = 225° - a$	When $a \geq 45$
	$\beta = -135° - a$	When $a < 45$

Subsequently, the angles σ and τ can be derived from α and β by the equations 11.7 and 11.8 (Text box 11.1). After calculating angles σ and τ the sun path diagrams are drawn according to the equidistant projection function as described in chapter 10.

Text box 11.5: Procedure to determine the sun's position with the sun path diagrams

The movement of the sun throughout the year can be made visible by placing the right sunpath diagram onto the diagram with the basic projection. The diagram which has to be chosen depends on the viewing direction of point P, the point from which the projection is made. As mentioned in the former paragraphs, sunpath diagrams are made for eight geographical orientations. It is possible that point P is not exactly orientated at one of these orientations. In that case the sun path diagram should be chosen which most closely meets the orientation of point P.

The time displayed in the sun path diagram is the mean solar time. The mean solar time deviates slightly from the apparent or true solar time. The apparent solar time can be converted from the mean solar time by correcting for irregularities in the actual length of a solar day throughout the year (Hopkinson, et al., 1966, p. 490).

In order to convert the mean solar time into the current local time a correction has to be made for the longitude of the location in relation to the Greenwich meridian, and for the local time zone in relation to the Greenwich Mean Time (GMT). The current local time can be calculated with the equation:

$$LT = ST + C_{GMT+i} + L \cdot 4\min \qquad (11.17a)$$

where LT is the current local time, ST is the mean solar time, C_{GMT+i} is the difference between the local time zone and the Greenwhich Mean Time, and L is the longitude of the location of the projection in degrees east (negative) or west (positive) of the meridian.

The average longitude of the Netherlands is 5º east, and the time zone is MET (Middle European Time), which is GMT plus one hour. The current local time is:

$$LT = ST + 1:00 - 5 \cdot 4\min = ST + 0:40 \qquad (11.17b)$$

In the Netherlands Daylight Saving Time starts the last Sunday of March and ends the last Sunday of October. During this period one extra hour has to be added to the solar time, which means that the current local time is the mean solar time plus 1:40 hours.

11.4. Accuracy of the Sunpath Diagrams

For the validation of the sunpath diagrams, realistic renderings and luminance calculations are made with Desktop Radiance 2.0 BETA under a clear CIE sky. The results are used to examine if the sun’s position according to the sunpath diagrams agrees with the sun position according to the luminance pictures calculated with the light simulation software. For all simulations with Desktop Radiance the projection from view point P1 of the test model is used. The procedure of the simulations is described in text box 11.6.

Realistic renderings and luminance pictures of the three different orientations of the test model are displayed in figures 11.18 to 11.20. All pictures display the light distribution in the test model on 22 December at 9:00 hour true solar time. Sunpath diagrams with the same orientation as the test model are put onto the pictures. The position of the sun according to the sunpath diagrams corresponds with the outcome of Desktop Radiance 2.0 BETA. The luminance pictures show that the highest luminance levels are found in the same area as where the sun is located according to the sunpath diagrams.

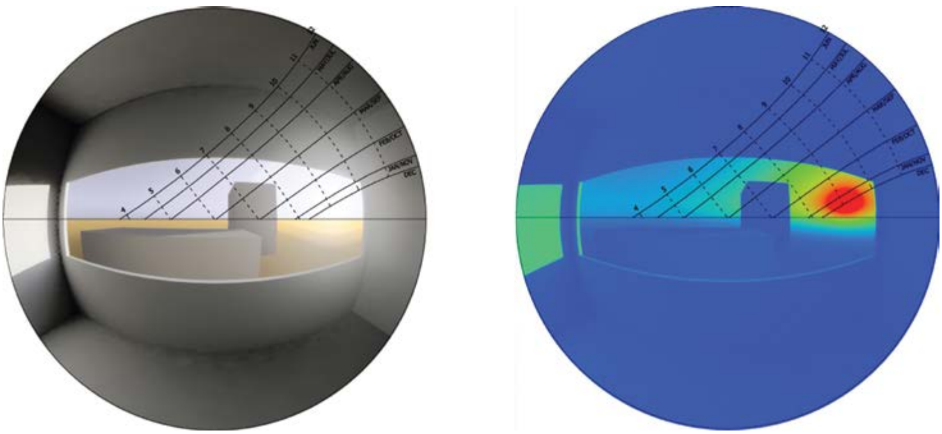


Figure 11.18: The sun’s position on 22 December at 9:00 hour true solar time. orientation of the model is East

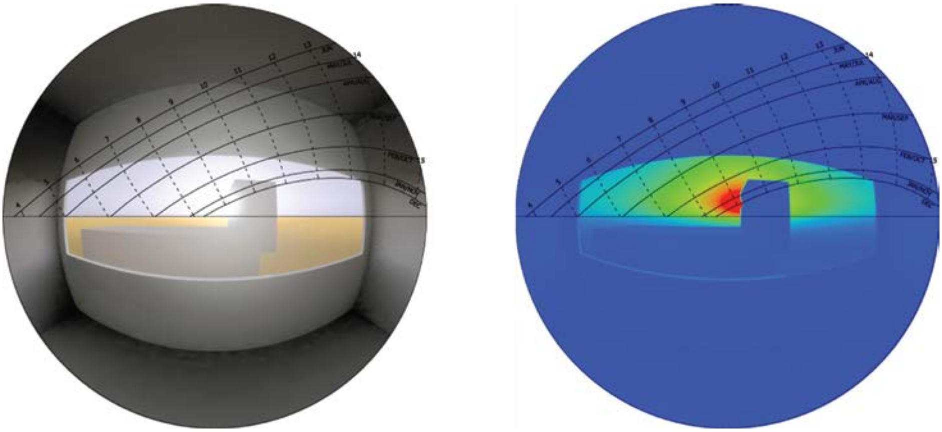


Figure 11.19: The sun's position on 22 December at 9:00 hour true solar time. orientation of the model is Southeast

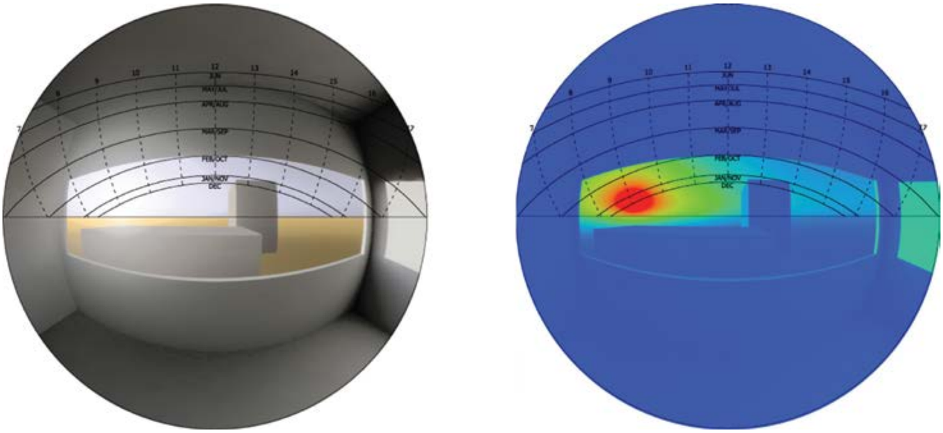


Figure 11.20: The sun's position on 22 December at 9:00 hour true solar time. orientation of the model is South

Text box 11.6: Sunlight simulations with Desktop Radiance 2.0 BETA

Simulations are made for three different orientations of the test model. As described in paragraph 11.3 sunpath diagrams are developed for eight different orientations of the view point. The orientations which are selected for the validation are East, Southeast and South. The input parameters of the simulations are displayed in Table 1.8.

Table 11.8: Input parameters of the test model in Desktop Radiance 2.0 BETA

Variable		Input
Location		Latitude is 52º North. Longitude is 5º East
Dates		22 December 21 March 21 June
Sky		CIE clear sky
Material properties	Interor	RAL7030_Stone_Grey (56.08% reflectance)
	Exterior	RAL7013_Brown_Grey (26.15% reflectance)
Simulation parameters	Lighting	Light Variability is set High Ambient Bounce is 4
	Geometric Detail	Geometric Detail is set High
	Rendering	Rendering Quality is set High

The longitude which is entered in Desktop Radiance is 5º East, because this is the mean longitude of the Netherlands.

In Desktop Radiance the current local time has to be entered, but the time displayed in the sunpath diagrams is the mean solar time. The choice is made to make simulations for full hours of the mean solar time on three different dates. The current local time is calculated according to the procedure described in paragraph 11.3. When the mean solar time in December or March is 9:00 hour, the current local time is 9:40 hour. In June the Daylight Saving Time is valid in the Netherlands, which means that in June the current local time would be 10:40 hour.

11.5. Key Findings

For the D&V analysis method existing dot and sunpath diagrams are transformed into vertical, equidistant projections. In this way, they can be used in combination with the projection diagrams described in Chapter 10. With the dot diagrams the light level in a measurement point can be predicted and the sunpath diagrams might be useful to predict when glare problems will occur and when there will be a need for sunshading. Moreover, the sunpath diagrams can also be used to test if regulations are met which prescribe a minimum number of uninterrupted sun hours at for instance the window sill (Chapter 2).

Dot diagrams are made for:

- a horizontal measurement point and uniform sky
- a vertical measurement point and uniform sky
- a horizontal measurement point and CIE overcast sky
- a vertical measurement point and CIE overcast sky

Sunpath diagrams are made for 52º northern latitude, and eight geographical orientations, i.e. North, Northeast, East, Southeast, South, Southwest, West, and Northwest.

The accuracy of the dot diagrams is tested by comparing calculations with the dot diagrams to computer calculations. The accuracy of the dot diagrams is found acceptable for two reasons. Firstly, the results of the dot diagrams are highly correlated with the results of Desktop Radiance and DIALux. Secondly, similar absolute and percent deviations are found between the results of the dot diagrams and Desktop Radiance as between the results of DIALux and Desktop Radiance. However, when someone is testing if a design meets the criterion of a minimum average sky component of 1%, he or she has to take into account that meeting this criterion can depend on which calculation method is selected. The dot diagrams give a more conservative estimation of the sky components than the light simulation software.

The accuracy of the sunpath diagrams is tested by comparing the diagrams with calculations of the luminance distribution in the projections from the test model. The sunpath diagrams are found to show correctly how the sun moves along a window on different dates and times.

In the next chapter the applicability of the D&V analysis method is explored by an experiment with a scale model. It investigates to what extent the daylight diagrams can be used to predict the measured and perceived light level in an indoor space. Furthermore, it explores the applicability of the new method for the analysis of view quality.

11.6. References

Hellinga, H.IJ., Daglichtsimulatie met Desktop Radiance en DIAlux, Bouwfysica, Vol. 19, No. 4, 2006, p 21-27

Hopkinson, R.G.; Petherbridge, P.; Longmore, J., Daylighting, London: Heinemann, 1966, p. 490

Santen, C. van, Hansen, ir. A.J., Licht in de architectuur: Een beschouwing over dag- en kunstlicht, Amsterdam: J.H. De Bussy bv, 1985

Van der Voorden, M, Dictaat Stedebouwfycia gc 49: Bezonning, Technische Hogeschool Delft, Afdeling der Civiele Techniek, Delft: TH Delft, 1979

Chapter 12

Experimental Validation of the Analysis Method

In the former two chapters a new method is described for the analysis of the daylight and view quality of window openings. This chapter explores the applicability of the method by an experiment with a scale model. A comparison is made between subjective perception of the daylight access into and view from the scale model and results of the D&V analysis method.

For the experiment, a scale model of an office is made. The façade of the model can be changed. A total of seven different facades are made, with a different window size, shape and/or position. The impact of the different window configurations on the daylight and view quality is studied by questionnaire research and measurements at three different locations.

In total, 91 people participated in the research. Each participant filled out the questionnaire for three different window designs. The questionnaire results are compared to measured illuminance levels, calculated sky components and the presence of direct sunlight. Furthermore, the assessment of the view quality by the participants is compared to the rating of view quality according to the D&V analysis method.

The research questions are:

- To what extent can the dot diagrams of the D&V analysis method be used to predict what the measured and perceived light level will be in an indoor space?
- To what extend can the sunpath diagrams of the D&V analysis method be used to predict when glare problems might occur?
- How accurate is the new assessment method for view quality?

Chapter outline

Text box 12.1: Procedure ANOVAs, t-tests, χ^2-test and Pearson's correlations

The questionnaire results are divided into different categories which are compared to each other by one-way analysis of variance (ANOVA) or an independent samples t-test:

Mean results of different window designs are compared by repeated measures ANOVA. Repeated measures ANOVA is chosen, because each participant in the research assessed three different conditions, of which the mean results are compared to each other. The accuracy of the standard ANOVA depends upon the assumption that scores in different conditions are independent. This is not the case with repeated measures, because it takes into account that the data comes from the same person. An additional assumption is made, which is the assumption that the relationship between pairs of experimental conditions is similar, which is called the assumption of sphericity (Field, p.459). Mauchly's test of Sphericity should be non-significant in order to meet the condition of sphericity. If not, the results of the Greenhouse-Geisser correction are reported.

The differences between the results obtained from the three different views is explored by between subjects ANOVA's. The same procedure is followed as described in the Introduction of Chapter 7. T-tests are done to explore if the presence of sunlight affects the perceived light levels and degree of discomfort glare.

The correlation between variables like the degree of discomfort glare and light level in the scale model is examined by calculating Pearson's correlations. Correlations are calculated between questionnaire results on light perception and measured or calculated light levels and perceived view quality. The results are interpreted according to Field, 2008, p. 173:

- r = .1 is a small effect
- r = .3 is medium effect
- r = .5 is large effect

12.1. Approach

12.1.1. Scale model

A scale model of an office room, scale 1:5, was built for the research. The dimensions of the scale model are 1.08 m wide × 0.72 m long × 0.54 m high. This means that the real size of the office room would be 3.6 x 5.4 m × 2.7 m. The ceiling and the walls are painted white (reflection factor = 0.85), and the ground floor is painted grey (reflection factor = 0.2).

The façade of the scale model is interchangeable. Four metal strips keep the façade in its place. One side wall and the back wall have an opening of 150x150 mm, which can be used to look into the scale model and to put measurement equipment inside. The openings can be closed by wooden shutters, which are painted in the same color as the walls. A black cloth prevents that daylight enters the room through these openings when they are opened. Only the opening in the back wall is used during the experiment.

In order to ease the reading of the space, two tables and chairs are put into the scale model. The interior layout, which is displayed in figure 12.1, is not a common layout for office rooms. The choice was made to put one table in front and one at the back of the space in order to stimulate the participant to observe the entire space. During tests prior to the experiment it was observed that, when both tables were put against the wall with the window, the participants would only assess the front part of the model, because the remainder of the space would be empty.

Figure 12.1: Scale model

12.1.2. Seven window designs

Three sets of facades are made in order to study how different window dimensions influence the visual perception of an office room. Each set consists of three different windows, which differ respectively by window size, window shape, and window position (Figure 12.2). The first window is a reference window. It is a wide horizontal window, which occupies 43% of the wall area. The real size (scale 1:1) of this window would be 3.30m × 1.30m. The first set includes two more facades, which have a different window area. Window 2 is a small window; the size is only 16% of the facade. The height and position of the window is the same as for the reference window. Window 3 is a fully glazed facade.

In the second set the window area of each facade is the same. Window 4 stands for the most common window dimension in office buildings. It's dimensions are the same as the standard window configuration described in IEA task 27 (Van Dijk, 2001 In Ariës, 2010) It consists of two vertical windows measuring 1.30 m × 1.7 m. Window 5 is one single vertical aperture reaching from the floor to the ceiling. Its dimensions are 1.77 × 2.40 m. In the third set even the window shape is the same. The only difference is the position of the window. Window 6 is positioned at the bottom of the façade and window 7 is positioned at the upper part of the façade.

Figure 12.2: Seven window design organized in three sets of facades

12.1.3. Three different views

The experiment took place at three different locations at the faculty of Architecture, in order to explore how different views affect the outcome of the questionnaire. Participants in the experiment could observe the view by looking through the window in the façade of the scale model.

The first location is at the corridor at the first floor. The orientation of the scale model is Southwest. The view consists of a neighbor building, a part of the faculty building, the sky, a street and a parking lot. The second location is also at the corridor, but at the ground floor and orientated Northwest. The view consists of a parking lot and another part of the faculty building. Finally, the third location is at the ground floor in a classroom near the main entrance of the building. The orientation of the scale model is again Northwest and the view consists of the main entrance (viewed sideways), the square in front of the entrance, and another part of the faculty building.

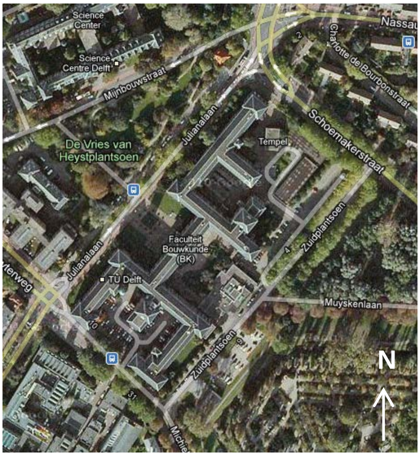


Figure 12.3: Faculty of architecture (Google Maps, 2012)

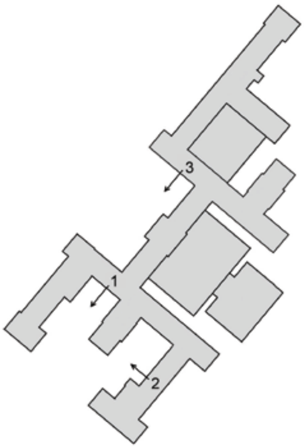


Figure 12.4: Three locations of the experiment

View 1 View 2 View 3

Figure 12.5: The three outside views

12.2. Questionnaire and Procedure

12.2.1. Questionnaire

The questionnaire is divided into 5 categories, starting with general and finishing with particular questions (Appendix J):

1. Personal information
2. Overall perception
3. Outside view
4. Lighting
5. Ideal window setting

The first part deals with personal information and general questions. Part two is related to the overall perception, and part three asks to assess the outside view quality. Subsequently, the fourth part is about the lighting of the office building. The questionnaire concludes with the fifth part, which asks the respondent to draw their ideal window setting.

The questionnaire is mostly composed of closed questions, with answers on a binary or 5-point Likert-scale. This enables to perform some statistical tests. However, the questionnaire also consists of a few open-ended questions in order to learn more about people's motivation to give certain answers.

Before the respondent answers the questionnaire, an introduction is given which describes the goal and the sequence of the experiment. Each person has to assess one set of three different facades at one of the three locations. Therefore, parts two, three and four are repeated three times, i.e. once for each façade.

12.2.2. Procedure

The experiment was carried out between the 4th of May and the 9th of June 2010. The periods in which different parts of the experiment took place are:

- View 1 from 4 to 11 May,
- View 2 from 11 to 20 May, and
- View 3 from 7 to 9 June.

Students of the faculty of Architecture were asked to volunteer in the research by a flyer, which is displayed in figure 12.6. Students and teachers were also asked personally if they wanted take part in the research. Furthermore, students of a bachelor course Building Physics participated in the research as a part of their education.

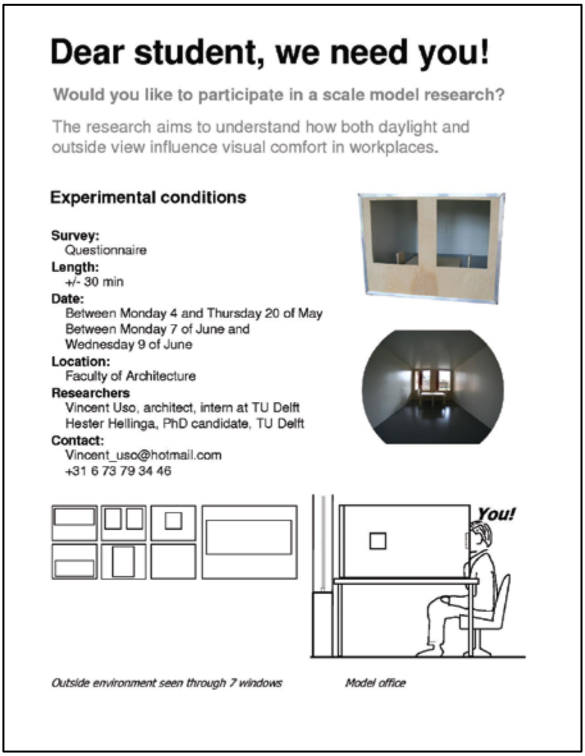


Figure 12.6: Flyer used to invite students to participate in the research (Uso, 2010)

Each participant is asked to assess one set of facades and is in this way classified into one of the three groups described in table 12.1. The participant answered the questionnaire at one location in the faculty building, which means that he or she was subjected to only one of the three different views. The order in which the facades were displayed to the participant varied.

Table 12.1: In the experiment three groups are distinguished

Group	Variable	Window designs
Group 1	Window Size	WD1: Reference WD2: Small WD3: Big
Group 2	Window Shape	WD1: Reference WD4: Two vertical WD5: One vertical
Group 3	Window Position	WD1: Reference WD6: Bottom WD7: Top

During the experiment daylight levels were measured with two illuminance meters. Vertical illuminances were measured inside the scale model at eye height at the back wall and outside the scale model on the window. Furthermore, pictures were taken inside the scale model with a CANON EOS 350D camera and Sigma 8mm Circular Fisheye lens (Figure 12.7). This was done before the participant started to fill out the questionnaire for the first façade. The measurements were repeated afterwards, and, subsequently, the first façade was replaced by the second one and the procedure was repeated, which was also done for the third façade.

Figure 12.7: Experimental set-up (Uso, 2010)

12.3. Participants

In total, 91 students and employees of the Delft University of Technology participated in the research, which took them about 1:30 hours per person. The table below displays how many people were involved in each group and in each view.

Table 12.2: Number of participants in each group and at each view

Group	View 1	View 2	View 3	Total
Group 1: Window Size	12	10	8	30
Group 2: Window Shape	12	10	7	29
Group 3: Window Position	13	11	8	32
Total	37	31	23	91

The average age is about 29 years old. The oldest person is 61 years old and the youngest is 20 years old. Most participants are younger than 40 (Table 12.3). About alf of the participants are men and half are woman (Table 12.4). However, the second view is assessed by two times more men than women.

Table 12.3: Age of the participants

Age	Percentage
< 30	73%
30-39	18%
40-49	4%
50-59	3%
> 59	2%

Table 12.4: Gender of the participants

Gender	Percentage
Male	52%
Female	48%

About half of the participants in the research were wearing glasses or contact lenses during the experiment (Table 12.5). The majority of the participants has a Dutch nationality (Table 12.6). A total of 13% comes from the rest of Europe. Most of them are from Italy, Greece or Eastern Europe. Finally, 23% of the participants are students coming from outside Europe. They are mostly from Asian countries (China, Indonesia, Malaysia) or Suriname.

Table 12.5: Number of participants who wear glasses and/or contact lenses

	Percentage glasses	Percentage contact lenses
Yes	33%	23%
No	67%	77%

Table 12.6: Nationality of the participants

Nationality	Percentage
Dutch	63%
Other European nationalities	13%
Non-European nationalities	23%

12.4. Results of the D&V Analysis Method

12.4.1. Access of day- and sunlight

The dot charts of the D&V analysis method are used to calculate the sky components in the scale model. The diagram for a vertical measurement point and CIE sky is used and the measurement point is located at eye height at the back wall of the scale model, the position of the observer. It was not possible to make projections at a distance which corresponds to 1.5 meter from the facade in the real office, like prescribed in chapter

10. Therefore the view in the picture is rather small (Appendix K), but the sky component at the observers eye could be calculated with the dot diagrams.

Sky components are calculated for the different window configurations without considering the view (Appendix K). The measured vertical illuminance and sky component per window are given in table 12.7. A strong correlation is found between the inside vertical illuminance and the sky component ($r=.76$, $p<.001$).

Table 12.7: Vertical illuminances and sky components

Window Design	E_{inside} [lux]		$E_{outside}$ [lux]		SC [%]
	Mean	St. dev	Mean	St. dev	
WD1: Reference	772	784	13.359	18.554	2.1
WD2: Small	464	505	18.855	23.291	1.0
WD3: Big	1.501	1.359	14.464	15.812	3.6
WD4: Two vertical	988	954	12.946	19.093	2.8
WD5: One vertical	737	619	12.345	17.559	2.2
WD6: Bottom	431	232	7.369	5.802	.4
WD7: Top	583	585	8.205	11.080	3.2

With the sunpath diagrams the access of direct sunlight is explored. The sunpath diagrams show that during the experiment there would never be direct sunlight in the viewpoint, so in the eyes of the observer, but that during some periods of the research sunlight might shine into the scale model (Appendix K). For this reason, a variable is constructed named SL-1 which represents the chance on direct sunlight when the questionnaire was filled out. The answer Yes is selected when there might be direct sunlight and the answer No is selected when no direct sunlight will shine into the scale model due to the sun’s position.

Subsequently, the pictures which were taken during the experiment are examined to see at what moments direct sunlight was shining into the scale model. If this was the case depended on the weather conditions. A second variable is constructed which answers the question if there was direct sunlight (SL-2 with answers 1 = Yes and 0 = No). In this way, a total of five light variables are constructed, which answers will be compared to the questionnaire results (Table 12.8).

Table 12.8: Variables daylight measurements and calculations

Light levels and direct sunlight		
E_{inside}	Vertical illuminance inside the model	Continuous [lux]
$E_{outside}$	Vertical illuminance outside the model	Continuous [lux]
SC	Sky component	0 to 100%
SL-1	Direct sunlight according to sunpath diagram	1 = Yes, 0 = No
SL-2	Direct sunlight according to pictures	1 = Yes, 0 = No

12.4.2. View quality

The quality of the views from the different windows at the three different locations of the experiment is determined by the researcher by following the procedure of the D&V analysis method which is described in paragraph 10.6. A summary of the results is given in table 12.9.

Table 12.9: View quality score

Window Design	View 1	View 2	View 3
WD1: Reference	6	5	6
WD2: Small	4	4	5
WD3: Big	7	5	6
WD4: Two vertical	6	5	6
WD5: One vertical	6	5	6
WD6: Bottom	5	3	4
WD7: Top	4	4	4

None of the views from the scale model has a high view quality (i.e. $\geq$ 8 points). The views from the scale model with WD1, WD3, WD4 and WD5 have a medium quality (i.e. 5-7 points). If the view from the scale model with WD2 or WD6 has a low or medium quality depends on the location of the scale model. WD2 with View 3 and WD6 with View 1 have a medium quality, the other combinations have a low view quality (i.e. $\leq$ 4 points). The views from the scale model with WD7 have a low view quality. Pictures of the views with the rating per item can be found in appendix L.

12.5. Questionnaire Results[7]

In this paragraph first the results of the questionnaire on window size, window shape, and window position are discussed. Subsequently, the results of the questions about the light level and experience of glare are examined. After exploring if there are statistically significant differences between the results of the different façades, correlations are calculated between the questionnaire results and the measured illuminance levels, calculated sky components and the access of direct sunlight.

[7] The scale model research was executed together with Vincent Uso, student from ENTPE, Lyon (France). The analysis of the results of the scale model research in this chapter focus on how the analysis method can be used to assess daylight and view quality. Results of the other questions can be found in the internship report of Vincent Uso (2010).

The final part of this paragraph is about the assessment of the view quality. First the difference between the results obtained from the different views at the three different locations is examined. Secondly, the differences are explored between the results of the different facades. The rating of the view quality by the subjects in the scale model research is compared to the rating of the view quality according to the D&V analysis method. Finally, the correlation between perceived view quality and the perception of glare is calculated. The variables discussed in this paragraph are displayed in the text box 12.2.

Text box 12.2: Variables from the questionnaire

The questionnaire asks the participants how satisfied they are with the size of the windows, measured on a scale from (1) much too big to (5) much too small. The questionnaire furthermore contains a Yes/No question about the appropriateness of the window position. Both the perceived light level in the scale model and the perceived degree of discomfort glare are measured on a 5-point rating scale (Table 12.10). Subsequently participants had to assess the view quality, measured on a scale from (0) very bad view to (10) very good view.

Table 12.10: Variables from questionnaire

Overall perception		
14	Satisfaction with the size of the window(s)	1 = Much too big, to 5 = Much too small
15	Appropriate window position	1 = Yes, 0 = No
Results lighting and view quality		
20	Light Level	1 = Far too much light, to 5 = Far too little light
22	Degree of discomfort glare	1 = Not perceptible, to 5 = Intolerable
17	View Quality	0 = Very bad view to 10 = Very good view

12.5.1. Window size and position

The participants in the research gave their opinion about the window size (Figure 12.8, table 12.11) .A Repeated Measures ANOVA on the results of group 1 shows that there is a statistically significant difference in the satisfaction with the size of the windows (Table 12.12). The graph shows that WD2 is considered to be too small by the far majority of the participants in the research. WD3 is found to be too big my most participants and overall the reference window WD1 is considered to be a good window size. The findings agree with the results of the literature study and field study that in an office space the window area should be at least 20-25% of the wall area, but that a fully glazed façade is not preferred (Chapter 2 and 7).

No statistically significant difference is found between the different window designs in group 2 and in group 3 (Table 12.12), although the graph shows that in group 2 there are somewhat more participants who think that the window size of WD4 is too small. One reason could be that the façade area between the two window openings blocks a part of the view, because the literature shows that this is a significant factor in window size preference (Chapter 2). This seems to be confirmed by the results of group 2. There are somewhat more participants who think that WD6 and WD7 are too small. The view quality, assessed by the researcher according to the D&V analysis method, is at all three locations of the experiment lower than the quality of the view through WD1 (Table 12.9), while the sky component is lower in the case of WD6 and higher in the case of WD7 (Table 12.7). However, conclusions should be drawn carefully, because no statistically significant are found, which could be due to the limited number of participant in the study, which may cause a lack of power.

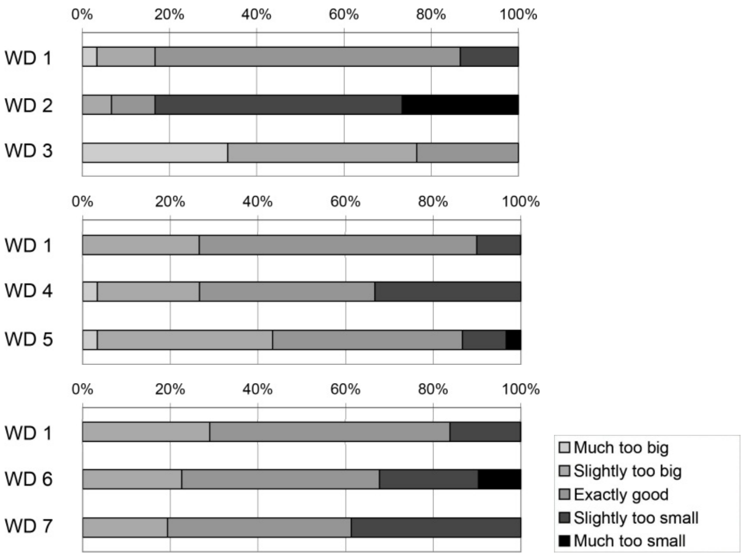


Figure 12.8: Results of the question: What do you think of the size of the windows?

Table 12.11: Results of the question: What do you think of the size of the windows?

Group 1	Mean	Std. deviation	Number (n)
WD1	2.93	.640	30
WD2	4.03	.808	30
WD3	1.90	.759	30
Group 2	Mean	Std. deviation	Number (n)
WD1	2.83	.602	29
WD4	3.03	.865	29
WD5	2.69	.850	29
Group 3	Mean	Std. deviation	Number (n)
WD1	2.88	.660	32
WD6	3.19	.896	32
WD7	3.19	.738	32

Table 12.12: Repeated Measures ANOVA on the assessment of the window size

Group	df1	df2	F	Significance
Group 1: Window Size	2	58	94.11	.000
Group 2: Window Shape	2	56	2.13	.13
Group 3: Window Position	2	62	2.63	.08

The results of the question about the appropriateness of the window position are displayed in figure 12.9. Groups 2 and 3 show an interesting outcome. The position of the reference window is appreciated by most participants. However, the position of WD4 and WD5 is disliked by many participants, and the far majority thinks that the position of WD6 and WD7 is inappropriate.

In group 2 the windows have an equal size, but different geometry. The sky component of WD4 and WD5 is higher than with WD1 (table 12.7) which means that more daylight will enter the eye of the observer. The view quality score is almost the same (table 12.9). Still the position of WD1 is much more appreciated. It seems that the respondents, independently of the daylight access and outside view, prefer a wide horizontal aperture. This would confirm the finding of Keighley (1973), who in his research also found that the subjects preferred wide horizontal apertures.

In group 3 the appropriateness of the window position seems to be related to the view quality scores. The size and geometry of the windows is the same, but due to the position of the window, WD6 and WD7 have a one or two points lower view quality score than WD1 (table 12.9).

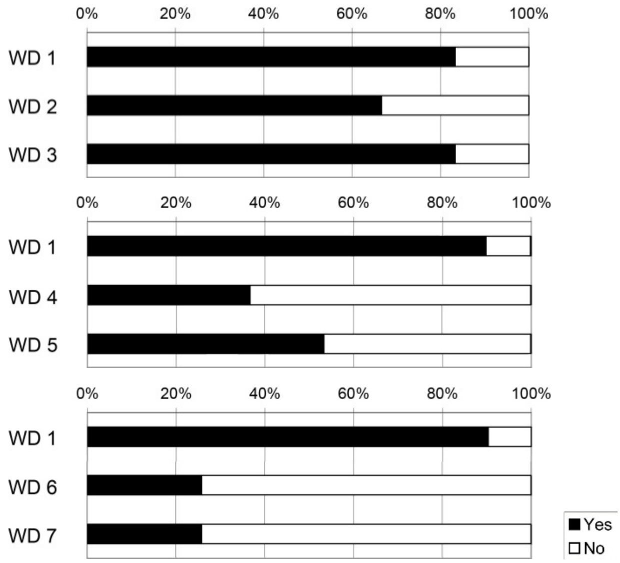


Figure 12.9: Results on the question: Is the position of the window appropriate?

12.5.2. Light level and glare

The light level in the scale model with WD1 is generally considered to be good (Figure 12.10, table 12.13). Results of group 1 show a statistically significant difference between the three different window designs (Table 12.14). The graph and table show that most participants think that there is too little light in the scale model with WD2. In contrary, there is slightly too much light in the scale model with WD3. Also a statistically significant difference is found for group 3 (Table 12.14). The light level in the scale model with WD1 or WD7 is considered to be good by far most participants, but the light level in the scale model with WD6, the window which is placed at the bottom of the façade, is found to be insufficient. For group 2 no statistically significant difference is found between the three different window designs.

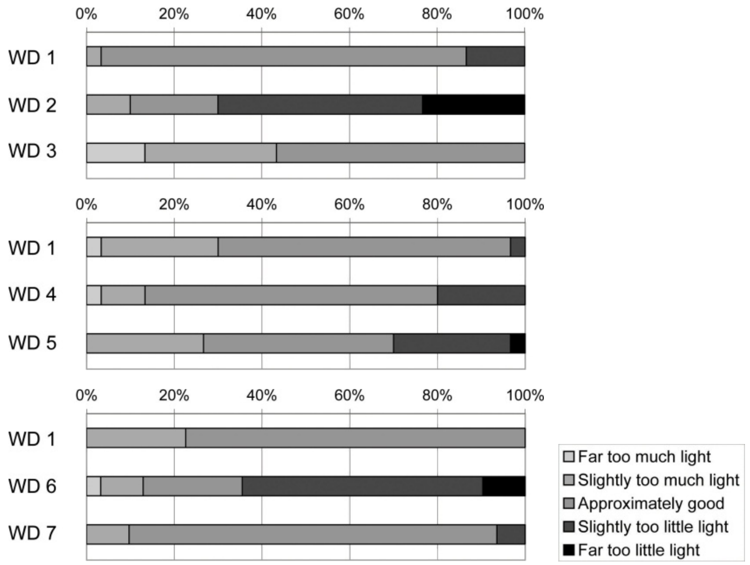


Figure 12.10: Results of the question: What do you think of the light level?

Table 12.13: Results of the question: What do you think of the light level?

Group 1	Mean	Std. deviation	Number
WD1	3.10	.403	30
WD2	3.83	.913	30
WD3	2.43	.728	30
Group 2	Mean	Std. deviation	Number
WD1	2.69	.604	29
WD4	3.03	.680	29
WD5	3.07	.842	29
Group 3	Mean	Std. deviation	Number
WD1	2.78	.420	32
WD6	3.56	.914	32
WD7	2.97	.400	32

Table 12.14: Repeated Measures ANOVA on the perceived light level

Group	Variable	df1	df2	F	Significance
Group 1	Window Size	2	58	37.79	.000
Group 2	Window Shape	1.62	45.45	2.96	.07
Group 3	Window Position	1.29	40.04	13.02	.000

If the perceived light level inside the scale model is related to the measured illuminance levels and sky components calculated with the D&V analysis method (paragraph 12.4) is explored by calculating Pearson's correlations between the variables. A statistically significant correlation is found between the perceived light level and the illuminance inside the scale model and even a medium strong correlation between the perceived light level and the sky component (Table 12.15). If the sky component was 1.0 or less, the light level in the scale model was found to be too low. A sky component of 3.6 was found to be too high. Conclusions, however should be drawn carefully, because each participant in the study assessed three different window views, and cases are therefore not statistically independent. It is difficult to estimate the effect of this, but it seems that the sky component can give a good indication of the perceived light level in an indoor space.

Table 12.15: Correlations between light perception and measured illuminance levels and calculated Sky Components

Variable	Data	E_{inside} [lux]	$E_{outside}$ [lux]	SC [%]
20 Light level	Pearson Correlation	-.21	-.00	-.42
	Significance	.000	.99	.000
	Number	273	260	273

A t-test is done on the results of the scale model with WD1 in order to explore if the perceived light level is related to the sunlight variables described in paragraph 12.4.1. No statistically significant difference is found.

Table 12.16: t-test on the results of WD1

Variable	Data	SL-1 Direct sunlight according to sunpath diagram	SL-2 Direct sunlight according to pictures
20 Light level	t	-1.05	.16
	df	89	80
	Significance	.30	.87

The respondents were also asked if they perceive any glare (Figure 12.11, table 12.17). Repeated Measures ANOVAs on the results did not show statistically significant differences between the window designs in either group 1, 2 or 3 (Table 12.18). In each situation there were some participants who experienced uncomfortable glare and only in the case of WD6 someone experienced intolerable glare.

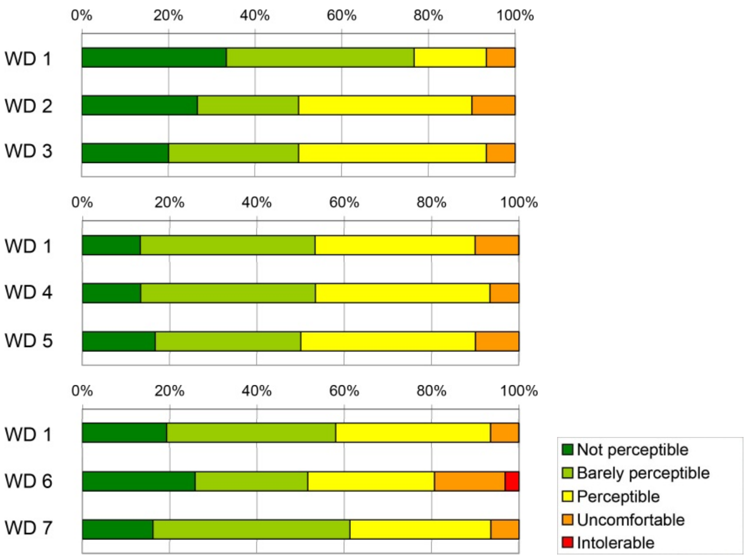


Figure 12.11: Results of the question: Evaluate the degree of discomfort glare in the entire space.

Table 12.17: Results of the question: Evaluate the degree of discomfort glare in the entire space.

Group 1	Mean	Std. deviation	Number
WD1	1.79	.890	30
WD2	2.33	.994	30
WD3	2.37	.890	30
Group 2	Mean	Std. deviation	Number
WD1	2.41	.867	29
WD4	2.41	.825	29
WD5	2.41	.907	29
Group 3	Mean	Std. deviation	Number
WD1	2.31	.859	32
WD6	2.44	1.134	32
WD7	2.31	.821	32

Table 12.18: Repeated Measures ANOVA on the assessment of the degree of discomfort glare

Group	Variable	df1	df2	F	Significance
Group 1	Window Size	2	58	2.54	.09
Group 2	Window Shape	2	56	.00	1.00
Group 3	Window Position	1.66	51.59	.27	.72

Correlations are calculated between glare perception and the measured illuminance levels and calculated sky components in the scale model (Table 12.19). No statistically significant correlations are found. Also no statistically significant correlation is found between the perceived light level in the space and the amount of glare (r=-.20, p=.06).The amount of glare seems not to depend on the light level at the eye. Finally, a t-tests on the data of the scale model with WD1 also shows no statistically significant relation between the sunlight variables and the amount of glare (Table 12.20).

Table 12.l9: Correlations between degree of discomfort glare and measured illuminance levels and calculated Sky Components

Variable	Data	E_{inside} [lux]	$E_{outside}$ [lux]	SC [%]
22 Degree of discomfort glare	Pearson Correlation	.06	-.01	-.02
	Significance	.30	.83	.76
	N	273	260	273

Table 12.20: t-test WD1

Variable	Data	SL-1 Direct sunlight according to sunpath diagram	SL-2 Direct sunlight according to pictures
22 Degree of discomfort glare	t	-.59	.34
	df	89	18.51
	Significance	.56	.74

The sky component seems to be a good predictor of the vertical illuminance inside the scale model, and also of the perceived amount of daylight. However, glare perception is not found to be related to the amount of daylight in the scale model and therefore the measured light levels and calculated sky component are no good predictors of the amount of glare. Also the access of direct sunlight is not found to be a statistically significant predictor of glare perception, which might be due to the fact that no direct sunlight was entering the eye of the observers during the experiment. Only in the latter situation the sunpath diagrams might be a good predictor of glare experience. In this study no severe glare was experienced and very few people thought there was too much light in the scale model during the experiment. In these situations other variables might play a more important role, for example the luminance ratios within the visual field or personal preferences. This is not studied during this experiment.

12.5.3. View quality

The experiment took place at three different locations, with three different views. The results of the scale model with WD1 are used to examine if the perceived view quality of these views differs. Analysis of the view according to the D&V analysis method shows that the views have a medium view quality. View 1 and 3 got six points and view 2 five points (Table 12.9, paragraph 12.4). One-way between groups ANOVA on the questionnaire results did not show a statistically significant difference between the three different views ($F(2,88)=.47$, $p=.63$). It should be noted that it were different participant who rated the three different views and it appears that their mean rating of the view with WD1 is very similar. They could not compare the three different views through WD1.

Figure 12.12: Three different views through Window Design 1, the reference window

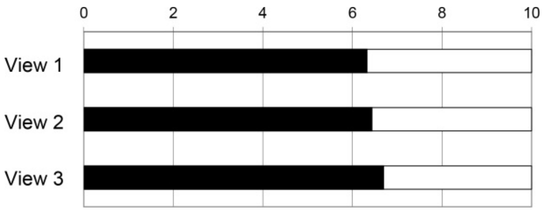


Figure 12.13: Assessment of view quality per view, WD1 (Mean=6.46, St.dev=1.44)

Table 12.21: Assessment of view quality per view

View	Mean	Std. deviation	Number
View 1	6.32	1.40	37
View 2	6.44	1.56	31
View 3	6.70	1.39	23

The differences between the view quality of the three different facades in each group is explored by Repeated Measures ANOVAs (Table 12.23). Statistically significant differences are found for each group, but are strongest in group 1. The graph in figure 12.14 shows the view through all windows except for WD3 is found to be worse than the view through WD1.

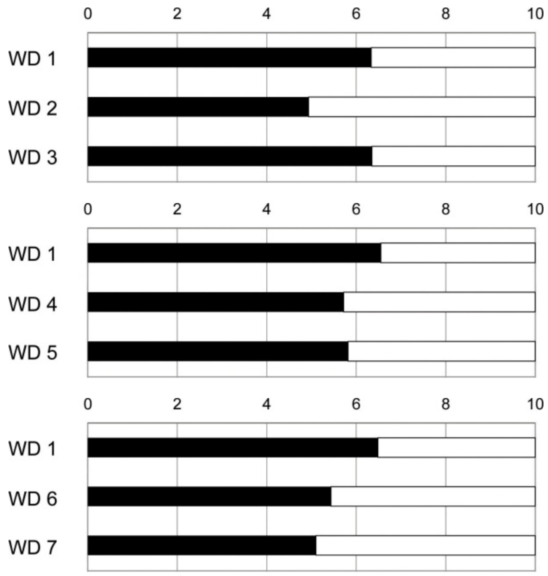


Figure 12.14: Assessment of view quality per group

Table 12.22: Assessment of view quality per group

Group 1	Mean	Std. deviation	Number
WD1	6.33	1.45	30
WD2	4.93	1.57	30
WD3	6.35	1.35	30
Group 2	**Mean**	**Std. deviation**	**Number**
WD1	6.57	1.45	29
WD4	5.71	1.39	29
WD5	5.84	1.88	29
Group 3	**Mean**	**Std. deviation**	**Number**
WD1	6.47	1.47	32
WD6	5.45	1.60	32
WD7	5.09	1.45	32

Table 12.23: Repeated Measures ANOVA on the assessment of view quality per group

Group	Variable	df1	df2	F	Significance
Group 1	Window Size	2	58	13.08	.000
Group 2	Window Shape	2	56	7.76	.001
Group 3	Window Position	2	62	9.01	.000

The results of the D&V analysis method demonstrate that on average the views through WD1, WD3, WD4 and WD5 have a medium view quality rating (i.e. 5-7 points), and that the views from the other windows on average have a low view quality rating (i.e. $\leq$ 4 points). The mean rating of the view quality by the participants in the research agrees with this finding that the view from WD2, WD6 and WD7, on average is worse than the view from the other windows (Table 12.24).

Table 12.24: Mean rating of the view quality over three locations.

Window Design	Mean score D&V analysis method	Mean rating questionnaire
WD1: Reference	5.7	6.5
WD2: Small	4.3	4.9
WD3: Big	6.0	6.4
WD4: Two vertical	5.7	5.7
WD5: One vertical	5.7	5.8
WD6: Bottom	4.0	5.4
WD7: Top	4.0	5.1

1. Answers range from 0 (low view quality) to 12 (high view quality)
2. Answers range from 0 (low view quality) tot 10 (high view quality)

The new analysis method seems to be a suitable method to predict if the view through a window has a low, medium or high view quality. The method gives a good indication of the effect of different window designs on the quality of the view through the window. On the other hand, perceived view quality depends on many more variables, than the variables which are included in the analysis method (Chapter 3, 7). Therefore, it will not be possible to provide very precise predictions of perceived view quality and individual differences might be high.

12.5.4. Correlation between view quality and glare perception

Pearson's correlations are calculated to examine if perceived view quality is correlated to perceived light level and degree of discomfort glare. No statistically significant correlations is found between the variables (Table 12.25).

Table 12.25: Correlation between perceived view quality and light level or degree of discomfort glare

Variable	Data	17 View quality
20 Light level	Pearson Correlation	.01
	Significance	.89
	Number	91
22 Degree of discomfort glare	Pearson Correlation	-.10
	Significance	.34
	Number	91

The quality of the views in this study is probably not different enough, in order to find a relationship between view quality and glare experience. Moreover, there were only a few people who experienced uncomfortable or intolerable glare, which i not related to the different window configurations in the study. A limitation of the research is that the number of participants is limited, which may cause a lack of power. This could also be a reason that no statistically significant differences are found.

12.6. Key Findings

The key findings of the scale model research are:

- The questionnaire results show that satisfaction with the window size is significantly correlated to window size and not to window shape and position. The results agree with the finding from the literature (Chapter 2) and main study (Chapter 7) that the window area should be at least 20-25% of the wall area but that a fully glazed façade is not preferred.
- It seems that the respondents, independently of the daylight access and outside view, prefer a wide horizontal aperture. This would confirm the finding of Keighley (1973), who in his research also found that the subjects preferred wide horizontal apertures (Chapter 2).
- When the size and shape of the window are the same, the appropriateness of the window position seems to be related to the quality of the outside view. The better the view quality, the better the window position.
- The perceived light level in the scale model is statistically significantly related to the window size and the window position.
- The questionnaire results show a statistically significant correlation between the perceived light level and the illuminance inside the scale model and a medium strong correlation between the perceived light level and the sky component. If the sky component was 1.0 or less, the light level in the scale model is found to be too low. A sky component of 3.6 is found to be too high. Conclusions, however should be drawn carefully, because each participant in the study assessed three different window views, and cases are therefore not statistically independent. However, it seems that the sky component can give a good indication of the perceived light level in an indoor space.
- Glare perception was not related to the different window configurations or to the amount of daylight in the scale model. For this reason, the amount of glare could not be predicted by the measured light levels and calculated sky components. The access of direct sunlight is also not found to be a statistically significant predictor of glare perception, which might be due to the fact that no direct sunlight was entering the eye of the observers during the experiment.
- The perceived view quality in the scale model is statistically significantly related to the window size, shape and position.
- The new analysis method for view quality gives a good indication of the effect of different window designs on the quality of the outside view from an office. It is not possible, however, to provide very precise predictions of perceived view quality, because it depends on many more variables, than those included in the analysis method (Chapter 3, 7).

- No relationship is found between view quality and glare experience.

In this chapter the quality of the different outside views in the experiment was quite similar and no severe glare was experienced by the participants. Very few people thought that there was too much light in the scale model during the experiment. In these situations it is difficult to predict if glare might occur. Other variables than the ones measured in this study might play an important role, for example the luminance ratios within the visual field. The outside view might only affect the perceived amount of glare if it is very good or very bad, because otherwise other variables play a more important role.

A limitation of the research is that the number of participants per window and view is very limited, which may cause a lack of power. In chapter 13 a summary is given of the results of the PhD research, general conclusions are drawn and suggestions are given for future studies.

12.7. References

Van Dijk, D., Reference office for thermal, solar and lighting calculations, report IEA task 27, subtask A, version 1.00, TNO Buidling and Construction Research, Delft, In Ariës, M.B.C., Human Lighting Demands: Healthy Lighting in an Office Environment, Eindhoven: Technical University of Eindhoven, Faculty of Architecture, Building and Planning, 2005

Field, A., Discovering Statistics Using SPSS, London: Taylor & Francis, 2003

Keighley, E.C, Visual requirements and reduced fenestration in office buildings — A study of window shape, Building Science, Vol. 8, No. 4, 1973, p. 311-320

Uso, V., Assessment of Daylight and Outside View: The Influence of Windows on the Visual Comfort of Workplaces, Internship report, Faculty of Architecture, Department Building Technology, Delft University of Technology, 2010

Websites

Satellite view of the Faculty of Architecture, https://maps.google.nl, accessed 09-10-2013

Chapter 13

Conclusion

13.1. Main Results of the Research

In this thesis, the influence of windows, daylight and outside view on the visual quality of indoor spaces is investigated. The main research question is:

How can an outside view and the access of daylight into a room be measured and visualized in an objective and comprehensible way and to what extent is it possible to predict perceived daylight and view quality?

In this chapter an overview is given of the main results of the research. An answer is given on the key question from the introduction of the thesis.

What are the benefits of windows and people's preferences regarding windows?

The most mentioned advantage of windows in the questionnaire research in this thesis was the outside view it provides, followed by the access of daylight (Chapter 5). The results confirm the finding of Christoffersen et al. (1999) and Farley & Veitch (2001) that the provision of an outside view is most valued by building occupants.

The literature shows that in an office the window should be at least 20-25% of the wall area and preferably 30% or more (Chapter 4). Results of both the questionnaire study (Chapter 7) and the scale model research (Chapter 12) agree with this finding and also show that a fully glazed façade is generally disliked.

Similar to the finding of Keighley (1973), the scale model research indicates that, independently of the daylight access and outside view, people prefer a wide horizontal aperture (Chapter 12). The results of the scale model research also indicate that when the size and shape of the window are the same, the appropriateness of the window position is related to the quality of the outside view.

What variables influence the daylight quality in indoor spaces?

People have an enormous natural capacity to change their sensitivity to light. Moreover, light perception and preferences are very variable from one person to another. Much research has been done on people's lighting preferences and what light levels are necessary to perform visual tasks. In the past, research focused on the effects of lighting on visual comfort, but the last decennium the focus has shifted towards the effects of lighting on health, which led to new insights (Chapter 3).

The literature shows no consistency in preferred illuminance levels in offices, but higher light levels seem to be preferred than the building standards prescribe (Chapter

3). Many models are developed to predict glare discomfort, amongst which the PGSV and DGP. A less complicated way to obtain information about the chance on glare, is by comparing luminance contrasts in an image of the visual field. Standards prescribe that luminance ratios between a work task and its surrounding should be no more than 10:3:1, although research shows that ratios between bright sources, like a window, and adjacent surfaces up to 40:1 are also acceptable (Chapter 3).

The questionnaire results in this thesis indicate that the amount of daylight in an office influences perceived visual comfort, but also the office layout and orientation. In the pilot study respondents who's office was orientated West had statistically significantly more complaints about glare than respondents who's office had an East orientation (Chapter 5). This is likely to be caused by the fact that during the winter months the West orientated offices receive more hours of direct sunlight during working time.

In the questionnaire study, the chance at discomfort glare was found to be lower when a workplace was orientated perpendicular to the window than when a workplace was facing the window (Chapter 7). Office workers with a window behind them experience significantly less glare by daylight shining into their eyes, but significantly more glare by daylight reflecting in the computer screen. Furthermore, respondents who filled out the questionnaire in summer were statistically significantly more satisfied with the amount of daylight than the respondents who filled out de questionnaire in autumn or winter (Chapter 7).

What variables influence the view quality in indoor spaces?

In this thesis the influence of view content on view quality is explored. In general, outside views with a high information content are found to me more interesting than views containing little information about the outside environment. For this reason, views having a horizontal stratification, containing different layers of information are preferred over single layer views (Chapter 4). This literature finding was confirmed by results of the picture question in the main study (Chapter 7). The results of the questionnaire research also show that office workers like to see the sky (Chapter 5, 7).

In the literature three characteristics of outside views are consistently found to be appreciated by building occupants (Chapter 4):

1. Natural views are preferred over build views;
2. Distant views are preferred over near views;
3. People like to see water (for example a lake or a river).

Results of the questionnaire study confirm that these elements affect perceived view quality and give more insight into the importance of the different elements (Chapter 5, 7). Natural green, as expected, appeared to be the most important variable influencing perceived view quality. This was shown by the results of a multiple regression analysis in chapter 7. Furthermore, pictures of views dominated by nature got higher preference ratings than views with little or no natural green (Chapter 7). Views containing vegetation which is blocking the view, however, got a lower preference rating than views which did not contain any obstructing objects, which agrees with findings from the literature (Chapter 4, Meerdink et al., 1988).

The results of the multiple regression analysis in chapter 7 also show that the more diverse and open and the less limited the view is, the higher the view quality rating. In building 8, an atrium building, respondents with a workplace near the atrium were less satisfied with the view than those who did not have a workplace near the atrium. In the pilot study, five different functions of a view were mentioned in a multiple choice question (Chapter 5). The results of this question are that a diverse view is considered to be important by more respondents than a wide view.

Results of the main study also show that the respondents like to see water (Chapter 7). However, many respondents in the pilot study appeared to have a neutral opinion about the water in their outside view. It seems that the attractiveness of water depends on the particular setting. In the pilot study the water seen by the respondents was not natural, but still, dirty water in a concrete water basin (Chapter 5).

Another variable which was found to have a positive effect on the view quality rating is the possibility to see what weather it is (Chapter 5, 7). In the pilot study this even appeared to be the most important one out of five different functions of a view which were mentioned in a multiple choice question (Chapter 5).

Although most respondents in the field survey like what they see, the questionnaire results show that buildings and traffic can be unpleasant to see (Chapter 5, 7). The results suggest that this is the case when buildings and traffic are at a close distance of the window. In the main study, however, the possibility to see traffic had a positive effect on the overall view quality rating. Perhaps the traffic was more or less accidentally part of views that contained other, highly attractive features.

In the literature four characteristics of buildings were found to influence view quality: building distance, maintenance, complexity, and building age. The literature shows that old buildings, if they are well maintained, are preferred over modern buildings. However, when buildings are poorly maintained or complexity is low, modern buildings are preferred over older buildings. The results of the picture question confirm that overall old, brick buildings are preferred over modern buildings and that complex buildings are preferred over simple buildings (Chapter 7). However, there are still many questions to be answered with respect to building preference. Little is known about the strength of the effect of maintenance, age and complexity on perceived view quality. Furthermore, other variables may also play a role, like the color and shape of the buildings. If a view contains multiple buildings with different characteristics, it is not known how this affects perceived view quality.

Research in the US shows that the size of an outside view also influences satisfaction with the view and the visual comfort. In this thesis, view quality ratings were higher when the window was located right, left, or in front of the respondent, than when the window was behind the respondents, which indicates that the accessibility of the outside view also influences the perception of view quality (Chapter 7).

Although personal preferences play an important role in view preference ratings, the PhD thesis demonstrates that many variables consistently are found to affect perceived view quality. The relation between preference variables is complex. Future research could give more insight in the relationship between view content variables and landscape preference variables like complexity and diversity.

How are perceived light and view quality related?

The literature study shows that occupant's subjective impression of an outside view can influence their sensation of glare (Chapter 1 and 4). To study this relationship in the questionnaire research, a light and a view factor were constructed based on the results of principle component analysis, and, subsequently, the correlation between the factors was calculated (Chapter 8). The two factors combine the results of multiple variables from the questionnaire and represent the occupant's perceived light quality and view quality.

The correlation between the light and view factor of the entire dataset was found to have a moderate strength. Because the questionnaire of building 8 contained more items, another light factor was constructed for building 8 which included these items. Interestingly, the correlation between this light factor and the view factor of building 8 appeared to be considerably lower than the correlation found for the entire dataset (Chapter 8). The difference between these results is probably caused by the different characteristics of the light factors. The light factor of building 8 contains more artificial light items, while the daylight items are much stronger correlated to perceived view quality.

In the scale model research, no relationship was found between view quality and glare experience (Chapter 12). The quality of the different outside views in the experiment was quite similar and no severe glare was experienced by the participants. A limitation of the research, however, is that the number of participants in the study was limited, which might have caused a lack of power. Although several studies show that perceived daylight and view quality are related, more extensive research is needed to investigate to what extent outside views affect the perceived amount of glare from windows.

To what extent do perceived light and view quality influence perceived workplace quality?

In this thesis perceived light quality was found to have a considerable effect on the perceived workplace quality. When a multiple regression analysis was performed on the results of the entire dataset of the main study, perceived view quality did not have a statistically significant effect on the perceived workplace quality (Chapter 9). However, a different result was found for the model of building 8. When the light and view factor of building 8 were put into the multiple regression analysis, both perceived light quality and perceived view quality had a statistically significant influence on the perceived workplace quality. The most likely reason for these contradicting results, is that the correlation between the light and view factor of building 8 is much weaker than the correlation between the factors which are composed for the entire dataset (Paragraph 8.5). When the light factor includes many daylight variables, the correlation between the light and the view factor is stronger and therefore the factor view quality seems not to add any new information to the outcome of the factor workplace quality. For this reason, no statistically significant effect is found.

The research demonstrates that the way a factor is constructed and the relationship between the variables entered in a multiple regression analysis, can have a considerable effect on the outcome of the analysis. If no statistically significant effect is found for a particular variable, it does not necessarily mean that the variable does not have an effect on the outcome, but it may also mean that other variables play a more important role.

The workplace factor in the questionnaire study consists of variables which represent three different topics: general impression of the workplace, possibility to concentrate, and thermal indoor climate (Chapter 9). The weight of the indoor climate variables in the workplace factor is rather high. Of course, many more variables, like the quality of the furniture, also affect workplace quality, but these kind of variables were not included in the questionnaire. Future research could give insight in the effect of light and view quality on different aspects of the perceived workplace quality. In this research the workplace quality was reduced to only one quality dimension.

How can an outside view and the access of daylight into a room be measured, visualized and assessed in an objective and comprehensible way?

The approach of the new analysis method described in chapter 10 is a basic theory of how the view and daylight access through a window can be recorded or measured in an objective way. First, a projection is made of the window and view through the window. Because this can be done in several ways, i.e. by a hand drawing, a computer model or with a camera with fisheye lens, the method can be used in different phases of a design or research process.

Existing methods for the analysis of daylight are implemented in the new method, which makes it possible to examine the access of daylight through a window in multiple ways, without the need to construct a new model for each daylight analysis method. Furthermore, a new method for the analysis of view quality is developed, which consist of two different parts. The first part is a general method for the assessment of view quality and the second part is a method which can be used to assess the availability of an outside view from a workplace. Both methods consist of a series of multiple choice questions. After answering these questions a view quality score is calculated, which shows if the view has a low, medium or high view quality.

The points per item in the assessment method for view quality are not derived from statistical tests, but are an educated guess based on the findings from the literature (Chapter 4) and questionnaire study (Chapter 5 and 7). The rating could be improved in the future by more extensive analysis of the validity of the method. Perceived view quality depends on many more variables than included in the method. Future research could investigate if by adding or removing one or two variables, more precise predictions can be done of people's perception of view quality.

The general method for the assessment of view quality combines the approach of the psychophysical model and the psychological model described in chapter 4 (paragraph 4.4.6). The assessment partly relies on the opinion of the assessor. More research is needed to explore if view quality scores will differ much between different assessors.

To what extent can the access of daylight be measured with dot and sunpath diagrams?

For the D&V analysis method existing dot and sunpath diagrams were transformed into vertical, equidistant projections. In this way, they can be used in combination with the projection diagrams described in chapter 10. With the dot diagrams the light level in a measurement point can be predicted and the sunpath diagrams show when direct sunlight will enter the space.

The accuracy of the dot diagrams is tested by comparing calculations with the dot diagrams to computer calculations. The accuracy of the dot diagrams is found to be acceptable. The diagrams give a slightly more conservative estimation of the sky components than the computer programs Desktop Radiance 2.0 Beta and DIALux 4.1.

The accuracy of the sunpath diagrams is tested by comparing the diagrams with calculations of the luminance distribution in the projections from the test model. The sunpath diagrams appeared to show correctly how the sun moves along a window on different dates and times. Additional research is needed to explore if the diagrams can be used to predict when glare problems will occur and when there will be a need for sunshading.

To what extent is it possible to predict the effect of different window configurations on perceived daylight and view quality?

In chapter 12, a scale model research was performed to test the applicability of the D&V analysis method. Subjects in the study were asked to answer a questionnaire on lighting and view for three different window configurations. The perceived light level in the scale model was found to be statistically significantly related to the window size and the window position. A statistically significant correlation was also found between the perceived light level and the illuminance inside the scale model and a medium strong correlation between the perceived light level and the sky component. The vertical sky component in the scale model was calculated with the dot diagrams which are implemented in the new analysis method. The sky component seems to be a good predictor of the vertical illuminance inside the scale model, and also of what the participants thought of the amount of daylight. A limitation of the study, however is that each participant in the study assessed three different window views, and cases are therefore not statistically independent. Further research with more different room sizes and window configurations is needed to explore to what extent daylight access can be predicted with the dot diagrams.

To what extent participants in the scale model research perceived glare was not related to the different window configurations or to the perceived and measured amount of daylight in the scale model. For this reason, the amount of glare could not be predicted with the dot diagrams. The access of direct sunlight was also not found to be a statistically significant predictor of glare perception, which might be due to the fact that no direct sunlight was entering the eye of the observers during the experiment.

Although the distance to the window was larger than described in chapter 10, the new analysis method for view quality was found to give a good indication of the effect of different window designs on the quality of the outside view from an office. It is not possible, however, to provide very precise predictions of perceived view quality, because it depends on many more variables, than those included in the analysis method (Chapter 3, 7).

13.2. Final Words

Based on the results of a literature study and a questionnaire research, a method is developed for the analysis of daylight and view quality. Many variables were found to affect daylight and view quality in the literature. The results of the questionnaire study give new insight into the relationship between the variables. The results demonstrate that the relationship between artificial light and daylight variables and between daylight and view variable is rather complex. If view quality has a significant on perceived workplace quality depends on how the factors are constructed and which variables are included in a statistical test.

A limitation of the analysis in part 2 of the thesis is that parametric tests are performed on data, which does not meet the criteria for parametric tests, i.e. following a normal distribution in the population and having at least an interval level scale (e.g. Field, 2009, p 131). Furthermore, the study was performed in eight office buildings which may not be representative for other office buildings in the Netherlands, because most employees working in the buildings are engineers.

The new analysis method for daylight and view quality, the D&V analysis method, makes the information about daylight and view quality found in the literature and questionnaire study accessible for designers and engineers. The method can be used for multiple purposes, because it combines different existing methods for the analysis of daylighting with a new method for the analysis of view quality. The validation of the method in this research was limited to a scale model study. By a more extensive validation of the method in the future, the D&V analysis method could be further improvement.

In this study the effect of glazing type on perceived light and view quality was not investigated. Low transmittance glazing is more and more often applied, but little is known about the effect of different types of low transmittance glazing on the perceived visual conditions inside buildings. In the future smart materials might be more often applied as sun shading (Hellinga & Lelieveld, 2011). These materials affect the color rendering index inside spaces. More research is needed on the effect of glazing type and sun shading on perceived visual quality of indoor spaces.

13.3 References

Christoffersen, J., Johnsen, K., Peterson, E., Hygge, S., Post-occupancy evaluation of Danish office buidings, Proceedings of the 24th Session of the Commission Internationale de l'Eclairage, Warsaw, Poland, Vienna, Austria: CIE Central Bureau, 1999, p. 333-337

Farley, K.M.J., Veitch, J.A., A room with a view; a review of the effects of windows on work and well-being, Research Report, Institute for Research in Construction, NRC-CNRC, 2001

Field, A., Discovering Statistics Using SPSS, London: Taylor & Francis, 2003

Hellinga, H.IJ., Lelieveld, C.M.J.L., Intelligente daglichtsystemen: de toepassingsmogelijkheden van ‘smart materials’, Bouwfysica, Vol. 22, No. 2, 2011, p. 17-21

Keighley, E.C, Visual requirements and reduced fenestration in office buildings — A study of window shape, Building Science, Vol. 8, No. 4, 1973a, p. 311-320

Appendix A

Questionnaire Pilot Study

(translation from Dutch)

PA. Questions about weather and date

1. What is the date? PA1
   …

2. What time is it? PA2
   …

3. What is the weather at the moment? PA3
   - Rainy
   - Cloudy
   - Partly cloudy
   - Sunny
   - Other, namely …

PB. Personal well-being

4. How well do you feel today (physically)? PB1
   - Very well
   - Well
   - Normally
   - Bad
   - Very bad

5. How is your mood today? PB2
   - Very well
   - Well
   - Normally
   - Bad
   - Very bad

6. Do you feel tired? PB3
   - Yes
   - No
   - A little

PC. Personal information

7. What is your age PC1
   - Younger than 30
   - 30-39
   - 40-49
   - 50-59
   - 60 year or older

8. Are you a male or a female? PC2
   - Male
   - Female

9. Do you wear glasses or contact lenses while you are working? PC3
   - Yes, glasses
   - Yes, contact lenses
   - No

10. Is your sight limited by an eye disease or eye disorder, even when you wear glasses or contact lenses? (for example cataract) PC4
    - Yes (please specify) …
    - No

11. Are your sensitive to intense light? PC5
    - Yes
    - No

12. Do you go outside frequently? PC6
    - Yes
    - No

13. Do you have suffer from a fear of heights? PC7
    - Yes
    - No

14. In which country did you grow up? PC8
    - The Netherlands
    - Other (please specify) …

PD. Questions about the office space

---

15. What is your room number? PD1
    …

16. For how long have you been working in this office space? PD2
    - Less than 1 year
    - 1 - 5 years
    - More than 5 years

17. How many days per week do you work at the faculty of Architecture? PD3
    …

18. What is your profession? *(mark as many as applicable)* PD4
    - PhD candidate
    - Researcher
    - Teacher
    - Professor
    - Secretary
    - Administrator
    - Student-assistant
    - Other (please specify) …

19. On average, how much time do you spend at your workstation? PD5
    - Less than 2 hours
    - 2-4 hours
    - More than 4 hours

20. On average, how much time do you spend behind your computer? PD6
    - Less than 2 hours
    - 2-4 hours
    - More than 4 hours

21. Do you use a separate computer table in addition to your desk? PD7
   - o Yes
   - o No

22. With how many people do you share your office space? PD8
   ...

23. Are your roommates and you present at the same time? PD9
   - o Always
   - o Often
   - o Regularly
   - o Sometimes
   - o Never

24. Are there often people walking through your room, when you are working? PD10
   - o Yes
   - o No

25. Is it possible for unknown people to look into your room? PD11
   - o Yes
   - o No

   If yes, is it a bother to you?
   - o Yes
   - o No

26. What is your general impression of your office space? PD12

a.	light	o	o	o	o	o	dark
b.	warm	o	o	o	o	o	cold
c.	evenly lit	o	o	o	o	o	unevenly lit
d.	quiet	o	o	o	o	o	busy
e.	spacious	o	o	o	o	o	cramped
f.	pleasant	o	o	o	o	o	unpleasant

27. Are you satisfied with the position of your desk? PD13
   - o Yes
   - o No

28. Are you satisfied with the position of your computer screen? PD14
   - o Yes
   - o No

29. If you look straight ahead, what do you see? *(mark as many as applicable)* PD15
   - o A window
   - o The workplace of a colleague
   - o A sidewall of the office space
   - o The back wall of the office space
   - o Something else (please specify) ...

30. Does your office space have windows? PD16
   - o Yes
   - o No

31. How close do you approximately sit to the nearest window? PD17
    - o Less than 2 meters
    - o More than 2 meter

32. Is it important that offices have windows, in your opinion? PD18
    - o Yes
    - o No

33. What is, in your opinion, the biggest advantage of a window? PD19
    ...

34. What is, in your opinion, the biggest disadvantage of a window? PD20
    ...

35. What do you think of the size of the window(s) in your office space? PD21
    - o Too big
    - o Good
    - o Too small

PE. Indoor climate

---

36. How satisfied are you with the following aspects of your workplace/workstation? PE1

		Very satisfied	Satisfied	Not satisfied and not dissatisfied	Dissatisfied	Very dissatisfied
a.	The lighting	o	o	o	o	o
b.	The temperature	o	o	o	o	o
c.	The ventilation	o	o	o	o	o
d.	The amount of privacy	o	o	o	o	o
e.	The outside view	o	o	o	o	o

37. How often are you disturbed at your workplace by noise? PE2
    - o Always
    - o Often
    - o Regularly
    - o Sometimes
    - o Never

38. How often are you disturbed at your workplace by draught? PE3
    - o Always
    - o Often
    - o Regularly
    - o Sometimes
    - o Never

39. What do you generally think of the light level at your workplace? PE4
    (daylight and artificial light combined)
    - o Far too much light
    - o Slightly too much light
    - o Good
    - o Slightly too little light
    - o Far too little light

40. How often is the artificial light on while you are working? PE5
   - Always
   - Often
   - Regularly
   - Sometimes
   - Never

41. Would you be able to carry out your work without artificial light, so only with the available daylight? PE6
   - Always
   - Often
   - Regularly
   - Sometimes
   - Never

42. Is it possible to manually control the artificial lighting? PE7
   - Yes
   - No

43. Do you find it important to be able to manually control the artificial lighting? PE8
   - Yes
   - No

44. Are you satisfied with the artificial lighting? PE9
   - Yes
   - No

   If not, why? …

45. Does it happen that direct sunlight enters your office space? PE10
   - Yes
   - No
   - Don't know

46. Do you like it when there is direct sunlight in your office? PE11
   - Always
   - Often
   - Regularly
   - Sometimes
   - Never

47. How often are you disturbed by the heat of direct sunlight? PE12
   - Always
   - Often
   - Regularly
   - Sometimes
   - Never

48. How often are you disturbed by annoying reflections, f.e. by light reflecting in your computer screen? PE13
   - Always
   - Often
   - Regularly
   - Sometimes
   - Never

49. If there are disturbing reflections, in what? *(mark as many as applicable)* PE14
- ○ Glossy paper
- ○ Computer screen
- ○ Other (please specify) …
- ○ Not applicable

50. What is causing annoying reflections? PE15
- o Daylight
- o Artificial light
- o Other (please specify) …
- o Not applicable

51. How often are you disturbed by daylight or sunlight shining annoyingly in your eyes? PE16
- o Always
- o Often
- o Regularly
- o Sometimes
- o Never

52. What type of window shades or blinds are present at your work place? PE17
(mark as many as applicable)
- o Curtains
- o Blinds outside
- o Blinds inside
- o Foil on the window
- o Other (please specify) …
- o Not applicable

53. Is it possible to manually control the sun shading? PE18
- ○ Yes, easily
- ○ Yes, but I think it is difficult
- ○ No
- ○ Don't know

54. Is it possible to vary the position of the sun shading? PE19
- o Yes
- o No
- o Don't know

If yes, do you use these different positions?
- o Yes
- o No

55. How often is the sun shading closed? PE20

	Always	Often	Regularly	Sometimes	Never
a. During the spring	○	○	○	○	○
b. During the summer	○	○	○	○	○
c. During the autumn	○	○	○	○	○
d. During the winter	○	○	○	○	○

56. Why would you close the sun shading? *(mark as many as applicable)* PE21
   - Because it becomes too hot by the sunlight
   - Because the day- and sunlight is to bright
   - So that people cannot look inside
   - Other (please specify) …

57. Are you satisfied with the window shades or blinds? PE22
   - Yes
   - No

   If not, why?
   …

PF. Questions about the outside view

---

58. Can you look outside from your workplace? PF1
   - Yes
   - No

59. Do you consider it to be important to have access to a view outwards? PF2
   - Yes
   - No

60. Do you ever walk to the window to look outside? PF3
   - Yes, often
   - Yes, sometimes
   - No

61. Is there in your view, which you have from your workplace, movement visible (for example traffic or passing people)? PF4
   - Yes
   - No
   - Sometimes

62. Do you consider it to be pleasant to observe movement? PF5
   - Very pleasant
   - Pleasant
   - Not pleasant, not unpleasant
   - Unpleasant
   - Very unpleasant

63. Are the following topics visible through the window from your workplace? PF6

		Yes	No
a.	The ground (street level)	o	o
b.	The sky	o	o
c.	Buildings		
d.	Water	o	o
e.	Green *(trees, plants, etc.)*	o	o

64. Do you consider it pleasant to see these topics through the window? PF7

		Very pleasant	Pleasant	Not pleasant, not unpleasant	Unpleasant	Very unpleasant
a.	The ground	○	○	○	○	○
b.	The sky	○	○	○	○	○
c.	Buildings	○	○	○	○	○
d.	Water	○	○	○	○	○
e.	Green *(trees, plants, etc.)*	○	○	○	○	○

65. What do you think of the distance to the buildings which are part of the view? PF8
The buildings are:
- ○ Too close
- ○ Close
- ○ At a good distance
- ○ Far away
- ○ Too far away
- ○ Not applicable

66. What do you think of the distance to the green which is part of the view? PF9
The green is:
- ○ Too close
- ○ Close
- ○ At a good distance
- ○ Far away
- ○ Too far away
- ○ Not applicable

67. What would you like to see through the window from your workplace? PF10
(mark as many as applicable)
- o The weather
- o The time
- o What happens outside
- o A diverse view of the environment
- o An extensive view
- o Other (please specify) …

68. Can you see what weather it is from your workplace? PF11
- o Very well
- o Well
- o Moderate
- o Bad
- o Not at all

69. What is your general impression of the view from your workplace? PF12
(mark as many as applicable)

- o Restricted
- o Far
- o Pleasant
- o Limited
- o Stimulating
- o Messy
- o Open
- o Well-ordered
- o Boring
- o Unpleasant
- o Spacious
- o Diverse
- o Calming
- o Beautiful
- o Ugly
- o Monotonous
- o Busy
- o Interesting
- o Other (please specify)…

70. At the next page there are some pictures. PF13

a. Which view do you prefer most?
Picture …

b. Which view do you prefer least?
Picture …

Thank you for filling in the questionnaire

If you would like to receive a digital newsletter with the results, please enter your e-mail address below.

...

Appendix B

Questionnaire Main Study

(translation from Dutch)

A. Personal information

1. What is your age? A1
   …

2. What is your gender? A2
   - o Male
   - o Female

3. Do you wear glasses while you are working? A3
   - o Yes, always
   - o Yes, sometimes
   - o No

4. Do you wear contact lenses while you are working? A4
   - o Yes, always
   - o Yes, sometimes
   - o No

5. Is your sight limited by an eye disease or eye disorder, even when you wear glasses or contact lenses? (for example color blindness or cataract) A5
   - o Yes (please specify) …
   - o No

6. Are your eyes sensitive to intense light? A6
   - o Yes, very sensitive
   - o Yes, somewhat sensitive
   - o No

7. Do you wear sunglasses outdoors during sunny weather? A7
   - o Always
   - o Often
   - o Regularly
   - o Sometimes
   - o Never

B. Questions about the office space

8. At which floor is your office located? B1
   … *(displayed answers depend on floors that are questioned)*

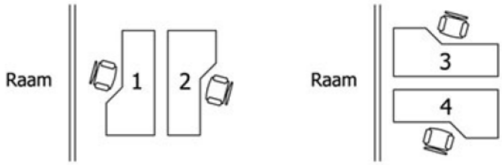
The next question depends on the floor plan of the building

9. In which part of the building do you work? B2
   (see floor plan)
   - o Part A
   - o Part B
   - o Other (please specify) …

10. Does your office space have windows? B3
    - o Yes
    - o No

11. How close do you approximately sit to the nearest window? B4
   - Less than 2 meters
   - 2 - 4 meter
   - More than 4 meter

12. How is your workstation orientated in relation to the window(s)? B5
   (Multiple answers possible if more than one wall in your office has windows)
   - I sit with my **back** to the window (1)
   - I sit with my **face** to the window (2)
   - The window is located **right** of me (3)
   - The window is located **left** of me (4)
   - Other (please specify) …



13. Can you look out of the window at this moment if you look straight ahead? B6
   - Yes
   - No

14. Can you look out of the window if you look around? B7
   - Yes
   - No

15. Is the outside view obstructed by the following? B8

		Yes, (almost) entirely blocked	Yes, somewhat blocked	No
a.	Plants	o	o	o
b.	A computer screen	o	o	o
c.	Furniture	o	o	o
d.	Blinds	o	o	o

16. Are there other objects blocking the view? B9
   - Yes (please specify) …
   - No

17. What do you think of the size of the window(s) in your office space? B10
   - Far too big
   - Slightly too big
   - Exactly good
   - Slightly too small
   - Far too small

18. What do you think of the distance between your workplace/workstation and the window? B11
   - I prefer sitting further away from the window
   - I am sitting at a good distance to the window
   - I prefer sitting closer to the window

19. What is your general impression of your office space? B12

a.	comfortable	o	o	o	o	o	uncomfortable
b.	light	o	o	o	o	o	dark
c.	evenly lit	o	o	o	o	o	unevenly lit
d.	quiet	o	o	o	o	o	busy
e.	spacious	o	o	o	o	o	cramped
f.	pleasant	o	o	o	o	o	unpleasant

20. How satisfied are you with your workplace/workstation? B13
   - o Very satisfied
   - o Satisfied
   - o Not satisfied, not dissatisfied
   - o Dissatisfied
   - o Very dissatisfied

21. Do you have difficulties with reading the computer screen? B14
   - o Yes, always
   - o Yes, sometimes
   - o No

22. What kind of computer do you have at your desk? B15
   - o Flat screen
   - o Monitor
   - o Laptop/notebook

23. For how long have you been working at your current workplace/workstation? B16
   - o Less than 1 year
   - o 1 - 3 years
   - o More than 3 years

24. What is your profession? B17
   ...

25. How many hours per week do you work? B18
   ...

26. During which percentage of your working hours are you present at your workstation? B19
   ...

27. On average, how much time do you spend at your workstation behind your computer? B20
   - o Less than 2 hours
   - o 2-4 hours
   - o 4-6 hours
   - o More than six hours

28. With how many people do you share your office space? (excluding yourself) B21
   ...

29. Are there often conversations or meetings in your office space? B22
   - o Always
   - o Often
   - o Regularly
   - o Sometimes
   - o Never

30. Can unknown people easily look into your office space? B23
- o Yes, through the window
- o Yes, from the corridor
- o Yes, (please specify) …
- o No

C. Questions about the indoor environment

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31. How satisfied are you with the following aspects of your workplace/workstation? C1

		Very satisfied	Satisfied	Not satisfied and not dissatisfied	Dissatisfied	Very dissatisfied
a.	The lighting	o	o	o	o	o
b.	The temperature	o	o	o	o	o
c.	The ventilation	o	o	o	o	o
d.	The amount of privacy	o	o	o	o	o
e.	The amount of daylight	o	o	o	o	o
f.	The outside view	o	o	o	o	o

32. How often are you disturbed at your workplace/workstation by the following? C2

		Always	Often	Regularly	Sometimes	Never
a.	Noise	o	o	o	o	o
b.	Draught	o	o	o	o	o
c.	Heat from sunlight shining into the room	o	o	o	o	o

33. How often do you experience nuisance at your workplace/workstation by the following? C3

		Always	Often	Regularly	Sometimes	Never
a.	**Artificial light** shining into your eyes	o	o	o	o	o
b.	**Artificial light** reflected in your computer screen	o	o	o	o	o
c.	**Daylight** shining into your eyes	o	o	o	o	o
d.	**Daylight** reflected in your computer screen	o	o	o	o	o
e.	Other annoying reflections	o	o	o	o	O

34. What do you generally think of the light level (daylight and artificial light combined)? C4

		Far too much light	Slightly too much light	Approximately good	Slightly too little light	Far too little light
a.	At your workstation (desk)	o	o	o	o	O
b.	In the entire room	o	o	o	o	O
c.	At your computer screen	o	o	o	o	O

35. How often is the artificial light on while you are working? C5
- Always
- Often
- Regularly
- Sometimes
- Never

36. Would you be able to carry out your work without artificial light, so only with the available daylight? C6
- Always
- Often
- Regularly
- Sometimes
- Never

37. How satisfied are you with the possibilities to control the lighting? C7
- Very satisfied
- Satisfied
- Not satisfied and not dissatisfied
- Dissatisfied
- Very dissatisfied

38. What type of window shades or blinds are present at your work place? C8
(mark as many as applicable)
- Blinds outside
- Blinds inside
- Foil on the window or tinted glass
- Curtains
- Other (please specify) …
- There are no blinds or window shades

39. What is generally the reason that you or a colleague closes the blinds? C9
(mark as many as applicable)
- To block the heat of solar radiation
- To prevent light shining annoyingly into my eyes
- To prevent annoying reflections on my computer screen
- Because the computer screen will be too dark otherwise
- Because then people will no longer be able to look inside
- Other (please specify) …

40. What is generally the reason that you or a colleague opens the blinds? C10
- To increase the access of day- or sunlight
- To look outside
- Other (please specify) …

41. Is it possible to close the blinds and still see a part of the view? C11
- Yes
- No
- I don't know

42. How satisfied are you with the possibilities to control the access of day- and sunlight? C12
- Very satisfied
- Satisfied
- Not satisfied and not dissatisfied
- Dissatisfied
- Very dissatisfied

D. Questions about the outside view

43. What is your general impression of the outside view? D1

a.	diverse	o	o	o	o	o	monotonous
b.	finite	o	o	o	o	o	infinite
c.	distracting	o	o	o	o	o	not distracting
d.	quiet	o	o	o	o	o	busy
e.	open	o	o	o	o	o	closed
f.	pleasant	o	o	o	o	o	unpleasant

44. What do you think of the view in summer compared to the view in winter? D2
   - o More pleasant
   - o Equally pleasant
   - o Less pleasant

45. Can you see what weather it is from your workplace? D3
   - o Good
   - o Moderate
   - o Bad
   - o Not at all

46. Can you see the sky through the window from your workplace/workstation? D4
   - o Yes
   - o No

47. Do consider it pleasant to see the sky through the window? D5
   - o Very pleasant
   - o Pleasant
   - o Not pleasant, not unpleasant
   - o Unpleasant
   - o Very unpleasant

48. Are the following topics visible through the window from your workplace? D6

		Yes	No
a.	The ground (street level)	o	o
b.	Buildings	o	o
c.	Water	o	o
d.	Green *(trees, plants, etc.)*	o	o
e.	People	o	o
f.	Traffic	o	o

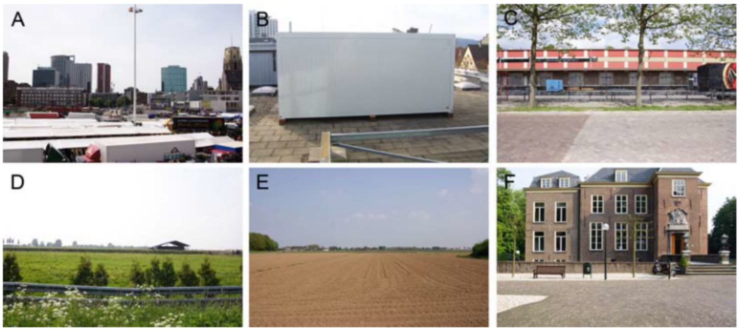
49. Do you consider it pleasant to see these topics through the window? D7

		Very pleasant	Pleasant	Not pleasant, not unpleasant	Unpleasant	Very unpleasant
a.	The ground	○	○	○	○	○
b.	Buildings	○	○	○	○	○
c.	Water	○	○	○	○	○
d.	Green *(trees, plants, etc.)*	○	○	○	○	○
e.	People	○	○	○	○	○
f.	Traffic	○	○	○	○	○

50. What do you think of the distance between the view topics and the window? D8

		Far too close	Slightly too close	At a good distance	Slightly too distant	Far too distant
a.	The ground	○	○	○	○	○
b.	Buildings	○	○	○	○	○
c.	Water	○	○	○	○	○
d.	Green *(trees, plants, etc.)*	○	○	○	○	○
e.	People	○	○	○	○	○
f.	Traffic	○	○	○	○	○

51. Below some pictures are shown *(the displayed set of pictures is one of eight different sets).* D9
Now imagine that these pictures would be the view from your office. How would you assess these views?
Give the pictures a mark between 0 (very bad view) and 10 (very good view)



52. How would you assess your own view? D10
Give a mark between 0 (very bad view) and 10 (very good view)
...

Now that you have reached the end of the questionnaire, do you have any questions or comments?
If yes, please specify ...

Additional questions DSM

Question 20 (B13) was replaced by the following question

- How satisfied are you with the following? B*

	Very satisfied	Satisfied	Not satisfied, not unsatisfied	Unsatisfied	Very unsatisfied
a. The workplace where you are sitting now	○	○	○	○	○
b. The openness and transparency of the work environment	○	○	○	○	○
c. The ambience and appearance of the interior	○	○	○	○	○
d. The possibility to concentrate	○	○	○	○	○
e. The possibility for communication and social interaction	○	○	○	○	○

The following question was added after question 34 (C4)

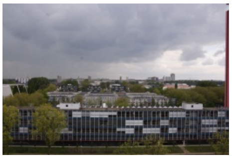
- How satisfied are you with the following? C*

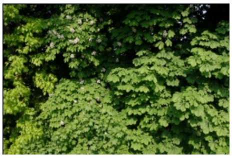
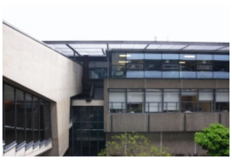
	Very satisfied	Satisfied	Not satisfied, not unsatisfied	Unsatisfied	Very unsatisfied
a. The colour of the artifical lighting	○	○	○	○	○
b. The colour of the daylighting	○	○	○	○	○
c. The colour of the interior (furniture, walls, floor, and ceiling)	○	○	○	○	○

Appendix C

View Quality Ratings – Results of the Main Study

Picture	Questionnaires	Respondents	Mean rating
1. 	B3 and B4	117	8.3
2. 	B3 and B5	48	8.1
3. 	B5 and B6	90	8.0
4. 	B5	19	7.9
5. 	B3 and B6	100	7.4
6a. 	B7	71	7.4
7. 	B6	71	7.1

Picture	Questionnaires	Respondents	Mean rating
8. 	B4	88	6.8
9a. 	B7	38	6.8
9b. 	B8	239	6.6
10. 	B4 and B6	159	6.2
11. 	B4 and B6	159	6.2
12. 	B3 and B4	117	5.8
13. 	B8	239	5.6

Picture	Questionnaires	Respondents	Mean rating
14. 	B7 and B8	277	5.5
15. 	B7	38	5.4
16. 	B5 and B6	90	4.8
17. 	B8	239	4.8
18. 	B3	29	4.7
19. 	B7	38	4.4
20. 	B3 and B4	117	4.1

Picture	Questionnaires	Respondents	Mean rating
21. 	B7 and B8	277	3.9
22. 	B5	19	3.7
23. 	B5	19	2.0

Appendix D

Results per Dataset of the PCA on the Items that Measure Visual Quality

Table D.1: Pattern Matrix with factor loadings, buildings 3-7

Variables		Component		
		1	2	3
D10	Assessment of view quality	-.84		
D1-1	Diversity of view	.80		
D1-6	Pleasantness of view	.79		
D1-5	Openness of view	.73		
D1-2	Limitation of view	-.67		
C1-6	Satisfaction with view from window	.59		.40
D4, D6	Number of visible topics in the view	-.49		
D1-3	Distraction of view	.37		
D1-4	Quietness of view	-.33		
C4	Satisfaction with light level		-.73	
C2-3	Discomfort by heat from sunlight		.70	
C3-4	Discomfort by daylight reflecting in the computer screen		.70	
C3-3	Discomfort by daylight shining into the eyes		.63	
C3-2	Discomfort by artificial light reflecting in the computer screen			
B12-3	Uniformity of lighting of office space			.72
B12-2	Lightness of office space		.47	.66
C1-1	Satisfaction with lighting			.64
C1-5	Satisfaction with amount of daylight			.62
C13	Satisfaction with control of day- and sunlight penetration			.44
C3-1	Discomfort by artificial light shining into the eyes			-.42
C7	Satisfaction with control of (artificial) lighting			.39

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.
Rotation converged in 9 iterations.

Table D.2: Pattern Matrix with factor loadings, building 8

Variables		Component		
		1	2	3
D10	Assessment of view quality	-.84		
D1-5	Openness of view	.83		
D1-6	Pleasantness of view	.82		
D1-1	Diversity of view	.80		
D1-2	Limitation of view	-.74		
C1-6	Satisfaction with view from window	.66	.35	
D4, D6	Number of visible topics in the view	-.65		
D1-3	Distraction of view	.38		
C1-1	Satisfaction with lighting		.77	
C1-5	Satisfaction with amount of daylight		.74	
B12-2	Lightness of office space		.70	.37
B12-3	Uniformity of lighting of office space		.70	
C4	Satisfaction with light level		.62	-.33
C13	Satisfaction with control of day- and sunlight penetration		.53	
C3-2	Discomfort by artificial light reflecting in the computer screen		-.50	.45
C3-1	Discomfort by artificial light shining into the eyes		-.49	
D1-4	Quietness of view		.35	
C7	Satisfaction with control of (artificial) lighting			
C3-4	Discomfort by daylight reflecting in the computer screen			.78
C3-3	Discomfort by daylight shining into the eyes			.71
C2-3	Discomfort by heat from sunlight			.61

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.
Rotation converged in 9 iterations.

Appendix E

Results per Dataset of the PCA on the Items that Measure Workplace Quality

Table E.1: Rotated Component Matrix with factor loadings, buildings 1-7, 3 factors

Variables		Component		
		1	2	3
C2-1	Discomfort by noise	-.81		
C1-4	Satisfaction with privacy	.78		
B12-4	Quietness of office space	.67		.35
B13	Satisfaction with workplace	.52	.33	.44
C1-2	Satisfaction with temperature		.84	
C1-3	Satisfaction with ventilation		.75	
C2-2	Discomfort by draught		-.58	
C2-3	Discomfort by heat from sunlight	-.35	-.56	.34
B12-5	Spaciousness of office space			.73
B12-6	Pleasantness of office space	.37	.31	.71
B12-1	Comfort of office space		.42	.67

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 5 iterations.

Table E.2: Component Matrix with factor loadings, buildings 1-7, 1 factor

Variables		Component
		1
B12-6	Pleasantness of office space	.80
B13	Satisfaction with workplace	.75
B12-1	Comfort of office space	.73
B12-4	Quietness of office space	.59
C1-4	Satisfaction with privacy	.59
C1-2	Satisfaction with temperature	.57
C2-1	Discomfort by noise	-.55
C1-3	Satisfaction with ventilation	.51
B12-5	Spaciousness of office space	.48
C2-2	Discomfort by draught	-.42
C2-3	Discomfort by heat from sunlight	-.33

Extraction Method: Principal Component Analysis.

Table E.3: Rotated Component Matrix with factor loadings, buildings 8, 3 factors

Variables		Component		
		1	2	3
B12-1	Comfort of office space	.79		
B12-6	Pleasantness of office space	.78	.30	
B12-5	Spaciousness of office space	.75		
B13	Satisfaction with workplace	.70	.35	
C2-1	Discomfort by noise		-.91	
C1-4	Satisfaction with privacy	.32	.76	
B12-4	Quietness of office space	.40	.76	
C1-2	Satisfaction with temperature			.86
C1-3	Satisfaction with ventilation			.79
C2-3	Discomfort by heat from sunlight			-.63
C2-2	Discomfort by draught		-.35	-.58

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 5 iterations.

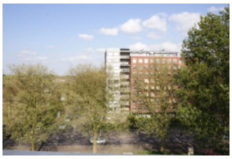
Table E.4: Component Matrix with factor loadings, building 8, 1 factor

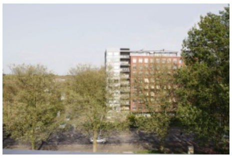
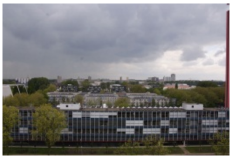
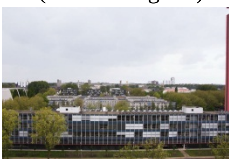
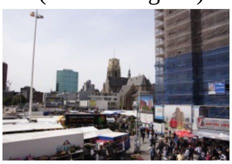
Variables		Component
		1
B12-1	Comfort of office space	.81
B12-6	Pleasantness of office space	.79
B13	Satisfaction with workplace	.74
B12-4	Quietness of office space	.71
C1-4	Satisfaction with privacy	.70
C1-3	Satisfaction with ventilation	.69
C2-1	Discomfort by noise	-.59
B12-5	Spaciousness of office space	.58
C1-2	Satisfaction with temperature	.58
C2-2	Discomfort by draught	-.55
C2-3	Discomfort by heat from sunlight	-.35

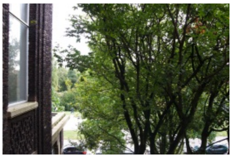
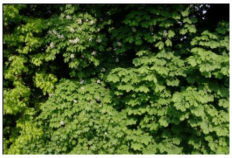
Extraction Method: Principal Component Analysis.

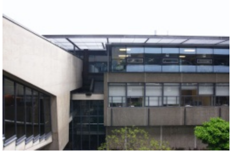
Appendix F

View Quality Ratings – Results of the D&V Analysis Method

Pictures with view quality rating main study	View quality rating with the new analysis method
1. (mean rating 8.3) 	View dominated by nature (4pt) Visible layers: The ground, nearby greenery, distant landscape, the sky (4pt) Water (2pt) Medium diversity (1pt) Total: 11pt
2. (mean rating 8.1) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery, the sky (3pt) Natural green (2pt) Water (2pt) Medium diversity (1pt) Total: 8pt
3. (mean rating 8.0) 	View dominated by nature (4pt) Visible layers: The ground, nearby greenery, distant landscape, the sky (4pt) Medium diversity (1pt) Total: 9pt
4. (mean rating 7.9) 	View dominated by nature (4pt) Visible layers: The ground, nearby greenery, distant landscape, the sky (4pt) Medium diversity (1pt) Total: 9pt
5. (mean rating 7.4) 	View dominated by nature (4pt) Visible layers: The ground, distant landscape, the sky (3pt) Low diversity (0pt) Total: 7pt
6a. (mean rating 7.4) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery, distant city- or landscape, the sky (4pt) Natural green (2pt) Medium diversity (1pt) Total: 7pt

Pictures with view quality rating main study	View quality rating with the new analysis method
6b. (mean rating 7.2) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery, distant city- or landscape, the sky (4pt) Natural green (2pt) Medium diversity (1pt) Total: 7pt
7. (mean rating 7.1) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery, the sky (3pt) Natural green (2pt) Medium diversity (1pt) Features of the building(s): Old building, complex architecture, well maintained (1pt) Total: 7pt
8. (mean rating 6.8) 	View dominated by nature (4pt) Visible layers: The ground, distant landscape, the sky (3pt) Low diversity (0pt) Total: 7pt
9a. (mean rating 6.8) 	Built view (0pt) Visible layers: The ground, distant city- or landscape, the sky (3pt) Natural green (2pt) High diversity (2pt) Total: 7pt
9b. (mean rating 6.6) 	Built view (0pt) Visible layers: The ground, distant city- or landscape, the sky (3pt) Natural green (2pt) High diversity (2pt) Total: 7pt
10. (mean rating 6.2) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery, distant city- or landscape, the sky (4pt) High diversity (2pt) Total: 6pt

Pictures with view quality rating main study	View quality rating with the new analysis method
11. (mean rating 6.2) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery, the sky (3pt) Natural green (2pt), Water (2pt) Low diversity (0pt) Features of the building(s): Modern building, simple architecture, well maintained (-1pt) Total: 6pt
12. (mean rating 5.8) 	Built view (0pt) Visible layers: The ground, distant city- or landscape, the sky (3pt) Natural green (2pt) Medium diversity (1pt) Total: 6pt
13. (mean rating 5.6) 	Built view (0pt) Visible layers: Nearby buildings and/or greenery, the sky (2pt) Natural green (2pt) Low diversity (0pt) Total: 5pt
14. (mean rating 5.5) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery, the sky (3pt) Natural green (2pt) Medium diversity (1pt) Total: 6pt
15. (mean rating 5.4) 	View dominated by nature (4pt) Visible layers: Nearby greenery (1pt) Low diversity (0pt) Total: 5pt
16.(mean rating 4.8) 	Built view (0pt) Visible layers: Nearby buildings and/or greenery, distant city- or landscape, the sky (3pt) Natural green (2pt) Medium diversity (1pt) Total: 6pt

Pictures with view quality rating main study	View quality rating with the new analysis method
17. (mean rating 4.8) 	Built view (0pt) Visible layers: Nearby buildings and/or greenery, the sky (2pt) Low diversity (0pt) Features of the building(s): Old building, complex architecture well maintained (1pt) Total: 3pt
18. (mean rating 4.7) 	Built view (0pt) Visible layers: The ground, distant city- or landscape, the sky (3pt) High diversity (2pt) Total: 5pt
19. (mean rating 4.4) 	Built view (0pt) Visible layers: Nearby buildings and/or greenery, the sky (2pt) Natural green (2pt) Low diversity (0pt) Features of the building(s): Modern building, complex architecture, well maintained (0pt) Total: 4pt
20. (mean rating 4.1) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery, the sky (3pt) Natural green (2pt) Nearby cars/traffic (-1pt) Medium diversity (1pt) Total: 5pt
21. (mean rating 3.9) 	Built view (0pt) Visible layers: Nearby buildings and/or greenery, distant city- or landscape, the sky (3pt) Medium diversity (1pt) Features of the building(s): Modern buildings, simple architecture, well maintained (-1pt) Total: 3pt

Pictures with view quality rating main study	View quality rating with the new analysis method
22. (mean rating 3.7) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery, the sky (3pt) Natural green (2pt) Low diversity (0pt) Features of the building(s): Modern buildings, simple architecture, well maintained (-1pt) Total: 4pt
23. (mean rating 2.0) 	Built view (0pt) Visible layers: Nearby buildings and/or greenery, distant city- or landscape, the sky (2pt) Low diversity (0pt) Total: 2pt

Appendix G

Construction of the Dot Diagrams

G.1. Introduction

This appendix describes how the dot diagrams are constructed. It is based on a reader of Cauberg et al. (2001), a reader of the Vakgroep Bouwfysica (1995) and additional notes of M. Pel (c.a. 2005).

First the concept sky dome is explained. Subsequently, an equation is derived which is used to calculated the illumimance by the visible part of the uniform sky and an equation which is used to calculate the illuminance by the visible part of the CIE sky. Then the sky dome is divided into a number of surface areas, and equations are derived in order to calculate the coordinates of each surface area in the diagram.

G.2. The concept sky dome

From point P a part of the sky is seen that, in a certain direction, is situated within solid angle dω. This part of the sky can be replaced by a diffuse shining surface element dS* that is also situated within solid angle dω. The luminance of this surface in the direction of point P is L*(α,β). The amount of daylight that is distributed from dS* to a surface element dS that is located around point P equals:

$$d^2\varphi = L^*(\alpha,\beta)\cos\theta dSd\omega \qquad \text{(G.1)}$$

When all parts of the sky are replaced by surface element dS_b with luminance $L_H(\alpha,\beta)$, the sky can be displayed as a dome, the sky dome. When the luminance distribution of the sky dome is known, it is possible to calculate the illuminance of a point on a random surface area.

The luminance of the uniform sky is the same in every part of the sky dome. The equation is:

$$L_H(\alpha,\beta) = L_0 \qquad \text{(G.2)}$$

The luminance of the CIE overcast sky is lowest at the horizon and increases closer to the zenith, the highest point of the sky dome, where the luminance is three times higher. The luminance distribution is:

$$L_H(\alpha,\beta) = L_H(\alpha) = \frac{1+2\cos\alpha}{3}L_Z \qquad \text{(G.3)}$$

where L_z is the luminance at the zenith

G.3. Illuminance on a random surface area caused by the visible part of the sky

Derivation of the general equation

The amount of daylight which is send from the sky dome to a surface element dS equals:

$$d\varphi = \int_{\omega} L_H(\alpha, \beta) \cos\theta dS d\omega \qquad \text{(G.4)}$$

where ω is the solid angle which contributes to the visible part of the sky

The illuminance in a point on this surface element dS can be calculated according to the equation:

$$E = \int_{\omega} L_H(\alpha, \beta) \cos\theta d\omega \qquad \text{(G.5)}$$

where $L_H(\alpha,\beta)$ is the luminance of a surface area dS_H of the sky dome, θ is the angle between the normal of surface element dS and the line through dS and dS_H, and ω is the solid angle through which dS_H is seen from point P.

Now an expression has to be found for angles ω and θ, in order to make it possible to use the equation for further calculations. The parameters ω and θ are written as a function of angles α and β.

An expression for dω

The following two equations are general expressions which are used to calculate surface area dS.

$$dS = R^2 d\omega \qquad \text{(G.6)}$$

$$dS = R \sin\alpha d\beta R d\alpha \qquad \text{(G.7)}$$

This means that:

$$d\omega = \sin\alpha d\alpha d\beta \qquad \text{(G.8)}$$

where R is the radius of the sky dome; the distance between point P and surface area dS_H

An expression for cosθ

For the angle θ between vectors N and R counts:

$$\cos\theta = \frac{N^2 + R^2 - X^2}{2NR} \qquad \text{(G.9)}$$

where N is the length of the normal of the surface area dS, R is the length of the vector from point P to shining surface element S_H, and X is the distance between vectors N and R (figure G.1).

The angle between the projection of both vectors in the xy-plane is β-ξ. The distance between the projection of the vectors in the xy-plane is Y. The length of the projection of the vectors in the XY-plane is respectively Nsinη and Rsinα.

Similar to the expression for θ now an expression for β can be found:

$$\cos(\beta-\xi)=\frac{N^2\sin^2\eta+R^2\sin^2\alpha-Y^2}{2NR\sin\eta\sin\alpha} \qquad \text{(G.10a)}$$

The expression can be rewritten as a function of Y^2:

$$Y^2=N^2\sin^2\eta+R^2\sin^2\alpha-2NR\sin\eta\sin\alpha\cos(\beta-\xi) \qquad \text{(G.10b)}$$

With Pythagoras' theorem the relation between X and Y is found:

$$X^2=Y^2+(R\cos\alpha-N\cos\eta)^2 \qquad \text{(G.11)}$$

From the two equations above the following equation is derived:

$$X^2=N^2\sin^2\eta+R^2\sin^2\alpha-2NR\sin\eta\sin\alpha\cos(\beta-\xi)+(R\cos\alpha-N\cos\eta)^2 \qquad \text{(G.12)}$$

An expression for cosθ can now be found by combining equations G.9 and G.12.

$$\cos\theta=\frac{N^2+R^2-X^2}{2NR}$$

$$=\frac{N^2+R^2-\left\{N^2\sin^2\eta+R^2\sin^2\alpha-2NR\sin\eta\sin\alpha\cos(\beta-\xi)+(R\cos\alpha-N\cos\eta)^2\right\}}{2NR}$$

$$=\frac{N^2+R^2-N^2\sin^2\eta-R^2\sin^2\alpha+2NR\sin\eta\sin\alpha\cos(\beta-\xi)-R^2\cos^2\alpha+2NR\cos\alpha\cos\eta-N^2\cos^2\eta}{2NR}$$

$$=\frac{2NR\sin\eta\sin\alpha\cos(\beta-\xi)+2NR\cos\alpha\cos\eta}{2NR}$$

$$=\sin\eta\sin\alpha\cos(\beta-\xi)+\cos\alpha\cos\eta \qquad \text{(G.13)}$$

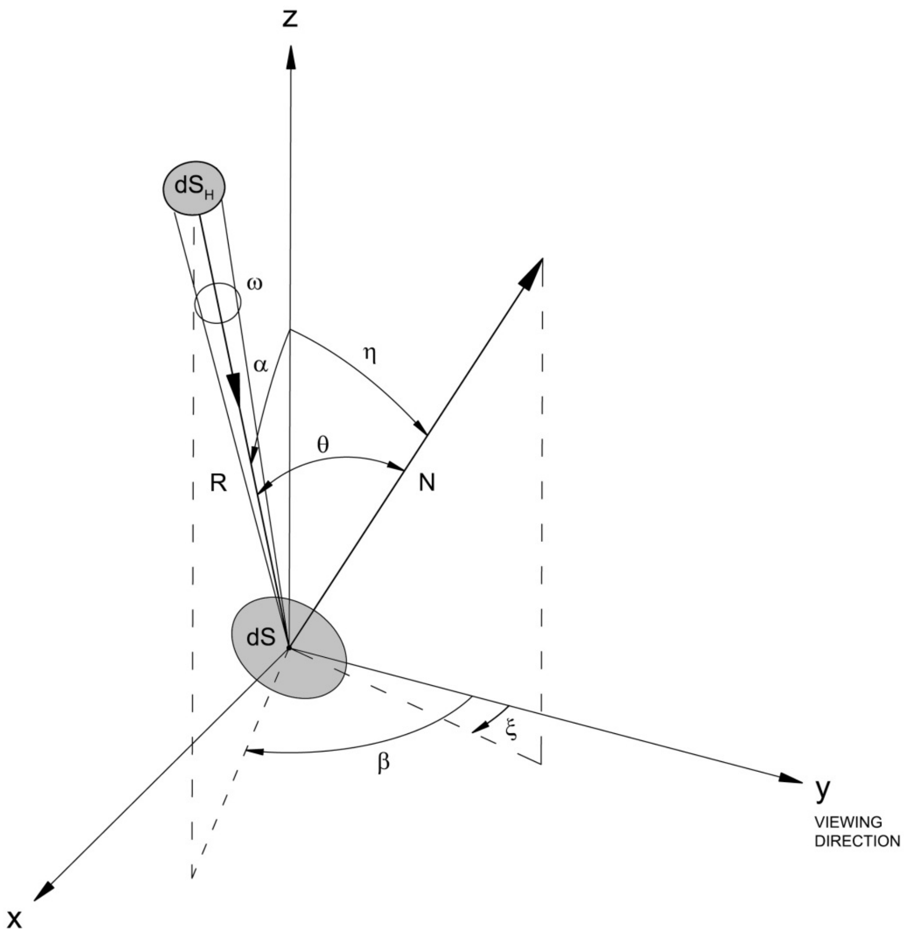


Figure G.1: The contribution of one surface area dS_H to the illuminanc in a measurement point P on a surface element dS

General expression

Based on the equations above the general expression for the illuminance is:

$$E = \int_\alpha \int_\beta L_H(\alpha, \beta)(\sin\eta \sin\alpha \cos(\beta - \xi) + \cos\alpha \cos\eta) \sin\alpha d\alpha d\beta \qquad (G.14)$$

G.4. Illuminance by the visible part of the uniform sky

Based on the general expression of the unform sky (equation G.2) the expression for the illuminance in a surface randomly rotated around the x-axis, under the unform sky is:

$$E = L_0 \iint_{\alpha,\beta} (\sin\eta \sin\alpha \cos(\beta-\xi) + \cos\alpha \cos\eta) \sin\alpha \, d\alpha \, d\beta \qquad \text{(G.15)}$$

The equation needs to be worked out for two situations, i.e. for a horizontal surface and for a vertical surface.

Horizontal surface: η = 0°

The general expression for the illuminance is found by filling in η = 0°:

$$\begin{aligned} E_{hor} &= L_0 \iint_{\alpha,\beta} \cos\alpha \sin\alpha \, d\alpha \, d\beta \\ &= L_0 \int_{\beta=0}^{2\pi} d\beta \int_{\alpha=0}^{\pi/2} \cos\alpha \sin\alpha \, d\alpha \\ &= 2\pi L_0 \int_{\alpha=0}^{\pi/2} \sin\alpha \, d \sin\alpha \\ &= 2\pi L_0 \left[\frac{1}{2} \sin^2 \alpha \right]_0^{\pi/2} \\ &= \pi L_0 \end{aligned} \qquad \text{(G.16)}$$

Vertical surface: η = 90°

The general expression for the illuminance is found by filling in η =90°:

$$\begin{aligned} E_{vert} &= L_0 \iint_{\alpha,\beta} \sin\alpha \cos(\beta-\xi) \sin\alpha \, d\alpha \, d\beta \\ &= L_0 \int_0^{\pi/2} \sin^2\alpha \, d\alpha \int_{\xi-\pi/2}^{\xi+\pi/2} \cos(\beta-\xi) d\beta \\ &= L_0 \int_0^{\pi/2} \frac{1-\cos 2\alpha}{2} d\alpha \int_{-\pi/2}^{\pi/2} \cos(\beta-\xi) d\beta \\ &= L_0 \left[\frac{\alpha}{2} - \frac{\sin 2\alpha}{4} \right]_0^{\pi/2} \cdot \left[-\sin\beta \right]_{\xi-\pi/2}^{\xi+\pi/2} \\ &= 2L_0 \cdot \frac{\pi}{4} \\ &= \frac{\pi L_0}{2} \end{aligned} \qquad \text{(G.17)}$$

G.5. Illuminance by the visible part of the CIE sky

Based on the general expression of the CIE overcast sky (equation G.3) the expression for the illuminance in a surface randomly rotated around the x-axis, under the CIE sky is:

$$E = \iint_{\alpha,\beta} \frac{1+2\cos\alpha}{3} L_Z (\sin\eta \sin\alpha \cos(\beta-\xi) + \cos\alpha\cos\eta)\sin\alpha d\alpha d\beta \tag{G.18}$$

The equation again needs to be worked out for two situations, i.e. for a horizontal surface and for a vertical surface.

Horizontal surface: η = 0°

The general expression for the illuminance is found by filling in $\eta = 0°$:

$$E_{hor} = \frac{L_Z}{3} \iint_{\alpha,\beta} (1+2\cos\alpha)\cos\alpha\sin\alpha d\alpha d\beta$$

$$= \frac{L_Z}{3} \int_0^{2\pi} d\beta \int_0^{\pi/2} (1+2\cos\alpha)\cos\alpha\sin\alpha d\alpha \tag{G.19}$$

And with $\cos\alpha = x$:

$$E_{hor} = \frac{2\pi L_Z}{3} \int_0^1 (1+2x)x dx$$

$$= \frac{2\pi L_Z}{3} \left[\frac{x^2}{2} + \frac{2x^3}{3} \right]_0^1$$

$$= \frac{7\pi L_Z}{9} \tag{G.20}$$

Vertical surface: η = 90°

The general expression for the illuminance is found by filling in $\eta = 90°$:

$$E_{vert} = \frac{L_Z}{3} \iint_{\alpha,\beta} (1+2\cos\alpha)\sin\alpha\cos(\beta-\xi)\sin\alpha d\alpha d\beta$$

$$= \frac{L_Z}{3} \int_{\alpha=0}^{\pi/2} (1+2\cos\alpha)\sin^2\alpha d\alpha \int_{\xi-\pi/2}^{\xi+\pi/2} \cos(\beta-\xi) d\beta$$

$$= \frac{L_Z}{3} \left(\int_{\alpha=0}^{\pi/2} \sin^2\alpha d\alpha + \int_{\alpha=0}^{\pi/2} 2\cos\alpha\sin^2\alpha d\alpha \right) \int_{\xi-\pi/2}^{\xi+\pi/2} \cos(\beta-\xi) d\beta$$

$$= \frac{L_Z}{3}\left(\int_{\alpha=0}^{\pi/2} \frac{1-\cos 2\alpha}{2} d\alpha + \int_{\alpha=0}^{\pi/2} 2\cos\alpha \sin^2 \alpha d\alpha\right)\int_{\xi-\pi/2}^{\xi+\pi/2} \cos(\beta-\xi) d\beta$$

$$= \frac{L_Z}{3}\left\{\left[\frac{\alpha}{2} - \frac{\sin 2\alpha}{4}\right]_0^{\pi/2} + \left[\frac{2t^3}{3}\right]_0^1\right\}\left[-\sin(\beta-\xi)\right]_{\xi-\pi/2}^{\xi+\pi/2}$$

$$= \frac{2L_Z}{3}\left(\frac{\pi}{4} + \frac{2}{3}\right)$$

$$= \frac{L_Z}{18}(3\pi + 8) \qquad \text{(G.21)}$$

G.6. Division of the equal sky dome in mxn surface areas

For the construction of the daylight diagrams the sky domes are divided into a number of surface areas dS_H, in such a way that each surface equally contributes to the illuminance in point P. The size of the surface areas depends on the type of sky and the orientation of surface area dS on which point P is located.

A total of mxn surface areas is constructed:

- m is the division in the horizontal plane (angle β)
- n is the division in the vertical plane (angle α)

In this research diagrams are created with 20 x 5 surface areas and in each area 4 x 4 dots. All dots together represent 80 x 20 surface areas and they are located in the centre of the surface area they represent.

Illuminance on a horizontal plane of the uniform sky

The contribution of one surface area to the illuminance in the measurement point is:

$$E_{hor,sa} = L_0 \iint_{\alpha,\beta} \cos\alpha \sin\alpha d\alpha d\beta$$

$$= L_0 \int_{\beta_j}^{\beta_{j+1}} d\beta \int_{\alpha_i}^{\alpha_{i+1}} \cos\alpha \sin\alpha d\alpha$$

$$= \frac{\pi L_0}{mn} \qquad \text{(G.22)}$$

Division of β

In the horizontal direction the sky dome is divided in m equal surfaces, because the luminance is independent of β. So:

$$d\beta = \frac{2\pi}{m} \qquad \text{(G.23a)}$$

The equation can be written as:

$$\beta_j = \frac{2j \cdot \pi}{m} \qquad \text{(G.2bb)}$$

with j from -½m to ½m

Division of α

The division of the sky in the vertical direction is:

$$\int_{\alpha_i}^{\alpha_{i+1}} \cos\alpha \sin\alpha d\alpha = \int_{\alpha_i}^{\alpha_{i+1}} \sin\alpha d \sin\alpha = \left[\frac{\sin^2\alpha}{2}\right]_{\alpha_i}^{\alpha_{i+1}} = \frac{1}{2}(\sin^2\alpha_{i+1} - \sin^2\alpha_i) = \frac{1}{2n} \qquad \text{(G.24a)}$$

The equation can be written as:

$$\sin^2\alpha_i = \frac{i}{n} \qquad \text{(G.24b)}$$

with i from 0 to n

Illuminance on a vertical plane of the uniform sky

The contribution of one surface area to the illuminance in the measurement point is:

$$E_{vert,sa} = L_0 \iint_{\alpha,\beta} \sin\alpha \cos(\beta - \xi) \sin\alpha d\alpha d\beta$$

$$= \frac{\pi L_0}{2mn} \qquad \text{(G.25)}$$

Division of β

The division of the sky in the horizontal direction is:

$$\int_{\xi-\pi/2}^{\xi+\pi/2} \cos(\beta-\xi) d\beta = \left[-\sin(\beta-\xi)\right]_{\xi-\pi/2}^{\xi+\pi/2} = 2$$

$$\int_{\xi-\pi/2}^{\xi+\pi/2} \cos(\beta-\xi) d\beta = 2\int_{0}^{\pi/2} \cos\beta d\beta = \left[2\sin\beta\right]_0^{\pi/2} = 2$$

$$\int_{\beta_j}^{\beta_{j+1}} \cos\beta d\beta = \frac{2}{m} \qquad \text{(G.26a)}$$

This means that:

$$\sin\beta_{j+1} - \sin\beta_j = \frac{2}{m} \qquad \text{(G.26b)}$$

The equation can be written as:

$$\sin\beta_j = \frac{2j}{m} \qquad \text{(G.26c)}$$

with j from -½m to ½m

Division of α

The division of the sky in the vertical direction is:

$$\int_0^{\pi/2} \sin^2\alpha\, d\alpha = \int_0^{\pi/2} \frac{1-\cos 2\alpha}{2} d\alpha = \left[\frac{\alpha}{2} - \frac{\sin 2\alpha}{4}\right]_0^{\pi/2} = \frac{\pi}{4}$$

$$\left[\frac{\alpha}{2} - \frac{\sin 2\alpha}{4}\right]_{\alpha_i}^{\alpha_{i+1}} = \frac{\alpha_{i+1}}{2} - \frac{\sin 2\alpha_{i+1}}{4} - \frac{\alpha_i}{2} + \frac{\sin 2\alpha_{i+1}}{4} = \frac{\pi}{4n} \qquad \text{(G.27a)}$$

The equation can be written as:

$$2\alpha_i - \sin 2\alpha_i = \frac{\pi \cdot i}{n} \qquad \text{(G.27b)}$$

with i from 0 to n

G.7. Division of the CIE sky dome in mxn surface areas

For both diagrams, of a horizontal and vertical measurement point, the CIE sky is also divided in 20 x 5 surface areas with in each area 4 x 4 dots.

Illuminance on a horizontal plane of the CIE sky

The contribution of one surface area to the illuminance in the measurement point is:

$$E_{hor,sa} = \frac{L_Z}{3} \iint_{\alpha,\beta} (1+2\cos\alpha)\cos\alpha\sin\alpha\, d\alpha\, d\beta$$

$$= \frac{L_Z}{3} \int_{\beta_i}^{\beta_{i+1}} d\beta \int_{\alpha_i}^{\alpha_{i+1}} (1+2\cos\alpha)\cos\alpha\sin\alpha\, d\alpha$$

$$= \frac{7\pi L_z}{9mn} \qquad \text{(G.28)}$$

Division of β

In the horizontal direction the sky dome is divided in m equal surfaces, because the luminance is independent of β. So:

$$d\beta = \frac{2\pi}{m} \tag{G.29a}$$

The equation can be written as:

$$\beta_j = \frac{2j \cdot \pi}{m} \tag{G.29b}$$

with j from -½m to ½m

Division of α

The division of the sky in the vertical direction is:

$$\int_{\alpha_i}^{\alpha_{i+1}} (1+2\cos\alpha)\cos\alpha\sin\alpha d\alpha = \frac{7}{6n} \tag{G.30a}$$

When $\cos\alpha = t$ and $dt = -\sin\alpha d\alpha$ the equation is rewritten as:

$$-\int_{\cos\alpha_i}^{\cos\alpha_{i+1}} (1+2t)tdt = \frac{7}{6n}$$

$$\left[\frac{t^2}{2}+\frac{2t^3}{3}\right]_{\cos\alpha_{i+1}}^{\cos\alpha_i} = \frac{\cos^2\alpha_i}{2}+\frac{2\cos^3\alpha_i}{3}-\frac{\cos^2\alpha_{i+1}}{2}-\frac{2\cos^3\alpha_{i+1}}{3} = \frac{7}{6n} \tag{G.30b}$$

The equation can be written as:

$$\frac{1}{2}\cos^2\alpha_i + \frac{2}{3}\cos^3\alpha_i = \frac{7}{6}\left(1-\frac{i}{n}\right) \tag{G.30c}$$

with i from 0 to n

Illuminance on a vertical plane

The contribution of one surface area to the illuminance in the measurement point is:

$$E_{vert,SA} = \frac{L_z}{3} \iint_{\alpha,\beta} (1+2\cos\alpha)\sin\alpha\cos(\beta-\xi)\sin\alpha d\alpha d\beta$$

$$= \frac{L_z}{18mn}(3\pi+8) \tag{G.31}$$

$$= \frac{2L_z}{3mn}\left(\frac{\pi}{4}+\frac{2}{3}\right) \quad \text{(G.31)}$$

Division of β

The division of the sky in the horizontal direction is the same as for the equal sky:

$$\sin\beta_{j+1} - \sin\beta_j = \frac{2}{m} \quad \text{(G.32a)}$$

The equation can be written as:

$$\sin\beta_j = \frac{2j}{m} \quad \text{(G.32b)}$$

with j from -½m to ½m

Division of α

The division of the sky in the vertical direction is:

$$\int_{\alpha=0}^{\pi/2} (1+2\cos\alpha)\sin^2\alpha\, d\alpha = \left[\frac{\alpha}{2}-\frac{\sin 2\alpha}{4}\right]_0^{\pi/2} + \left[\frac{2t^3}{3}\right]_0^1 = \frac{\pi}{4}+\frac{2}{3}$$

$$\int_{\alpha_i}^{\alpha_{i+1}} (1+2\cos\alpha)\sin^2\alpha\, d\alpha = \left[\frac{\alpha}{2}-\frac{\sin 2\alpha}{4}\right]_{\alpha_i}^{\alpha_{i+1}} + \left[\frac{2t^3}{3}\right]_{\sin\alpha_i}^{\sin\alpha_{i+1}} = \frac{1}{n}\left(\frac{\pi}{4}+\frac{2}{3}\right)$$

$$\frac{\alpha_{i+1}}{2} - \frac{\sin 2\alpha_{i+1}}{4} - \frac{\alpha_i}{2} + \frac{\sin 2\alpha_i}{4} + \frac{2\sin^3\alpha_{i+1}}{3} - \frac{2\sin^3\alpha_i}{3} = \frac{1}{n}\left(\frac{\pi}{4}+\frac{2}{3}\right) \quad \text{(G.33a)}$$

The equation can be written as:

$$\frac{1}{2}\alpha_i - \frac{1}{4}\sin 2\alpha_i + \frac{2}{3}\sin^3\alpha_i = \frac{i}{n}\left(\frac{\pi}{4}+\frac{2}{3}\right) \quad \text{(G.33b)}$$

with i from 0 to n

G.8. *Derivation of angles σ and τ from angles α and β*

After calculating angles α and β for each line and dot of the four diagrams, angles σ and τ are derived from α and β by the following two equations:

$$\sigma = f(\alpha,\beta) = \arccos\left(\sin\alpha\cdot\cos\beta\right) \quad \text{(G.43)}$$

$$\tau = f(\alpha, \beta) = \arccos(\tan\alpha \cdot \sin\beta) \qquad \text{(G.44)}$$

After calculating angles σ and τ, the dot diagrams are drawn according to the equidistant projection function as described in Chapter 10.

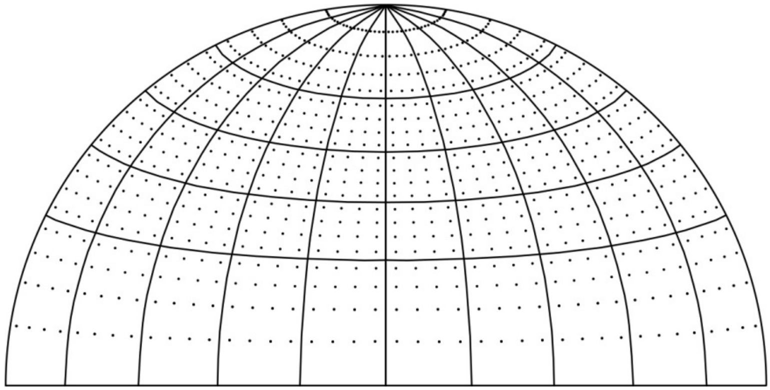
G.9. References

Cauberg, J.J.M., Van der Linden, A.C., Van den Ham, E.H., Bouwfysica 1, Technische Universiteit Delft, Faculteit Civiele Techniek en Geowetenschappen, 2001 Vakgroep Bouwfysica, GC 45, Bouwfysica deel 2: Akoestiek/Licht, Delft, TU Delft, 1995

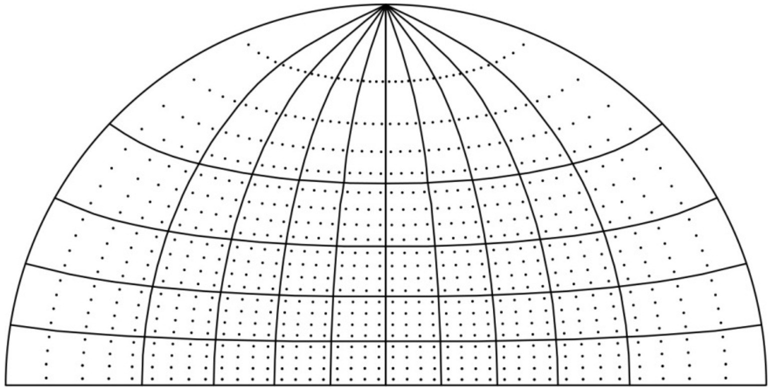
Notes of M. Pel, c.a. 2005 (These notes were lost in a fire in 2008)

Appendix H

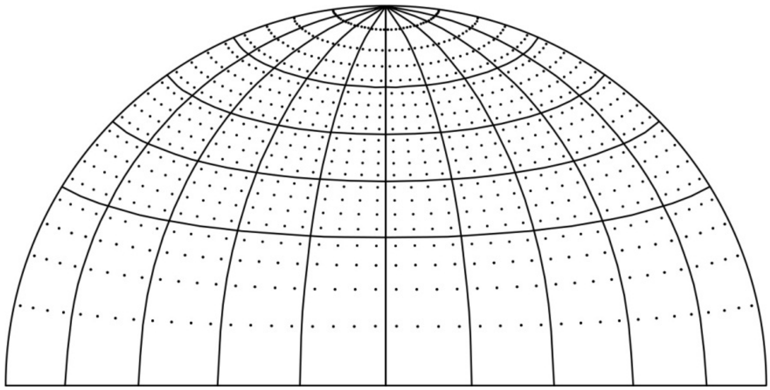
Dot and Sunpath Diagrams for the LMK Mobile Advance and Sigma 8mm Circular Fisheye lens



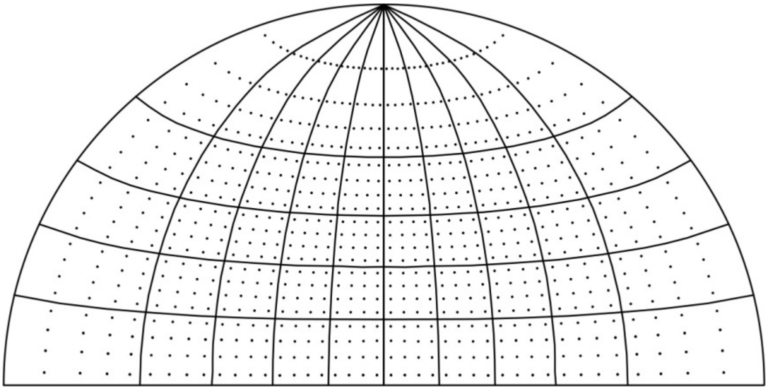
Dot diagrams of uniform sky dome and horizontal point (SF = Σdots/1600)



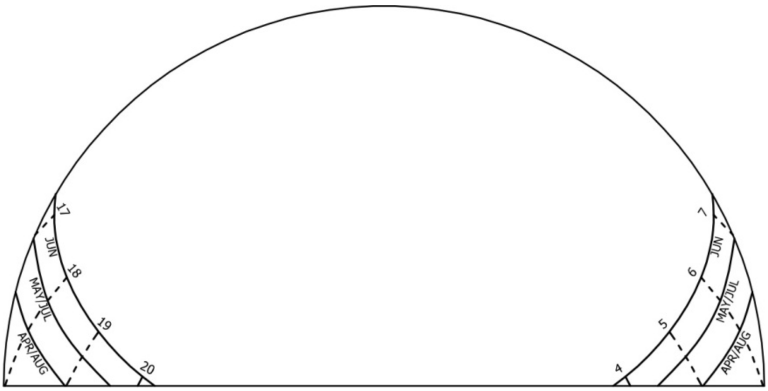
Dot diagram of uniform sky dome and vertical point (SF = Σdots/1600)



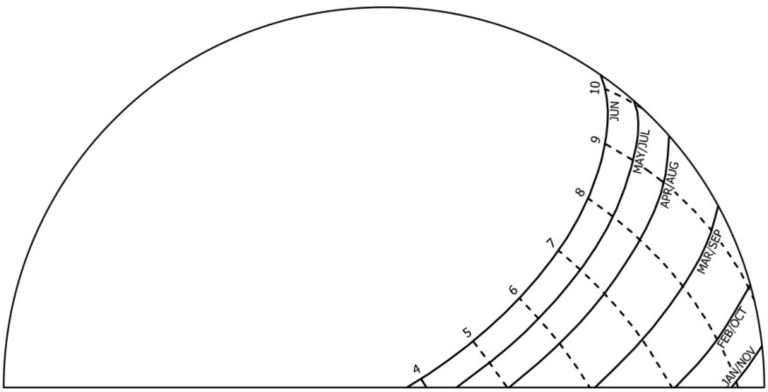
Dot diagrams of CIE overcast sky and horizontal point (SC = Σdots/1600)



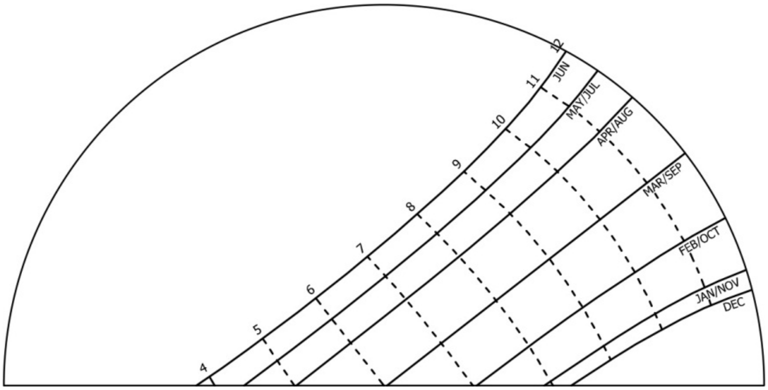
*Dot diagrams of CIE overcast sky and vertical point (SC = Σdots/800*0.396)*



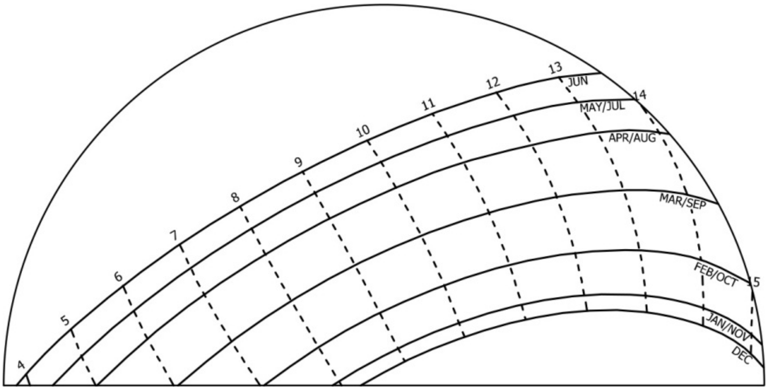
Sunpath diagram north



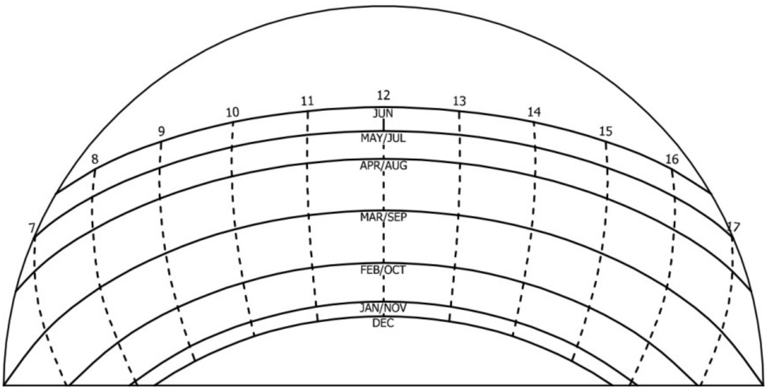
Sunpath diagram northeast



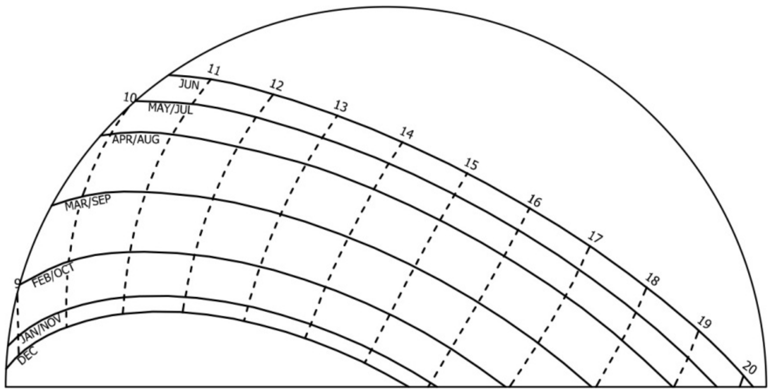
Sunpath diagram east



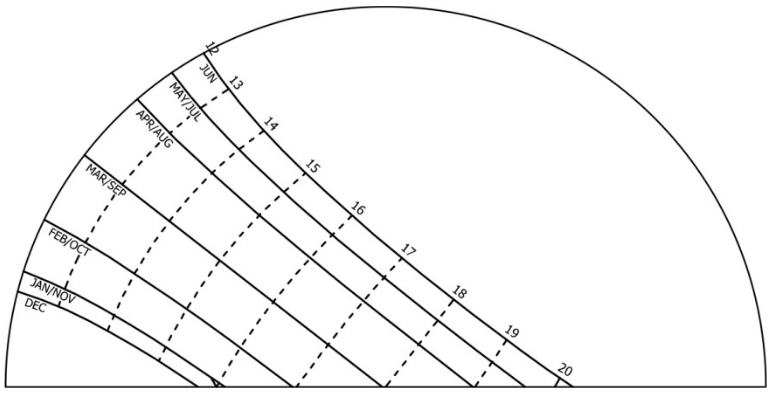
Sunpath diagram southeast



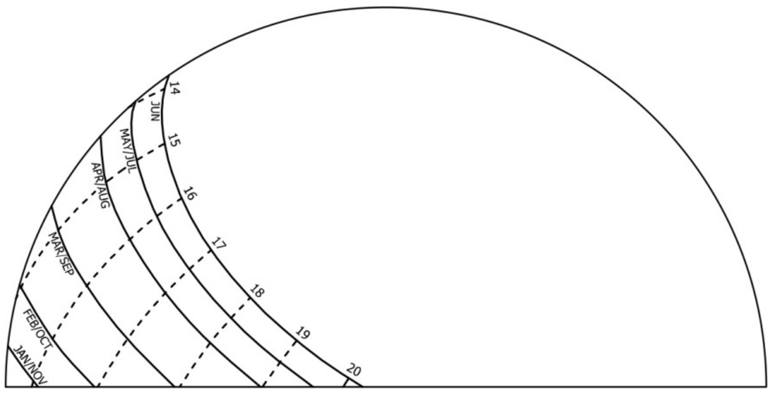
Sunpath diagram south



Sunpath diagram southwest



Sunpath diagram west



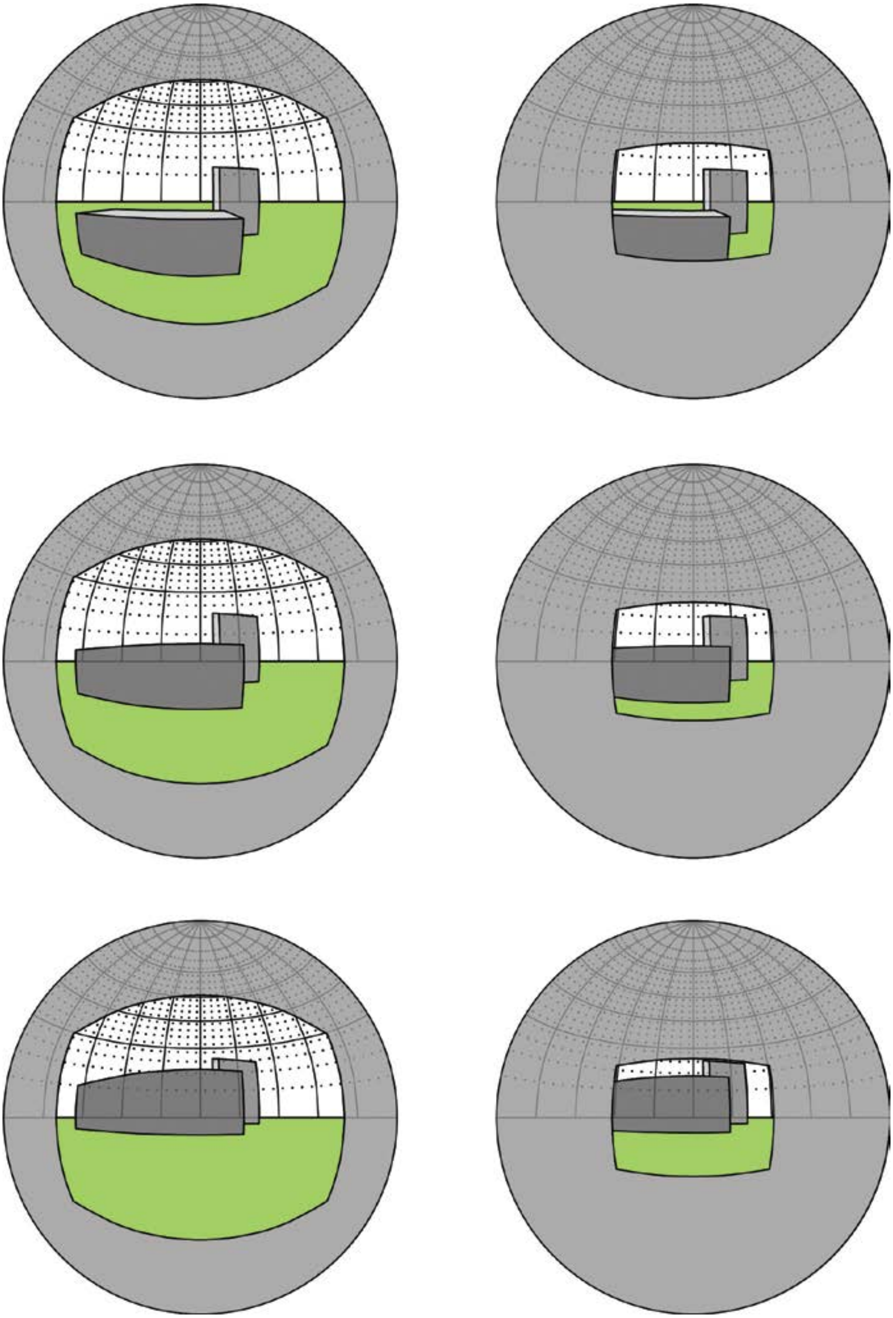
Sunpath diagram northwest

Appendix I

Sky Component per Measurement Point in the Three Variations of the Test Model

I.1. Test model with no façade

Below the projections are shown from the test model with no façade and the CIE overcast sky for a horizontal measurement point.



Below the projections are shown from the test model with no façade and the CIE overcast sky for a vertical measurement point.

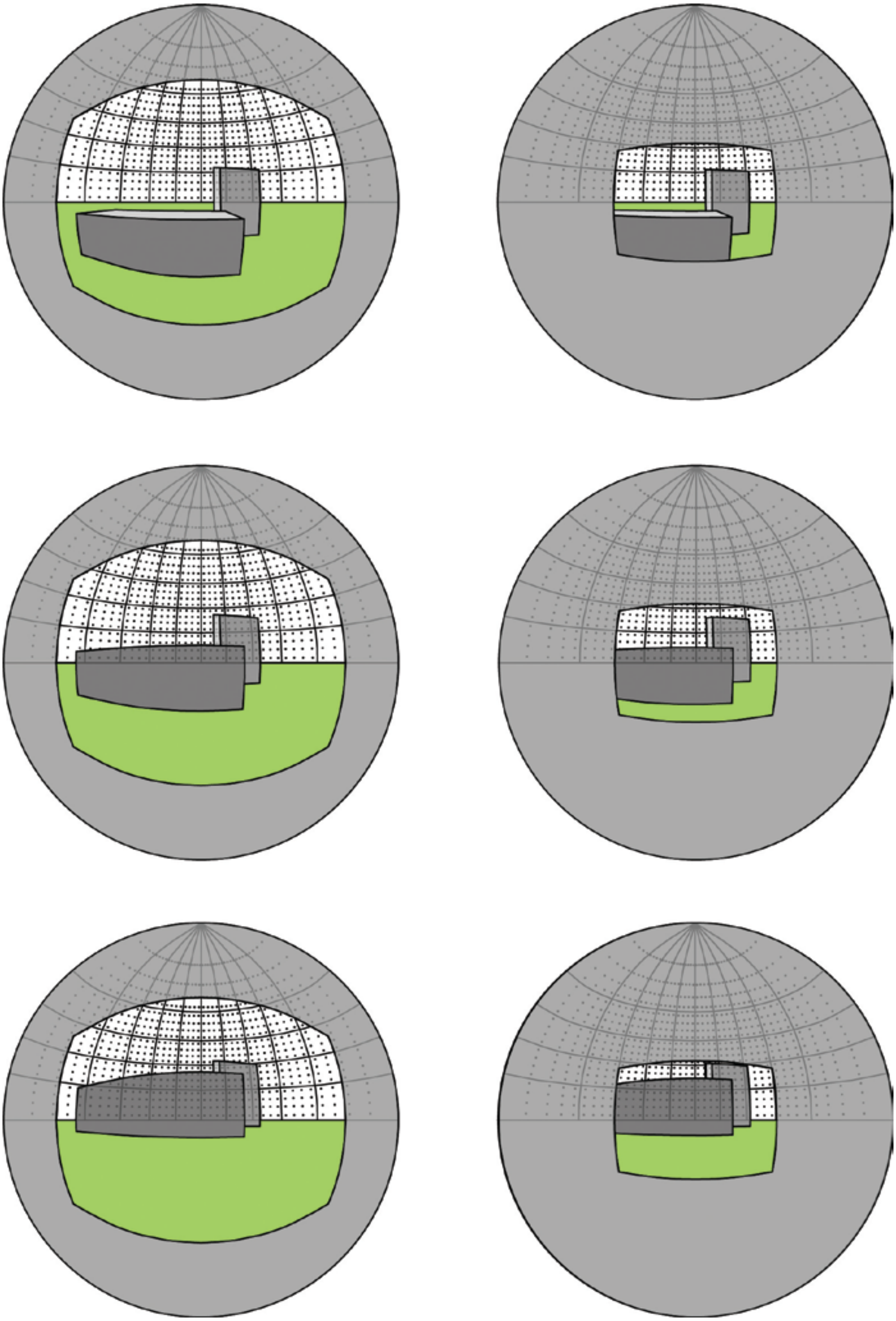


Table I.1. shows the calculated sky components per measurement point. Table I.2 shows per measurement point to what extent the sky components found with the dot diagrams deviates from the results of Desktop Radiance and DIALux.

Table I.1: Calculated sky components in the test model with no facade

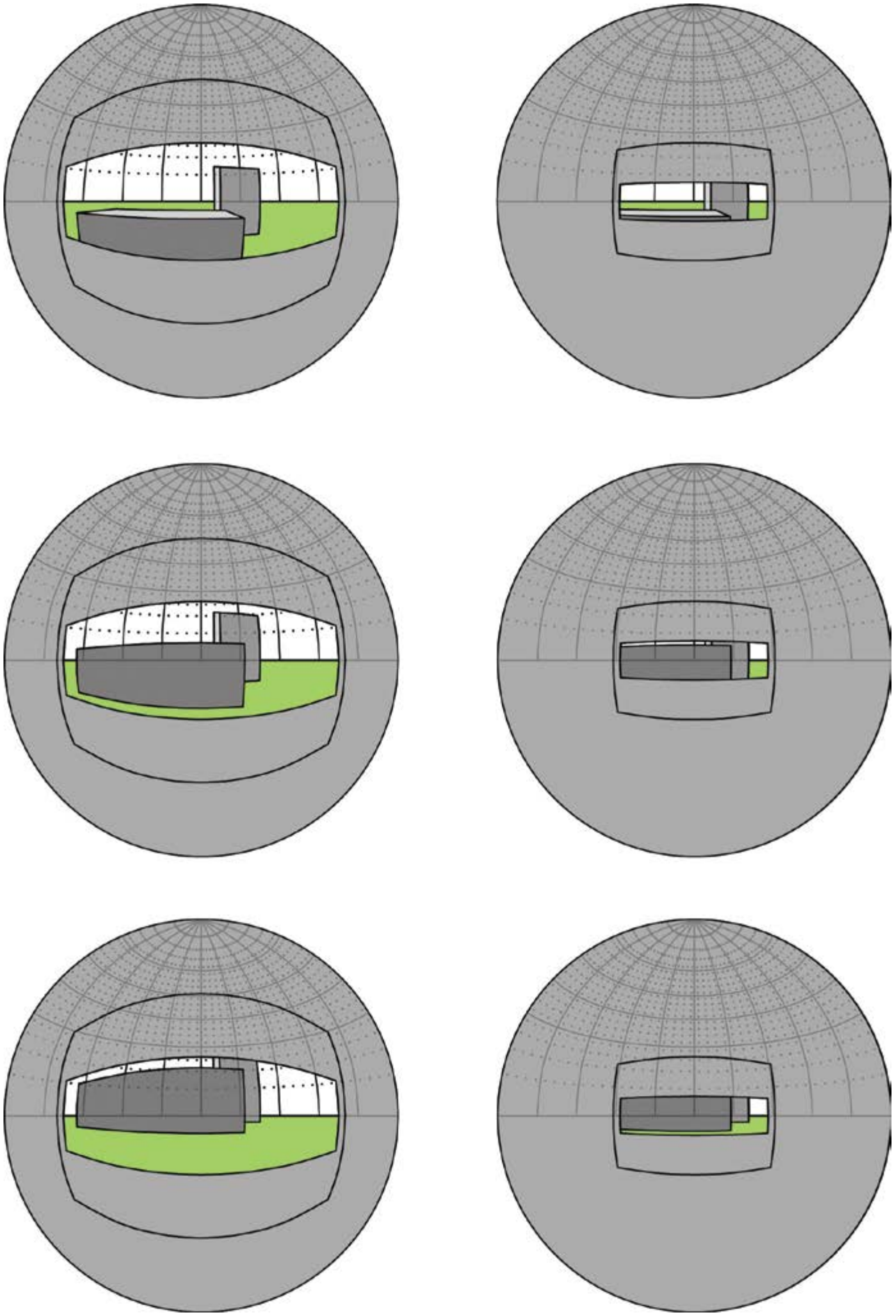
Measurement point		Dot diagram	Desktop Radiance	DIALux
1	Horizontal	16.9%	17.5%	18.0%
1	Vertical	26.6%	27.1%	28.0%
2	Horizontal	2.1%	2.2%	2.4%
2	Vertical	7.5%	7.9%	8.3%
3	Horizontal	16.6%	17.2%	18.0%
3	Vertical	23.9%	24.8%	25.0%
4	Horizontal	1.8%	2.0%	2.1%
4	Vertical	5.5%	6.4%	6.6%
5	Horizontal	14.9%	15.8%	16.0%
5	Vertical	19.4%	20.3%	21.0%
6	Horizontal	1.1%	1.1%	1.2%
6	Vertical	2.5%	3.2%	3.4%

Table I.2: Deviation of the results of the dot diagrams from the light simulation software in the test model with no façade

Measurement Point		Absolute deviation of the dot diagrams from		Percent deviation of the dot diagrams from	
		Desktop Radiance	DIALux	Desktop Radiance	DIALux
1	Horizontal	-0.5%	-1.1%	-3%	-6%
1	Vertical	-0.5%	-1.4%	-2%	-5%
2	Horizontal	-0.2%	-0.3%	-8%	-12%
2	Vertical	-0.3%	-0.8%	-4%	-9%
3	Horizontal	-0.6%	-1.4%	-4%	-8%
3	Vertical	-0.9%	-1.1%	-3%	-4%
4	Horizontal	-0.3%	-0.3%	-13%	-16%
4	Vertical	-0.9%	-1.0%	-13%	-16%
5	Horizontal	-0.9%	-1.1%	-6%	-7%
5	Vertical	-0.9%	-1.6%	-4%	-8%
6	Horizontal	-0.1%	-0.2%	-6%	-14%
6	Vertical	-0.7%	-0.9%	-22%	-26%

I.2. Test model with façade 1

Below the projections are shown from the test model with façade 1 and the CIE overcast sky for a horizontal measurement point.



Below the projections are shown from the test model with façade 1 and the CIE overcast sky for a vertical measurement point.

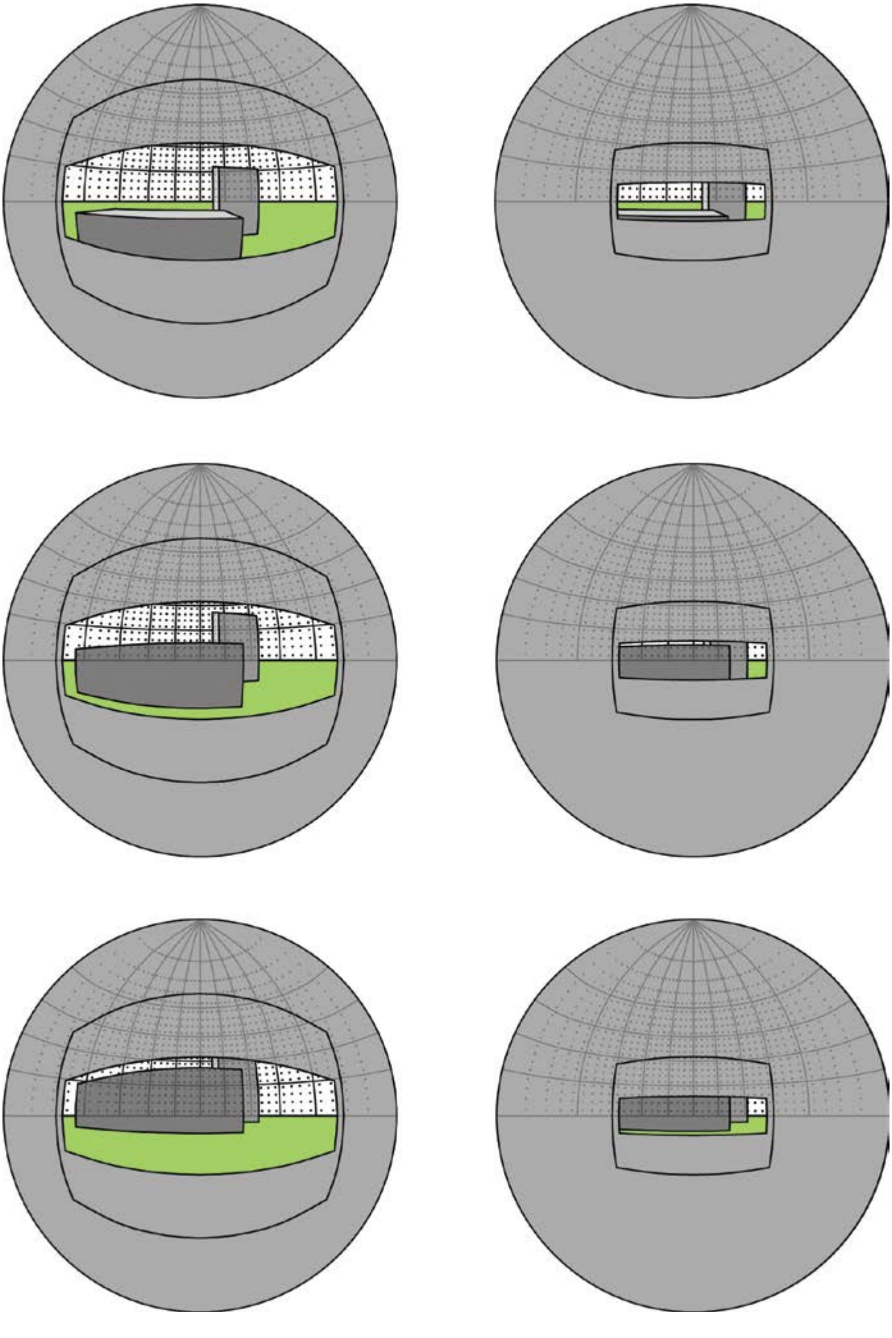


Table I.3 shows the calculated sky components per measurement point. Table I.4 shows per measurement point to what extent the sky components found with the dot diagrams deviates from the results of Desktop Radiance and DIALux.

Table I.3: Calculated sky components in the test model with façade 1

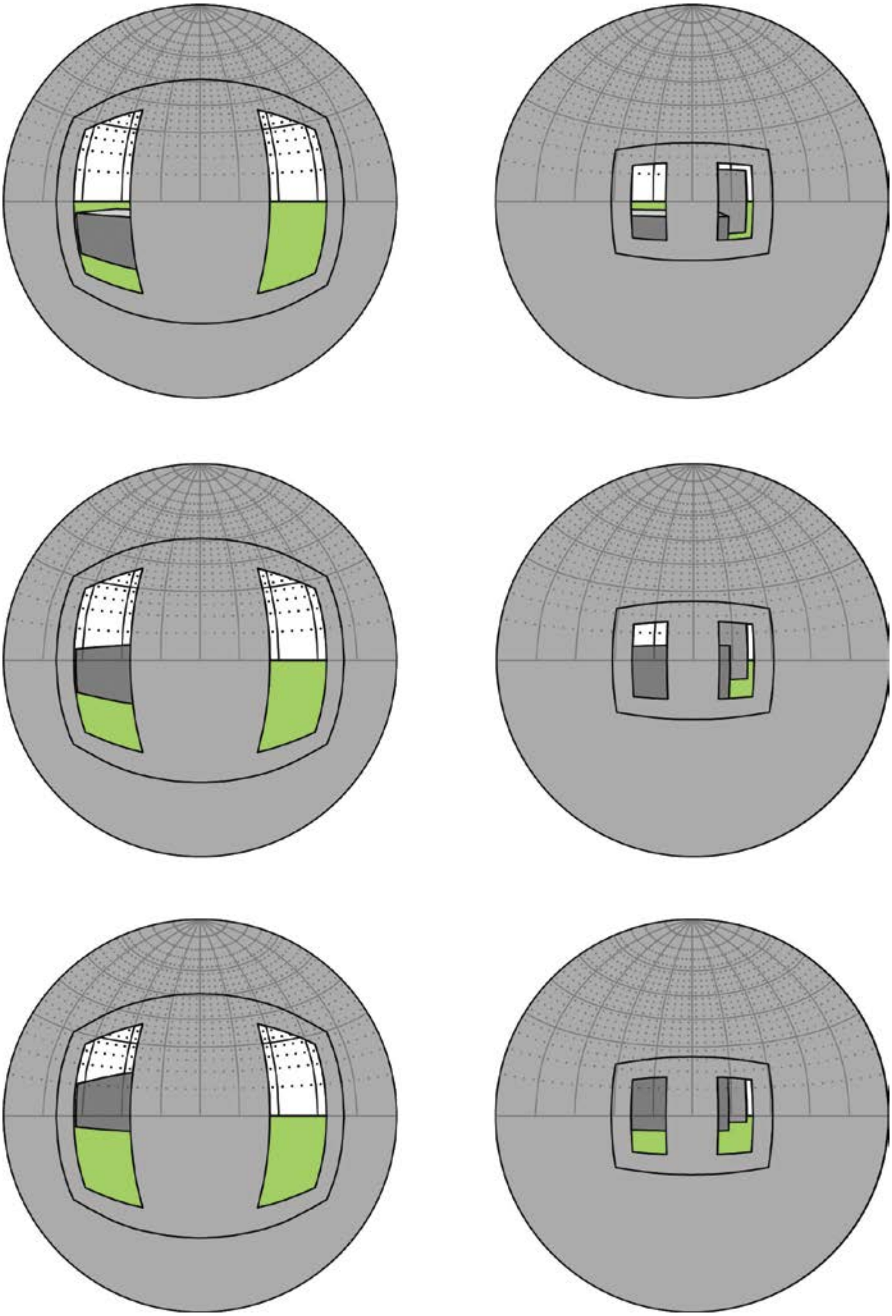
Measurement point		Dot diagram	Desktop Radiance	DIALux
1	Horizontal	2.9%	2.8%	3.2%
1	Vertical	10.7%	10.8%	11.0%
2	Horizontal	0.0%	0.0%	0.2%
2	Vertical	1.4%	1.6%	2.0%
3	Horizontal	2.6%	2.6%	2.8%
3	Vertical	8.0%	8.5%	8.9%
4	Horizontal	0.0%	0.0%	0.1%
4	Vertical	0.2%	0.6%	0.9%
5	Horizontal	1.1%	1.1%	1.4%
5	Vertical	3.8%	4.2%	4.3%
6	Horizontal	0.0%	0.0%	0.0%
6	Vertical	0.2%	0.1%	0.3%

Table I.4: Deviation of the results of the dot diagrams from the light simulation software in the test model with façade 1

Measurement point		Absolute deviation of the dot diagrams from		Percent deviation of the dot diagrams from	
		Desktop Radiance	DIALux	Desktop Radiance	DIALux
1	Horizontal	0.1%	-0.2%	5%	-7%
1	Vertical	-0.1%	-0.3%	-1%	-2%
2	Horizontal	0.0%	-0.2%	-100%	-100%
2	Vertical	-0.2%	-0.6%	-13%	-29%
3	Horizontal	0.0%	-0.1%	2%	-5%
3	Vertical	-0.5%	-0.8%	-6%	-9%
4	Horizontal	0.0%	-0.1%	-	-100%
4	Vertical	-0.4%	-0.7%	-69%	-78%
5	Horizontal	0.0%	-0.3%	3%	-20%
5	Vertical	-0.4%	-0.5%	-9%	-11%
6	Horizontal	0.0%	0.0%	-	-100%
6	Vertical	0.1%	-0.1%	58%	-32%

I.3. Test model with façade 2

Below the projections are shown from the test model with façade 2 and the CIE overcast sky for a horizontal measurement point.



Below the projections are shown from the test model with façade 2 and the CIE overcast sky for a vertical measurement point.

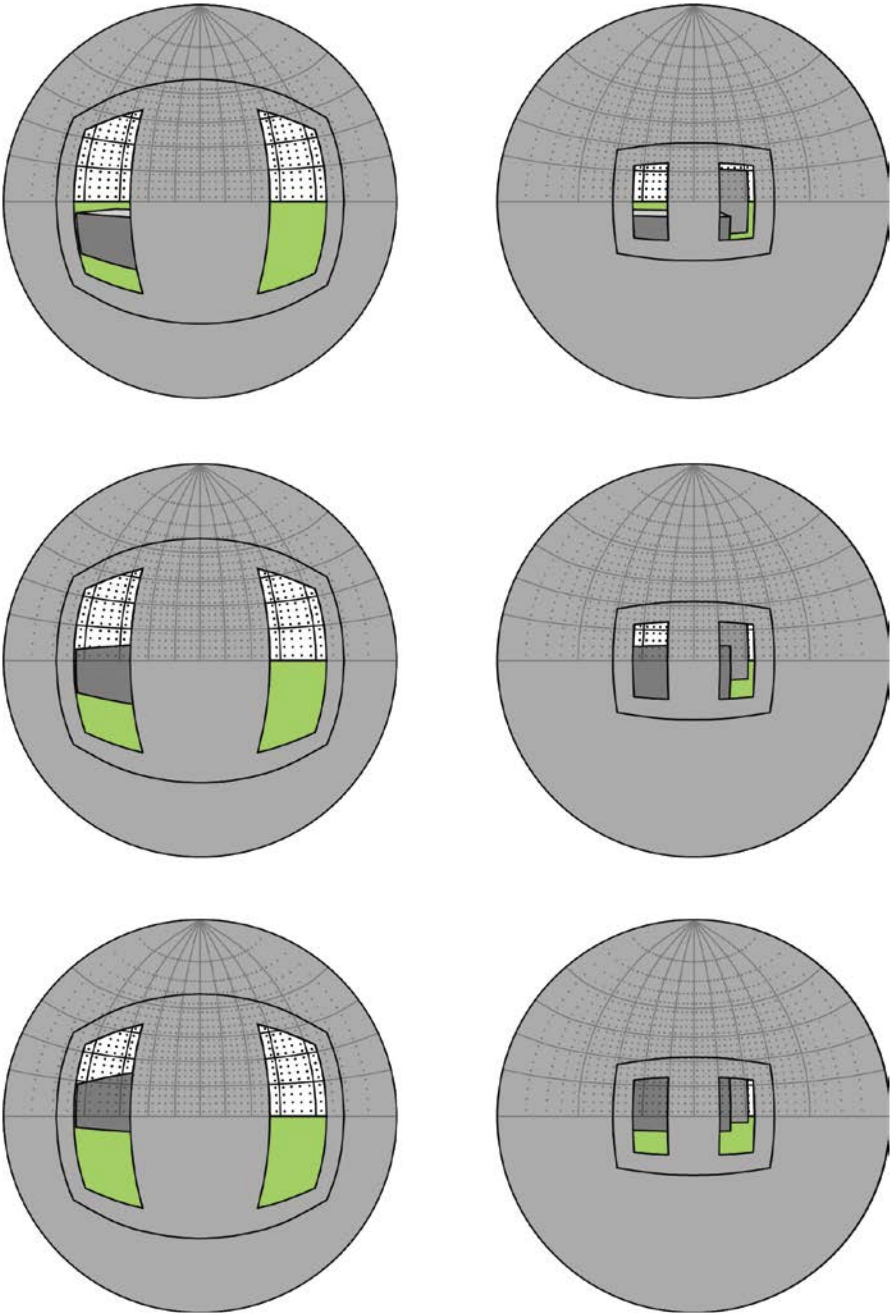


Table I.5 shows the calculated sky components per measurement point. Table I.6 shows per measurement point to what extent the sky components found with the dot diagrams deviates from the results of Desktop Radiance and DIALux.

Table I.5: Calculated sky components in the test model with façade 2

Measurement point		Dot diagram	Desktop Radiance	DIALux
1	Horizontal	3.5%	3.0%	3.6%
1	Vertical	6.6%	6.9%	7.3%
2	Horizontal	0.2%	0.3%	0.4%
2	Vertical	1.2%	1.6%	1.9%
3	Horizontal	3.5%	3.1%	3.5%
3	Vertical	6.1%	6.5%	6.9%
4	Horizontal	0.2%	0.2%	0.3%
4	Vertical	0.7%	0.9%	1.3%
5	Horizontal	3.1%	2.9%	3.3%
5	Vertical	5.1%	5.5%	5.8%
6	Horizontal	0.0%	0.0%	0.1%
6	Vertical	0.0%	0.2%	0.3%

Table I.6: Deviation of the results of the dot diagrams from the light simulation software in the test model with façade 2

Measurement point		Absolute deviation of the dot diagrams from		Percent deviation of the dot diagrams from	
		Desktop Radiance	DIALux	Desktop Radiance	DIALux
1	Horizontal	0.5%	-0.1%	15%	-3%
1	Vertical	-0.2%	-0.7%	-3%	-9%
2	Horizontal	-0.2%	-0.2%	-45%	-49%
2	Vertical	-0.4%	-0.7%	-24%	-35%
3	Horizontal	0.4%	0.0%	13%	-1%
3	Vertical	-0.4%	-0.8%	-6%	-11%
4	Horizontal	0.0%	-0.1%	13%	-31%
4	Vertical	-0.2%	-0.5%	-20%	-41%
5	Horizontal	0.3%	-0.1%	9%	-4%
5	Vertical	-0.4%	-0.7%	-8%	-12%
6	Horizontal	0.0%	-0.1%	-	-100%
6	Vertical	-0.2%	-0.3%	-100%	-100%

Appendix J

Questionnaire Scale Model Study

Dear student,

This experiment aims to understand how both daylight and outside view influence visual comfort. The scale model represents an office room. Assume that you are working on a paper task sited on one of the chairs inside the model. Three tests will be done with three different facades.

This questionnaire will ask you about your impression of the outside view and day lighting.
It is structured in 5 parts. The first part deals with personal information and has to be filled out only once. Parts 2, 3 and 4 are respectively related to your overall perception, general impression of the outside view and daylight. These three parts have to be filled out for each facade. The final part proposes general questions and has to be filled out once only.

Please tick the appropriate boxes; do not circle the words. You just have to answer freely based on your first impression; there are no right or wrong answers.

Thank you very much for your cooperation,

With warm greetings,

Vincent Uso, architect and student in civil engineering at ENTPE in France;
Hester Hellinga, PhD candidate, Delft University of technology;
Dr Truus de Buin-Hordijk, assistent professor, Delft University of technology.

Date: ….. - 05 - 2010
Hour: ….:…...
N#

Particular conditions:

Personal information

1. What is your age? ………..

2. What is your gender?

- ○ Male ○ Female

3. Do you wear glasses?

- ○ Yes ○ No

4. Do you wear contact lenses?

- ○ Yes ○ No

5. Is your sight limited by an eye disease or eye disorder, even when you wear glasses or contact lenses? (For example color blindness or cataract)

- ○ Yes (please specify) ○ No

……………………………………

6. Are your eyes sensitive to intense light?

- ○ Yes, very sensitive ○ Yes, somewhat sensitive ○ No

7. Do you wear sunglasses outdoors during sunny weather?

- ○ Always
- ○ Often
- ○ Regularly
- ○ Sometimes
- ○ Never

8. Where do you come from originally? Please specify country

……………………………………………………………………

9. In general, what do you prefer to see through a window?

……………………………………………………………………

……………………………………………………………………

Date: ….. - 05 - 2010	N#	Particular conditions:
Hour: ….:…...	View N#	
Weather:	Window design N#	

Overall perception

10a. Would you feel well in this space?

○ Very well ○ Well ○ Neutral ○ Not really ○ Not at all

11a. What improvements could be made? Please explain

....

....

....

12a. Would you like to work in this space?

○ Yes ○ No

13a. What is your general impression of this space?

Attractive	○	○	○	○	○	Repulsive
Light	○	○	○	○	○	Dark
Spacious	○	○	○	○	○	Cramped
Pleasant	○	○	○	○	○	Unpleasant
Warm	○	○	○	○	○	Cold
Stimulating	○	○	○	○	○	Tiring

14a. What do you think of the size of the window(s)?

○ Much too big ○ Slightly too big ○ Exactly good ○ Slightly too small ○ Much too small

15a. Is the position of the window appropriate? Please explain why

○ Yes ○ No

....

....

Outside view

16a. What is your general impression of the outside view?

Attractive	○	○	○	○	○	Repulsive
Bright	○	○	○	○	○	Dark
Diverse	○	○	○	○	○	Monotonous
Organized	○	○	○	○	○	Unorganized
Distracting	○	○	○	○	○	Not distracting
Complex	○	○	○	○	○	Uniform

17a. How would you assess this view?
Give the picture a mark between 0 (very bad view) and 10 (very good view)

....

18a. What element do you prefer most in this view?
You may give more than one answer (max 3)

○ People ○ Buildings
○ The ground ○ The sky
○ Traffic ○ Green
○ Water ○ One detail in particular: ....

19a. What element do you dislike most in this view?
You may give more than one answer (max 3)

○ People ○ Buildings
○ The ground ○ The sky
○ Traffic ○ Green
○ Water ○ One detail in particular: ....

Daylight quality & indoor environment

20a. What do you think of the light level?

○ Far too much light ○ Slightly too much light ○ Rather good ○ Slightly too little light ○ Far too little light

21a. What do you think of the light distribution in the scale model?

○ Very comfortable ○ Comfortable ○ Neutral ○ Uncomfortable ○ Intolerable

22a. Evaluate the degree of discomfort glare in the entire space.

○ Not perceptible ○ Barely perceptible ○ Perceptible ○ Uncomfortable ○ Intolerable

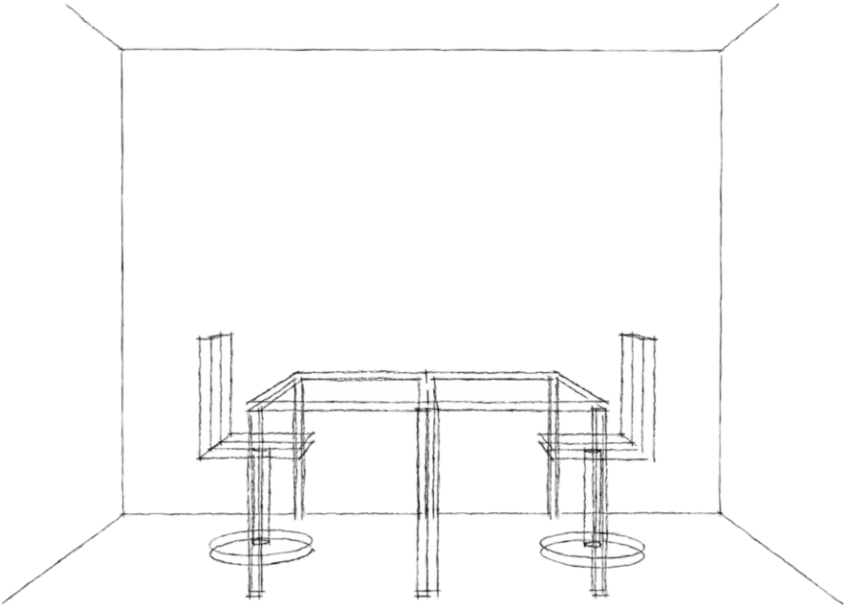
23a. Assume you have to conduct your daily work in this room, how satisfied are you with the lighting condition?

○ Very satisfied ○ Satisfied ○ Fairly Satisfied ○ Dissatisfied ○ Very dissatisfied

24a. Assume you have to conduct your daily work in this room, do you feel that the perceived glare from the window is acceptable?

○ Yes ○ No

25. Could you draw in the picture below what would be the best window configuration for this office?



26. Do you have any questions or comments on this research? If yes, please specify

....

....

....

....

Thank you very much for your contribution to our research!

Appendix K

Projections from the Scale Model and View 1 with the Dot and Sunpath Diagrams

WD1


10
11
12
13
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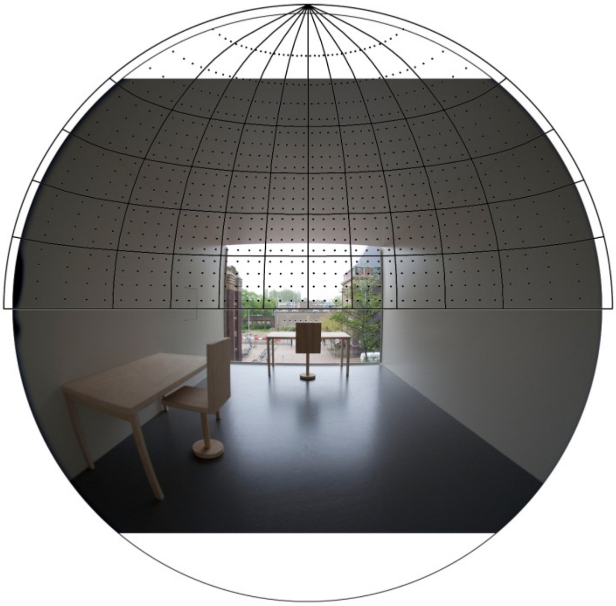
15
16
17
18
19
9
JUN
MAY/JUL
APR/AUG
MAR/SEP
FEB/OCT
JAN/NOV
DEC

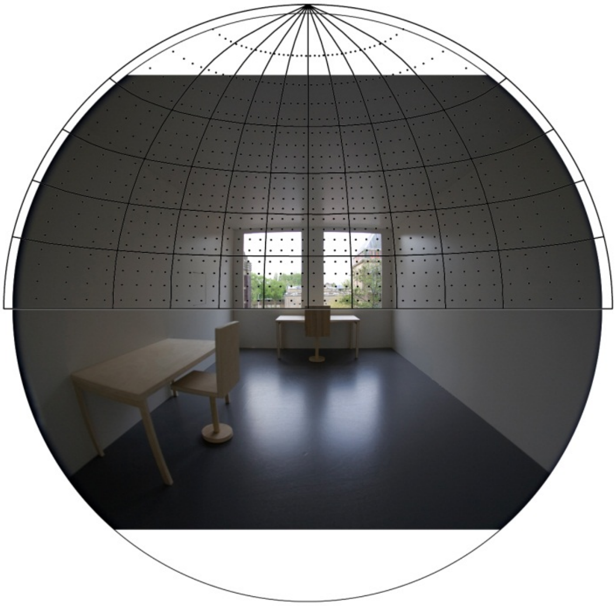
WD2


11
JUN
12
10
13
APR/AUG
14
15
16
MAR/SEP
17
9
FEB/OCT
18
JAN/NOV
DEC
19
20

WD3



WD4



WD5


9
10
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16
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19
20
JUN
MAY/JUL
APR/AUG
MAR/SEP
FEB/OCT
JAN/NOV
DEC

WD6

JUN
MAY/JUL
APR/AUG
MAR/SEP
FEB/OCT
JAN/NOV
DEC
9
10
11
12
13
14
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17
18
19
20

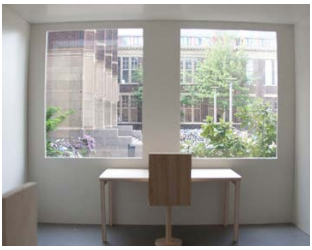
WD7

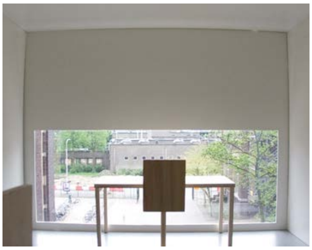
Appendix L

Rating of the Views from the Scale Model with the D&V Analysis Method

View from the scale model with view quality rating by the participants in the research	View quality rating with the new analysis method
WD1 - View 1 (mean rating 6,3) 	Built view (0pt) Visible layers: Nearby buildings and/or greenery , the sky (2pt) Natural green (2pt) Medium diversity (1pt) Features of the building(s): Old building(s), complex architecture , well maintained (1pt) Total: 6pt
WD1 - View 2 (mean rating 6,4) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery (2pt) Natural green (2pt) Nearby cars/traffic (-1pt) Medium diversity (1pt) Features of the building(s): Old building(s), complex architecture , well maintained (1pt) Total: 5pt
WD1 - View 3 (mean rating 6,7) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery (2pt) Natural green (2pt) Medium diversity (1pt) Features of the building(s): Old building(s), complex architecture , well maintained (1pt) Total: 6pt
WD2 – View 1 (mean rating 4,5) 	Built view (0pt) Visible layers: Nearby buildings and/or greenery, the sky (2pt) Natural green (2pt) Low diversity (0pt) Features of the building(s): Old buildings, simple architecture, well maintained (0pt) Total: 4pt

View from the scale model with view quality rating by the participants in the research	View quality rating with the new analysis method
WD2 – View 2 (mean rating 4,7) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery (2pt) Natural green (2pt) Nearby cars/traffic (-1pt) Low diversity (0pt) Features of the building(s): Old buildings, complex architecture, well maintained (1pt) Total: 4pt
WD2 – View 3 (mean rating 5,9) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery (2pt) Natural green (2pt) Low diversity (0pt) Features of the building(s): Old buildings, complex architecture, well maintained (1pt) Total: 5pt
WD3 – View 1 (mean rating 6,2) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery , the sky (3pt) Natural green (2pt) Medium diversity (1pt) Features of the building(s): Old building(s), complex architecture , well maintained (1pt) Total: 7pt
WD3 – View 2 (mean rating 6,2) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery (2pt) Natural green (2pt) Nearby cars/traffic (-1pt) Medium diversity (1pt) Features of the building(s): Old building(s), complex architecture , well maintained (1pt) Total: 5pt

View from the scale model with view quality rating by the participants in the research	View quality rating with the new analysis method
WD3– View 3 (mean rating 6,8) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery (2pt) Natural green (2pt) Medium diversity (1pt) Features of the building(s): Old building(s), complex architecture , well maintained (1pt) Total: 6pt
WD4 – View 1 (mean rating 5,5) 	Built view (0pt) Visible layers: Nearby buildings and/or greenery, the sky (2pt) Natural green (2pt) Medium diversity (1pt) Features of the building(s): Old building(s), complex architecture , well maintained (1pt) Total: 6pt
WD4 – View 2 (mean rating 5,7) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery (2pt) Natural green (2pt) Nearby cars/traffic (-1pt) Medium diversity (1pt) Features of the building(s): Old building(s), complex architecture , well maintained (1pt) Total: 5pt
WD4 – View 3 (mean rating 6,1) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery (2pt) Natural green (2pt) Medium diversity (1pt) Features of the building(s): Old building(s), complex architecture , well maintained (1pt) Total: 6pt

View from the scale model with view quality rating by the participants in the research	View quality rating with the new analysis method
WD5 – View 1 (mean rating 5,8) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery, the sky (3pt) Natural green (2pt) Medium diversity (1pt) Features of the building(s): Old building(s), simple architecture , well maintained (0pt) Total: 6pt
WD5 – View 2 (mean rating 5,5) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery (2pt) Natural green (2pt) Nearby cars/traffic (-1pt) Medium diversity (1pt) Features of the building(s): Old building(s), complex architecture , well maintained (1pt) Total: 5pt
WD5– View 3 (mean rating 6,4) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery (2pt) Natural green (2pt) Medium diversity (1pt) Features of the building(s): Old building(s), complex architecture , well maintained (1pt) Total: 6pt
WD6 – View 1 (mean rating 6,2) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery, (2pt) Natural green (2pt) Medium diversity (1pt) Features of the building(s): Old building(s), simple architecture , well maintained (0pt) Total: 4pt

View from the scale model with view quality rating by the participants in the research	View quality rating with the new analysis method
WD6 – View 2 (mean rating 4,8) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery (2pt) Natural green (2pt) Nearby cars/traffic (-1pt) Low diversity (0pt) Total: 3pt
WD6– View 3 (mean rating 5,0) 	Built view (0pt) Visible layers: The ground, nearby buildings and/or greenery (2pt) Natural green (2pt) Low diversity (0pt) Total: 4pt
WD7 – View 1 (mean rating 5,2) 	Built view (0pt) Visible layers: Nearby buildings and/or greenery, the sky (2pt) Natural green (2pt) Low diversity (0pt) Total: 4pt
WD7 – View 2 (mean rating 5,0) 	Built view (0pt) Visible layers: Nearby buildings and/or greenery (1pt) Natural green (2pt) Low diversity (0pt) Features of the building(s): Old building(s), complex architecture , well maintained (1pt) Total: 4pt

View from the scale model with view quality rating by the participants in the research	View quality rating with the new analysis method
WD7– View 3 (mean rating 5,1) 	Built view (0pt) Visible layers: Nearby buildings and/or greenery (1pt) Natural green (2pt) Low diversity (0pt) Features of the building(s): Old building(s), complex architecture , well maintained (1pt) Total: 4pt

Appendix M

Curriculum Vitae

Hester Hellinga was born on 24 March 1981 in Hallum, the Netherlands. She studied at the Delft University of Technology and received a Master degree in both Architecture and Building Technology in 2006.

During her studies Hester had several part time jobs. Amongst others, she was mentor of first year architecture students from 2001 to 2004. In the summer of 2003 she went to Lubin, Poland, in order to work as a volunteer on a construction site for the 'Internationale Bouworde'. She worked as an intern for the architectural office GDA (Gunnar Daan Doeke van Wieren Architecten) in Burdaard, Netherlands, in 2004.

After graduation, Hester was a researcher at the Faculty of Architecture in the research group Climate Design, chair of Building Physics for five months. Subsequently, she started her PhD research. She published her research in various conference proceedings and journals.

During her employment by the Delft University of Technology Hester was teacher of several courses and supervisor of two graduation students and an intern from the ENTPE, Université de Lyon, France. She was an active member of the PhD counsel of the department Building Technology from March 2009 to March 2010.

Since September 2011 Hester is employed by Cauberg-Huygen Raadgevende Ingenieurs. Her aim as a consultant and researcher is to contribute to a pleasant and healthy environment and to bridge the gap between scientific research and building practice.