AALTO-UNIVERSITY
SCHOOL OF SCIENCE AND TECHNOLOGY

Faculty of Electronics, Telecommunications and Automation
Department of Electronics
Lighting Unit

Saara Jaatinen

The use of LEDs in pedestrian ways, parking areas and parks- A user study

Thesis for the degree of Master of Science
Espoo 23.4.2010

Supervisor Professor Liisa Halonen

Instructor D.Sc Marjukka Puolakka

AALTO-UNIVERSITY
SCHOOL OF SCIENCE AND TECHNOLOGY Abstract of the Master's Thesis

Author: Saara Jaatinen

Name of the thesis: The use of LEDs in pedestrian ways, parking areas and parks- A user study

Number of pages: 97

Date: 23.4.2010

Faculty: Electronics, Telecommunications and Automation

Professorship: S-188 Lighting Technology

Supervisor: Professor Liisa Halonen

Instructor: D.Sc Marjukka Puolakka

Abstract text:

The use of Light-Emitting Diodes (LEDs) in general lighting has continuously increased. One of the new areas of use are pedestrian ways, parking areas and parks. The aim of this master's thesis is to gain information of these outdoor area lighting areas through lighting measurements as well as through interviewing road users.

LED installations in pedestrian ways, parks, parking lots and smaller residential area streets in Finland that have existed at the stage of making this master's thesis, are plotted and documented.

Measurements have been made of a pedestrian way illuminated with LED luminaires, a footway illuminated with high pressure sodium lamp luminaires and a pedestrian way illuminated with induction lamp luminaires, respectively.

A user study has been made in this thesis. The aim of the user study is to become familiar with the attitudes of road users towards LED lighting in pedestrian ways. The user study was executed by having test persons walking on a street and afterwards answering questions about their feelings and opinions that were aroused in them during their walk.

Keywords: Light-Emitting Diodes, LED, pedestrian way, park, parking area, user study

AALTO YLIOPISTO
TEKNILLINEN KORKEAKOULU

Diplomityön tiivistelmä

Tekijä: Saara Jaatinen

Työn nimi: LEDien käyttö kevyen liikenteen väylillä, parkkialueilla ja puistoissa- Käyttäjätutkimus

Sivumäärä: 97

Päivämäärä 23.4.2010

Tiedekunta: Elektroniikan, tietoliikenteen ja automaation tiedekunta

Professuuri: S-188 Valaistustekniikka

Työn valvoja: Professori Liisa Halonen

Työn ohjaaja: TkT Marjukka Puolakka

Tiivistelmäteksti:

LED-valaistuksen käyttö lisääntyy jatkuvasti. Uusia käyttökohteita ovat kevyen liikenteen väylien valaistus, parkkialueiden valaistus sekä puistojen valaistus. Tämän diplomityön tarkoituksena on kerätä informaatiota näistä ulkovalaistuksen kohteista sekä valaistusteknillisin mittauksin että käyttäjien haastatteluin.

Tässä diplomityössä on kartoitettu ja listattu ne kevyen liikenteen väylien, parkkialueiden ja puistojen LED- asennukset, jotka ovat olleet olemassa Suomessa tämän työn tekovaiheessa.

Tässä diplomityössä on myös mitattu LED-valaistu kevyen liikenteen väylä, suurpainenatrium lampuilla valaistu jalkakäytävä sekä induktiolampuin valaistu kevyen liikenteen väylä.

Tämän työn puitteissa tehdyssä käyttäjätutkimuksessa on ollut tarkoituksena ymmärtää millaisia ajatuksia LED-valaistu kevyen liikenteen väylä herättää tien käyttäjissä. Tutkimus toteutettiin siten, että testihenkilöt kävelivät testiväylällä ja vastasivat jälkeenpäin kysymyksiin heidän mielipiteistään ja tunteistaan.

Avainsanat: LED, käyttäjätutkimus, kevyen liikenteen väylä, parkkialue, puisto

Preface

This work was carried out at the Lighting Unit of The School of Science and Technology at the Aalto University. I would like to thank my supervisor Prof. Liisa Halonen and my instructor D.Sc Marjukka Puolakka for their valuable guidance during the work of preparing this master's thesis.

I would also like to thank all partakers of the user study, especially the orchestra Humpsvakar, who participated with enthusiasm and eagerness.

Moreover, I would like to thank all my nearest and dearest for their support.

Espoo

Saara Jaatinen

Table of Contents

List of symbols and abbreviations

cd	candela
CIE	Commission Internationale de l´Eclairage
CLO	Constant Light Output
EU	European Union
EuP	Energy-using Products
K	kelvin
LED	Light Emitting Diode
lm	lumen
m	meter
MH	metal halide
W	watt

1 Introduction

The use of Light-Emitting Diodes (LEDs) in general lighting has continuously increased. One of the reasons for this expansion is the development of the luminous efficiency of LEDs. The luminous efficiency for LEDs depends on the semiconducting material but it was around 20 lm/W in the year 2000 and around 100 lm/W in the year 2009 (Wendt 2006, IES 2005, Osram Opto Semiconductors 2010, Philips 2010) .

The European Commission has specified a directive called The Ecodesign Directive that provides consistent EU-wide rules for improving the environmental performance of energy-using products (EuPs) through ecodesign (European Commission). The Ecodesign Directive will forbid the placement of mercury vapour lamps on the EU market by year 2015 because of its unacceptably low system efficacy. Would it be a good solution to replace old mercury vapour lamps with new LED installations?

Several companies in Finland have started to manufacture LED outdoor luminaires in the last few years. So far, the majority of the LED installations are test installations but as the customers seem to be pleased with the luminaires more and more installations are made.

LED installations in pedestrian ways, parks, parking lots and smaller residential area streets in Finland, that have existed at the stage of making this master's thesis, are plotted and documented. The majority of the installations are experimental installations, which are built mostly in cases where it has been topical to update or change old installations of mercury vapour lamps or high pressure sodium lamps. However, there are also some new LED installations that have not replaced any old lamps.

A user study has been made in this thesis. The aim of the user study is to get to know road user's attitudes to LED lighting in pedestrian ways. The user study was executed by having test persons walking on a street and afterwards answering questions about their feelings and opinions that were aroused in them during their walk. The user study was made on a pedestrian way illuminated with LED luminaires and on a reference street illuminated with metal halide lamps.

The questions that test persons were asked in the user study covered the following topics:

- Do the LED luminaires create glare for road users?
- Is it possible to recognize faces in LED illumination?
- Does the LED lighting impact on the feeling of safety?
- Is it possible to see obstacles on the road?
- Is the light from the LEDs distributed evenly?

Consequently, this thesis consists of comprehensive information about LED lighting in pedestrian ways, parking areas, parks and smaller residential area streets. The information is gained both through light technical measurements and through interviewing road users.

2 Outdoor Area Lighting

The main reason for having fixed lighting for public ways, for both vehicles and pedestrians, is to create a night time environment conductive to quick, accurate and comfortable vision conditions for the user of the facility. (Kaufman, Haynes, 1981)

2.1 Lighting in pedestrian ways and bicycle ways

Street lighting must meet the needs of the people who are going to use the area; these groups include pedestrians and cyclists in addition to drivers of motor vehicles. There are many differences in the lighting needs and visual tasks of pedestrians compared to drivers. The lighting of pedestrian ways and bicycle ways has three main functions (Tiehallinto, 2006):

- visibility – to provide illumination for visual activity
- perception – to form an understanding about the space and the environment
- atmosphere – to generate a feeling of safety and to set the right mood

Lighting shall be of such a level that the road user can, in time, get the right idea of their position, movement and speed compared to the road and to the other road users, when they have observed an obstacle on the roadway or in the immediate vicinity of the roadway. The road user shall get the right picture of the road and its continuity. On the other hand, the lighting must not interfere with pedestrians or dwellers. The need for a motorist to see the pedestrians and cyclists is also a lighting requirement for pedestrian and bicycle ways. (Tiehallinto, 2006)

2.1.1 Visibility

In order to be able to walk in a city it is necessary to know where you are and to be able to see the direction in which you are going. The main aspect to lighting for visual orientation is the vertical illuminance on the face of buildings and other objects. In neighbourhoods where most pedestrians are familiar with the residential area, large objects such as houses and trees serve as landmarks and thus very little light is needed. Indeed, in such areas too much light falling onto the front of houses may lead to light trespass and be regarded as visual intrusion by the residents. (de Kort et. al, 2009, Kyttä et. al, 2008)

In the centre of cities people are usually less familiar with their environment. The geometry and layout of centres of cities is generally more complex, thus it is necessary to provide the pedestrian with more information for orientation. Generally this is provided in two ways:

- by use of signage
- by the presence of key landmark features such as significant buildings or major open spaces.

For orientation that takes place at night it must be possible to read the signs and it helps if the key features are illuminated to a higher level than their surrounding area so that they can be recognised at a distance. (CIE, 2009)

2.1.2 Perception

For lighting to be visually comfortable it needs to feel pleasant for the user and it should be free from glare. To achieve pleasantness it is necessary to provide an attractively illuminated scene. This includes getting the right ratio between vertical and horizontal illuminance and ensuring that key features of the environment are adequately illuminated. However, the concept of pleasantness is most important in open areas in city centres which need to attract people and it is less important in transitory areas such as residential ways where people use the way purely for access to a particular location. (CIE, 2009)

2.2 Atmosphere

2.2.1 Feeling of safety

Lighting is not only needed to provide a street that is safe to use but also to provide a general feeling of safety to the users. Previous research suggests that there are three circumstances that indicate potential risk and increased fear for personal safety in outdoor areas (Painter, 1996):

- darkness
- disorder
- finding oneself alone or in the presence of others who are perceived to be threatening.

Darkness evokes a sense of insecurity, because it decreases visibility and recognition distance. According to Painter, dark or dimly lit streets create a limitless source of blindspots, shadows and potential entrapment locations. (Painter, 1996, Kyttä et. al, 2006)

Recognition of faces or expressions is important in all areas where pedestrians come into contact or need to pass each other. A study (Van Bommel and Caminada, 1980) suggested that it should be possible to recognise a face at a distance of 4 m, thus giving time for a person to take evasive action weather he or she should approach someone or not.

The following points should be considered while designing lighting for a pedestrian way (Kyttä et. Al, 2006):

- The street should be illuminated without blindspots and shadows
- Not only the pedestrian way should be lit, but also the closest neighbourhood, like bus stops, entrances to buildings, bushes, waste disposal areas, playgrounds, etc.
- Dark places should be avoided.
- The lighting should be designed so, that it is possible to recognize faces.

Even though the experience of falling victim to a crime and the feeling of safety are linked, they are two different things. Crime figures become evident from criminal statistics but we can only receive information about the feeling of safety through enquiries and interviews.

2.2.2 Safe movement

The detection of obstacles such as bumps, potholes or other pavement irregularities and other hazardous objects is a key criterion for safe movement. In estimating what kind of lighting is necessary for obstacle detection many authors refer to standards for emergency lighting, arguing that the task of walking out of a building is similar to that of walking along a road (CIE 2009). The current European Standard on Emergency Lighting requires a minimum horizontal illuminance of 1.0 lx on the centre line of an escape route.

The factors contributing to safe movement are:

- ability to detect obstacles on the pavement
- visual orientation
- the ability to recognise the faces of other people at a distance sufficient to take evasive action, if necessary.

It is important to note the difference of these factors. Without safe movement and visual orientation it would be impossible to walk along a street, without a general feeling of safety someone might choose not to walk along the street. (CIE, 2009)

2.2.3 Glare

Generally, glare is not due to excessive apparent brightness of the total field of view (popularly called "too much light") but to the presence in this field of local areas whose luminance is much higher than the average ambient luminance. Glare, in fact, is almost always a matter of excessive luminance contrast and this is true whether the bright 'core' of this contrast is one of the installed light sources or whether it is an excessive highlight seen by reflection from some shiny or highly polished surface (Hewitt et. Al, 1966).

The effects of glare include (Suomen standardisoimisliitto SFS, 1992):

- Discomfort glare (glare that causes discomfort without necessarily impairing the vision of objects)
- Disability glare (glare that impairs the vision of objects without necessarily causing discomfort)

There is a broad variety of methods for evaluating subjective glare. In some methods the test person is asked to inform when he/she feels the borderline between comfort and discomfort, in others he/she may have to choose a word from a scale that describes the amount of glare the best (Knight, 2009).

2.3 Lighting in parks

The designing of park lighting is considered from the pedestrian and the dweller point of view as motor vehicles are seldom allowed in parks. An important thing to consider in designing park lighting is the spatial light. The spatial light makes it easier to recognize people or to be able to interpret the faces of the other park users. This is important because of the feeling of safety, security and well-being. (Starby, 2003)

2.4 Lighting in Parking Areas

The aim of the lighting in parking areas is to make parking easy and safe. Movement by foot in parking areas shall be facilitated. Poorly carried out or maintained lighting can have negative effects such as increased risk of car burglaries. (Starby, 2003)

The lighting installations should be designed:

- to follow the given standards and requirements
- to give an impression of pleasantness and of aesthetic surroundings
- to give a steady distribution of the light without disturbing contrasts
- to give the least possible risk of glare
- to make the traffic safe for motorists and pedestrians
- to give a protection against burglary and vandalism

(Starby, 2003)

2.5 Lighting classes

The Finnish Road Administration gives recommendations for the lighting of sidewalks for pedestrians and cyclists, pedestrian ways and other areas beside the driveway and residential streets and courtyards, parking areas and courtyards. The K-classes are listed in Table 1.1. The selection principles of the class of illuminance of pedestrian ways and bicycle ways are listed in Table 1.2.

Table 1.1. Horizontal illuminance classes. (Tiehallinto, 2006) Em (lx,min) is the horizontally lowest mean illuminance of the area, given in lux. E (lx,min) is the horizontally lowest singular point of illuminance, in the area, given in lux.

class	Horizontal illuminance Em (lx, min)	E (lx, min)
K1	15	5
K2	10	3
K3	7,5	1,5
K4	5	1
K5	3	0,6
K6	2	0,6

Table 1.2. The selection of the lighting class of pedestrian ways and bicycle ways. (Tiehallinto 2006)

AREA	LEVEL OF ILLUMINANCE
WALKWAYS	
In the centre of a city	
only pedestrians, cyclists	K2
also service access	K1
Other areas of the city	
only pedestrians, cyclists	K3
also service access	K2
Rural Community	
only pedestrians, cyclists	K3,K4
also service access	K2
COURTYARD ROADS	
active	K2
non-active	K4,K5
PEDESTRIAN ZONE	
IN THE CENTER, ON	K1, K2
MARKET SQUARES	
PARKING AREAS	
active	K3
non-active	K4
PASSAGES, PATHS	
Park passages	K3
sawdust track, ski track	K4
SEPARATE PEDESTRIANS	
active	K4
non-active	K6

2.6 Light sources of pedestrian way and park lighting

Lighting of outdoor areas including streets, roadways, parking lots and pedestrian areas are currently dominated in Finland by mercury vapour and high pressure sodium light sources. The percentage of mercury vapour lamps is about 51.3 % of all outdoor light sources and respectively 44.5 % for high pressure sodium lamps. (Sippola, 2010)

2.7 High pressure sodium lamp

High pressure sodium lamps are based on a high pressure sodium discharge. They are currently the most common lamp type in road lighting in Finland because of their high luminous efficacy and long lifetime. The lamps have a power range of 35…1 000 W and their luminous efficiency vary between 40…150 lm/W. Their lifetime is 10 000… 24 000 hours. The colour rendering index lays around 25. (Puolakka et. al, 2009) The colour temperature is 2 000… 2 200 and the light is slightly yellow, where the colours of objects are distorted, but the ordinary barriers can be detected as well as with white light. (Tiehallinto, 2006)

2.8 Metal halide lamp

There are two different kinds of metal halide lamps; quartz metal halide lamps and ceramic metal halide lamps. Quartz metal halide lamps are based on a high-pressure mercury discharge in a quartz arc tube. A combination of metal iodide or bromide compounds added to the high pressure mercury discharge is used to generate radiation with specific colour characteristics and luminous efficacy. (CIE, 2009)

In ceramic metal halide lamps the arc tube is made from ceramic (usually polycrystalline aluminium oxide) instead of quartz. As a result, compounds can be added to the high-pressure mercury discharge that cannot be used in quartz lamps since they would attack the quartz or would not have enough vapour pressure. (CIE, 2009)

Metal halide lamps are in the power range of 35… 2 000 W and their luminous efficacy vary between 75… 125 lm/W. Their lifetime is 6 000… 20 000 hours. The colour temperature varies between 3 200… 5 200 K and the colour rendering index lies around

65… 70 but there are also metal halide lamps with the colour rendering index > 90. (Puolakka et. al, 2009)

Metal halide lamps are mainly used in parks, city centres and market places where the natural colour of the light and the colour rendering capability of lighting are important in terms of look and comfort. (Tiehallinto, 2006)

2.9 Mercury vapour lamp

A mercury vapour lamp produces light through an electric discharge in a gas. The gas consists of mercury and a small amount of some inert gas (usually argon). (Halonen, Lehtovaara, 1992) The mercury vapour lamp has a power range of 50… 2 000 W and a luminous efficacy of 40… 55 lm/W and a lifetime of 12 000…16 000 hours. Their colour rendering index lies around 50… 60 and the colour temperature 3 200… 4 200 K. (Tiehallinto, 2006)

Mercury vapour lamps are considerably less expensive at their purchase price, but their life-time is short and luminous efficacy is low compared to high pressure sodium lamps. Mercury vapour lamps are usually used in pedestrians and bicycle ways when it is wanted that motorists can separate ramps and pedestrians from each other. (Tiehallinto, 2006)

The Ecodesign Directive provides with consistent EU-wide rules for improving the environmental performance of energy-using products (EuPs) through ecodesign (European Commission). The Ecodesign Directive will forbid the placement of mercury vapour lamps to the EU market by 2015 because of its unacceptably low system efficacy (European Commission). It is estimated that there is about 664 000 mercury vapour lamps in Finland. (Sippola, 2010). Could LEDs be the right light source to replace this many lamps?

2.10 Light Emitting Diodes

A LED is a semiconductor device that converts electrical energy into light. It contains a chip that is produced of semi-conducting materials and forms a structure called a p-n (positive-negative) junction. When the supply voltage is fed to the LED, the voltage flows from the anode (positive electrode) to the cathode (negative electrode) but not in the opposite direction. Charge carriers, electrons and electron-holes are transported through the junction where they meet. In the meeting an electron moves to a lower energy level and the energy that is then released is emitted as a photon. (Paakkinen 2008)

The difference of LEDs compared to discharge lamps used in outdoor lighting is that the light is directional while the light from discharge lamps is undirectional. The advantages of LEDs are long lifetime, the adjustability of the luminous flux, the adjustability of colour characteristics, mechanical endurance and friendliness to the environment (no mercury). (Puolakka et. al 2009)

2.11 Conclusions

The function of light in outdoor areas like pedestrian ways, parking areas and parks is to illuminate activities, help the user to form an understanding about the space and the environment and to generate a feeling of safety. There are many differences in the lighting needs and visual tasks of pedestrian compared to drivers.

The aim of the lighting in parking areas is to make parking easy and safe. Movement by foot in parking areas shall be facilitated. Poorly carried out or maintained lighting can have negative effects such as increased risk of car burglaries.

Lighting of outdoor areas such as streets, roadways, parking lots and pedestrian areas are currently dominated in Finland by mercury vapour and high pressure sodium light sources. The percentage of mercury vapour lamps is about 51.3 % of all outdoor light sources and respectively 44.5 % for high pressure sodium lamps. Advances in LED technology have resulted in a new option for outdoor area lighting, with several potential advantages over mercury vapour, metal halide and high-pressure sodium lamps.

The Ecodesign Directive provides with consistent EU-wide rules for improving the environmental performance of energy-using products (EuPs) through ecodesign. The Ecodesign Directive will forbid the placement of mercury vapour lamps to the EU market by 2015 because of its unacceptably low system efficacy.

3 LED installations in Finland

This current work documents the LED installations in pedestrian ways, parks and smaller residential area streets in Finland that have existed at the time of making this master's thesis. The majority of the installations are experimental installations. The experimental installations are built mostly in cases where it has been topical to update or change old installations of mercury vapour lamps or high pressure sodium lamps. However, there are also new LED installations that have not replaced any old lamps.

The installations are listed in Chapters 3.1- 3.26. The values in the tables are provided by lamp and luminaire manufacturers.

3.1 Kupittaanpuisto playground, Turku

Kupittaanpuisto is a large park in the centre of Turku. There is a playground in the park where three old 70 watt metal halide lamp luminaires have been replaced with OverSol RoadLite 60 LED luminaires. The luminaires are placed in a triangle and they are controlled besides the normal streetlight control also by a movement detector. (Toivonen, 2009)

Table 3.1. The Kupittaanpuisto LED installation

Where	Kupittaanpuisto Playground, Turku
When installation made	November 2007
LED-luminaire	OverSol RoadLite 60
Quantity	3 pieces
Luminaire Power	60 W
Luminous Flux	3599 lm
Luminous Efficacy	60 lm/W
Colour Temperature	4000 K
Pole Height	4.5 m
Pole Spacing	In triangle 19m-14m-26m
Replaced installation	Philips CDO-ET, Metal halide lamp, 70 W

3.2 Kupittaankatu parkway, Turku

In Kupittaankatu 15-19 in Turku is installed three Philips CityWing LED luminaires are installed in a parkway. The LED luminaires have replaced old mercury vapour lamp luminaires. These lights are being controlled by the normal streetlight control. The road is in the area of the Kupittaanpuisto park. (Toivonen, 2009)

Table 3.2. The Kupittaankatu LED installation

Where	Kupittaankatu, Turku
When installation made	December 2007
LED-luminaire	Philips CityWing
Quantity	3 pieces
Luminaire Power	85 W
Luminous Flux	525 lm
Luminous Efficacy	6.2 lm/W
Colour Temperature	3200 K
Pole Height	4 m
Pole Spacing	17 m
Replaced installation	Mercury vapour lamp luminaires 125 W

3.3 Kiveriönkatu pedestrian way, Lahti

In a pedestrian way in Lahti five Philips Iridium LED luminaires are installed to replace the old mercury vapour lamp luminaires. The installation was made as an improvement to the lighting at the same time as the road was re-routed. (Talja, Nikkinen, 2009)

Table 3.3. The Kiveriönkatu LED installation

Where	Kiveriönkatu, Lahti
When installation made	September 2009
LED-luminaire	Philips Mini Iridium CLO
Quantity	5 pieces
Luminaire Power	22,3 W (with CLO)
Luminous Flux	1040 lm
Luminous Efficacy	46.6 lm/W
Colour Temperature	3000 K
Pole Height	5 m
Pole Spacing	30 m
Replaced installation	Idman Globus mercury vapour lamp, 125 W

3.4 Laiturikatu, small road in Lahti

In Lahti on a small road near a lake LED luminaires are installed. The new Philips City Spirit Cones replace old high pressure sodium lamp luminaires. (Talja, Nikkinen, 2009)

Table 3.4. The Laiturinkatu LED installation

Where	Laiturikatu, Lahti
When installation made	September 2009
LED-luminaire	Philips City Spirit Cone
Quantity	4 pieces
Luminaire Power	31 W
Luminous Flux	unknown
Luminous Efficacy	unknown
Colour Temperature	3000 K
Pole Height	About 5 m
Pole Spacing	Varies between 25-35 m
Replaced installation	Idman Cupola 360, High pressure sodium lamp, 70 W

3.5 Pihkaniitty park, Kerava

A LED installation is made in the city of Kerava in the Pihkaniitty park. All the old luminaires were replaced by new LED luminaires. The users have been pleased with the new installation. (Mäkirinta, 2009)

Table 3.5. The Pihkaniitty park LED installation

Where	Pihkaniitty, Kerava
When installation made	September 2009
LED-luminaire	Philips Mini Iridium
Quantity	10 pieces
Luminaire Power	31 W
Luminous Flux	1560 lm
Luminous Efficacy	50 lm/W
Colour Temperature	3000 K
Pole Height	5 m
Pole Spacing	Varies between 25-35 m
Replaced installation	High pressure sodium lamps, 125 W

3.6 Munkkiniemi walkway, Helsinki

In the Munkkiniemi district of Helsinki six Philips Iridium LED luminaires are installed. The new lights are replacing old mercury vapour lamps. The road users have complained about glare, which is due to the fact that the installation is made in Tiilirinne, which is an uphill environment (see Figure 3.1). (Markkanen, 2009)

Table 3.6. The Munkkiniemi LED installation

Where	Tiilirinne, Munkkiniemi, Helsinki
When installation made	September 2009
LED-luminaire	Philips Mini Iridium CLO
Quantity	6 pieces
Luminaire Power	22.3 W (with the CLO)
Luminous Flux	1040 lm
Luminous Efficacy	46.6 lm/W
Colour Temperature	3000 K
Pole Height	4 m
Pole Spacing	30 m
Replaced installation	Idman 8446 Mercury vapour lamps, 125 W

Figure 3.1. The Munkkiniemi LED installation

3.7 Jurvalanpuisto park, Tampere

The Philips Iridium LED luminaires that are installed in Rahola are a new installation. The luminaires are in the Jurvalanpuisto park. (Heikkilä, 2009)

Table 3.7. The Jurvalanpuisto LED installation

Where	Rahola, Tampere
When installation made	Summer 2009
LED-luminaire	Philips Mini-Iridium 24 LED NB
Quantity	7 pieces
Luminaire Power	31 W
Luminous Flux	1560 lm
Luminous Efficacy	50 lm/W
Colour Temperature	3000 K
Pole Height	5 m
Pole Spacing	Varies between 24-30 m
Replaced installation	New installation

3.8 Lauhatie, road in a residential area, Vantaa

In August 2009, old mercury vapour lamps from the 1970's were replaced with new LED luminaires. The installation consist of ten pieces LedZed's 60 W luminaires. The installation has received positive feedback from the road users. (Lindholm, 2009)

Table 3.8. The Lauhatie LED installation

Where	Lauhatie, Vantaa
When installation made	August 2009
LED-luminaire	Led Zed street light
Quantity	10 pieces
Luminaire Power	60 W
Luminous Flux	3808 lm
Luminous Efficacy	63.5 lm/W
Colour Temperature	6690 K
Pole Height	9 m
Pole Spacing	Varies between 30-35 m
Replaced installation	Mercury vapour lamp from 1970's, 125 W

3.9 Museokatu pedestrian way, Vaasa

In the centre of Vaasa, a pedestrian way with mercury vapour lamp luminaires from the 1960's have been replaced with LED luminaires from Oversol. (Heino, 2009)

Table 3.9. The Museokatu LED installation

Where	Museokatu 11, Vaasa
When installation made	January 2008
LED-luminaire	Oversol RoadLite 60
Quantity	4 pieces
Luminaire Power	60 W
Luminous Flux	3599 lm
Luminous Efficacy	60 lm/W
Colour Temperature	4000 K
Pole Height	9 m
Pole Spacing	40 m
Replaced installation	Mercury vapour lamp luminaires from 1960's, 125 W

3.10 Möyrykatu, pedestrian way, Jyväskylä

The city of Jyväskylä has tested LED luminaires in a pedestrian way. The street is 3.5 metres wide and 110 metres long. The pedestrian way is in a residential zone, so it is allowed to drive cars into yards over the pedestrian way.

The LED installation was made as a test installation, where two different LED luminaires were tested. The luminaires were Ecovalo 20 W from Artequa Oy and Starium Dragon 41 W from EasyLed Oy.

The city of Jyväskylä made tests in the new installations. They felt that the white light from the LEDs was more pleasant than the yellow light from the old high pressure sodium lamps. However, under the LED lighting it was impossible to recognize the faces of pedestrians, which was not a problem with the old lamps. The users felt that the Starium Dragon 41 W from EasyLed Oy caused too much glare and now the city will consider ordering more Ecovalo 20 W from Artequa Oy. (Piippo, 2009)

Table 3.10. The Möyrykatu LED installation

Where	Möyrykatu, Jyväskylä
When installation made	February 2009
LED-luminaire	Philips Mini Iridium
Quantity	1 piece
Luminaire Power	31 W
Luminous Flux	1560 lm
Luminous Efficacy	50 lm/W
Colour Temperature	3000 K
Pole Height	6 m
Pole Spacing	30 m
Replaced installation	High pressure sodium lamp, Sylvania SPXEcoarc, 98 W

When installation made	February 2009
LED-luminaire	Easy Led Starium Dragon
Quantity	3 pieces
Luminaire Power	41 W
Luminous Flux	2367 lm
Luminous Efficacy	57.7 lm/W
Colour Temperature	5600 K
Pole Height	6 m
Pole Spacing	30 m

3.11 Residential road, Kankaanpää

On a residential road in Kankaanpää LED installations are made with both Oversol RoadLite 60 W and Oversol RoadLite 90 W luminaires. (Korkalainen, van Heerden, 2009)

Table 3.11. The Kankaanpää LED installation

Where	Kankaanpää
When installation made	December 2008
LED-luminaire	Oversol RoadLite 60
Quantity	3 pieces
Luminaire Power	60 W
Luminous Flux	3599 lm
Luminous Efficacy	60 lm/W
Colour Temperature	4000 K
Pole Height	6 m
Pole Spacing	35 m
Replaced installation	Old mercury vapour lamps, 125 W

LED-luminaire	Oversol RoadLite 90
Quantity	3 pieces
Luminaire Power	90 W
Luminous Flux	4225 lm
Luminous Efficacy	46.9 lm/W
Colour Temperature	4000 K
Pole Height	9 m
Pole Spacing	40 m
Replaced installation	Old mercury vapour lamps, 250 W

3.12 Suotie, residential road Parainen

On a residential road in Parainen, seven Oversol RoadLite 60 W LED luminaires are installed. The new LED luminaires are replacing old mercury vapour lamp luminaires. (Korkalainen, van Heerden, 2009)

Table 3.12. The Suotie LED installation

Where	Suotie, residential area road, Parainen
When installation made	September 2007
LED-luminaire	Oversol RoadLite 60
Quantity	7 pieces
Luminaire Power	60 W
Luminous Flux	3599 lm
Luminous Efficacy	60 lm/W
Colour Temperature	4000 K
Pole Height	6 m
Pole Spacing	35 m
Replaced installation	Old mercury vapour lamps, 125 W

3.13 Otakaari pedestrian way, Espoo

In Espoo, in the campus area of Aalto University, a pedestrian way has been updated with LED luminaires. The old mercury vapour lamp luminaires were replaced by Philips Mini Iridium LED luminaires, with a driver that has Constant Light Output Functions (CLO). Due to the CLO the power is reduced to 22 W. The CLO saves energy by automatically compensating the depreciation of the luminous flux.

The electrical engineer from the technical centre of Espoo city and a lighting designer from the energy company Suomen Energia-Urakointi Oy are in charge of the installation. They feel however, that the solution was not as good as it could have been. The problems, according to them, are that the LED luminaires cause glare and that there is not enough diffused illumination on the sides of the pedestrian way. (Sillanpää, 2009)

This pedestrian way is measured in Chapter 4. The user study in chapter 5 has been made on this street.

Table 3.13. The Otakaari LED installation

Where	Otakaari, Espoo
When installation made	October 2009
LED-luminaire	Philips Mini Iridium CLO
Quantity	13 pieces
Luminaire Power	22.3 W (with the CLO)
Luminous Flux	1040 lm
Luminous Efficacy	46.6 lm/W
Colour Temperature	3000 K
Pole Height	4 m
Pole Spacing	varies between 22-25 m
Replaced installation	7 mercury vapour lamp luminaires 120 W and 6 high pressure sodium lamp luminaires 110 W

3.14 Olavinpuisto park, Salo

Olavinpuisto park is a park in the city centre of Salo. Six Philips Urbaline LED luminaires have been installed in the park. The LED luminaires are not replacing any old lamps; they are a completely new installation. (Virtanen, 2009)

Table 3.14. The Olavinpuisto LED installation

Where	Olavinpuisto, Salo
When installation made	Summer 2008
LED-luminaire	Philips Urbanline
Quantity	6 pieces
Luminaire Power	35 W
Luminous Flux	623 lm
Luminous Efficacy	17.8 lm/W
Colour Temperature	3000 K
Pole Height	4 m
Pole Spacing	30 m
Replaced installation	New installation

3.15 Salitunpuisto parkway, Salo

There is a park in the centre of Halikko, which is called Salitunpuisto. The parkways of this park have been illuminated with six Easy Led Oy's Starium Dragon LED luminaires and six Philip's Mini Iridium LED luminaires. The installation is not compensating any old installations.

The users have not been satisfied with the new luminaires, says the director of municipal technical services in Salo. The users have complained about glare and that the lighting is too spotted; with only light under the luminaires. The park lighting is shown in Figure 3.2. (Virtanen, 2009)

Table 3.15. The Salitunpuisto LED installation

Where	Salitunpuisto, Salo
When installation made	October 2009
LED-luminaire	EasyLed Starium Dragon
Quantity	6 pieces
Luminaire Power	41 W
Luminous Flux	2367 lm
Luminous Efficacy	57.7 lm/W
Colour Temperature	5600 K
Pole Height	4 m
Pole Spacing	30 m
Replaced installation	New installation
LED-luminaire	Philips Mini Iridium
Quantity	6 pieces
Luminaire Power	31 W
Luminous Flux	1560 lm
Luminous Efficacy	50 lm/W
Colour Temperature	3000 K
Pole Height	4 m
Pole Spacing	30 m

Figure 3.2 Salitunpuisto parkway

3.16 Saarela pedestrian way, Oulu

Three LED luminaires have been installed in a pedestrian way in Oulu as an experiment. The installation is made by Valopaa Oy and the luminaires are pilot-luminaires, that are not yet manufactured for the market. 15 pieces of these pilot-luminaires are tested as factory luminaires and the only ones that are used in outdoor lighting are the ones in Saarela. The pilot-luminaires consists of nine LED modules. Each module produces about 500 lm. (Lusikka, Vilmi, 2009)

Table 3.16. The Saarela LED installation

Where	Saarela, Oulu
When installation made	April 2009
LED-luminaire	Valopaa Pilot-lamp, 9 modules, not manufactured yet
Quantity	3 pieces
Luminaire Power	85 W
Luminous Flux	4500 lm (9 modules*500 lm)
Luminous Efficacy	52.9 lm/W
Colour Temperature	5650 K
Pole Height	6 m
Pole Spacing	40 m
Replaced installation	High pressure sodium lamp luminaires, 70 W

3.17 Äimärautio, Oulu

In a small road in Oulu old mercury vapour lamp luminaires have been replaced by new LED installations. The new installation consists of three luminaires and the installation is made as an experiment. The LED luminaires were installed in December 2007 and changed under guarantee in January 2009. (Lusikka, 2009)

Table 3.17. The Äimärautio LED installation

Where	Äimärautio, Oulu
When installation made	December 2007 and January 2009
LED-luminaire	EasyLed Starium Dragon
Quantity	3 pieces
Luminaire Power	41 W
Luminous Flux	2367 lm
Luminous Efficacy	57.7 lm/W
Colour Temperature	5600 K
Pole Height	6 m
Pole Spacing	50 m
Replaced installation	Mercury vapour lamp luminaires, 125 W

3.18 Kempele, ekokortteli

The Ekokortteli in Kempele is a residential area with about ten houses. The energy that the houses need for electricity and heating is produced in their own small power plant (by wood gas technology) and by wind power. The park in the Ekokortteli residential area is illuminated with two Valopaa VP1010 LED luminaires. (Vilmi, 2009)

Table 3.18. The Kempele LED installation

Where	Ekokortteli park, Kempele
When installation made	September 2009
LED-luminaire	Valopaa VP1010 M8
Quantity	2 pieces
Luminaire Power	72 W
Luminous Flux	4800 lm
Luminous Efficacy	66.7 lm/W
Colour Temperature	5650 K
Pole Height	6 m
Pole Spacing	unknown
Replaced installation	New installation

3.19 Kittilä, pedestrian way

The city of Kittilä decided to test LED luminaires in a pedestrian way in 2007. These luminaires were Easy Led's Starium 464. The LED sources in these luminaires were not good enough and the luminaires were changed in December 2009. The new installation consists of 30 Easy Led's Starium Dragon 60 LED luminaires. (Nummenpalo, Kinnunen, 2009)

Table 3.19. The Kittilä LED installation

Where	Kittilä, pedestrian way
When installation made	December 2009
LED-luminaire	Easy Led Starium Dragon
Quantity	30 pieces
Luminaire Power	41 W
Luminous Flux	2367 lm
Luminous Efficacy	57.7 lm/W
Colour Temperature	5600 K
Pole Height	5 m
Pole Spacing	Varies between 25-30 m
Replaced installation	Starium 464 LED luminaires, 16 W

3.20 Kittilä, hotel Koutalaki car park

Near the Levi downhill skiing centre there is hotel Koutalaki. The parking area of this hotel is illuminated with 21 Easy Led Oy's Starium Dragon 60 LED luminaires. (Nummenpalo, Kinnunen, 2009)

Table 3.20. The Koutalaki LED installation

Where	Kittilä, hotel car park
When installation made	Autumn 2009
LED-luminaire	Easy Led Starium Dragon
Quantity	21 pieces
Luminaire Power	41 W
Luminous Flux	2367 lm
Luminous Efficacy	57.7 lm/W
Colour Temperature	5600 K
Pole Height	About 6 m
Pole Spacing	Varies, about 30 m
Replaced installation	New installation

3.21 Markkamäki residential area, Äänekoski

50 pieces of Philips Mini Iridium LED luminaires have been installed in a residential area called Markkamäki in Äänekoski. The installations are all on residential area streets (Mustikkasuonkatu,Niinimäenkatu, Ekinkatu, Humpinkatu, Viherkatu and Ainolankatu streets). The luminaires replace old 125 W mercury vapour lamp luminaires. (Kaikkonen, Rautkylä, 2009)

Table 3.21. The Markkamäki LED installation

Where	Äänekoski, residential area
When installation made	Autumn 2009
LED-luminaire	Philips Mini Iridium
Quantity	50 pieces
Luminaire Power	31 W
Luminous Flux	1560 lm
Luminous Efficacy	50 lm/W
Colour Temperature	3000 K
Pole Height	6 m
Pole Spacing	30 m
Replaced installation	Mercury vapour lamp luminaires, 125 W

3.22 Lauritsanpuisto parkway, Turku

Nine Philips Mini Iridium LED luminaires are installed in a park in Turku. The luminaires are installed on a 300 meter long parkway that is located in a wooded terrain. The LED luminaires have a driver that has Constant Light Output Functions (CLO). Due to the CLO the power is reduced to 22 W. The CLO saves energy by automatically compensating for the depreciation of the luminous flux over time. (Rautkylä, 2009)

Table 3.22. The Lauritsanpuisto LED installation

Where	Lauritsanpuisto parkway, Turku
When installation made	December 2009
LED-luminaire	Philips Mini Iridium
Quantity	9 pieces
Luminaire Power	22,3 W (with the CLO)
Luminous Flux	1040 lm
Luminous Efficacy	46.6 lm/W
Colour Temperature	3000 K
Pole Height	5 m
Pole Spacing	Varies between 30-35 m
Replaced installation	New installation

3.23 Armaksenkuja street and pedestrian way, Harjavalta

A test installation is made in Harjavalta city centre. The installation consists of a city street and a pedestrian way. Philips Mini Iridium LED luminaires are installed in both streets but at different heights. In the city street the luminaires are at a height of eight metres and on the pedestrian way at a height of six metres. (Ramberg, Rautkylä, 2009)

Table 3.23. The Armaksenkuja LED installation

Where	Harjavalta street and pedestrian way
When installation made	October 2009
LED-luminaire	Philips Mini Iridium
Quantity	4 pieces on street, 3 pieces on pedestrian way
Luminaire Power	31 W
Luminous Flux	1560 lm
Luminous Efficacy	50 lm/W
Colour Temperature	3000 K
Pole Height	on street 8 m, on pedestrian way 6 m
Pole Spacing	35 m
Replaced installation	New installation

3.24 Residential Area Street, Kajaani

Ten Philips Mini Iridiums are installed in a residential are street in Kajaani. (Ratkylä, 2009)

Table 3.24. The Kajaani LED installation

Where	Kajaani, residential area street
When installation made	Autumn 2009
LED-luminaire	Philips Mini Iridium
Quantity	10 pieces
Luminaire Power	31 W
Luminous Flux	1560 lm
Luminous Efficacy	50 lm/W
Colour Temperature	3000 K
Pole Height	6 m
Pole Spacing	30 m
Replaced installation	New installation

3.25 Varastotie pedestrian way, Seinäjoki

Opposite to the Seinäjoen Energia- energy company is a pedestrian way, where the energy company has installed two Philips Mini Iridium LED luminaires as a test installation. The LED luminaires replace old 125 W mercury vapour lamps. (Rautkylä, Pesu, 2009)

Table 3.26. The Varastotie LED installation

Where	Varastotie, Seinäjoki
When installation made	Summer 2009
LED-luminaire	Philips Mini Iridium
Quantity	2 pieces
Luminaire Power	31 W
Luminous Flux	1560 lm
Luminous Efficacy	50 lm/W
Colour Temperature	3000 K
Pole Height	7 m
Pole Spacing	25 m
Replaced installation	Mercury vapour lamp luminaires, 125 W

3.26 Nyrkkilänpuisto pedestrian way, Pori

Three LED luminaires are installed in a park in Pori. The LED luminaires, together with the induction lamps, metal halide lamps and high pressure sodium lamps, which are installed on the same street, are participating in a research of Satakunta University of

Applied Sciences. The aim of the project is to compare different light sources. (Aspblom, 2010)

Table 3.27. The Nyrkkilänpuisto LED installation

Where	Nyrkkilänpuisto park, pedestrian way
When installation made	February 2010
LED-luminaire	Lumis LED
Quantity	3 pieces
Luminaire Power	36 W
Luminous Flux	2340 lm
Luminous Efficacy	65 lm/W
Colour Temperature	Ecowhite
Pole Height	5 m
Pole Spacing	31-35 m
Replaced installation	Mercury vapour lamp luminaires, 125 W

3.27 Conclusions

The use of LEDs has continuously increased in the lighting of pedestrian ways, parking areas and parks in Finland. The installations are made mostly in destinations where it has been topical to update or change old installations of mercury vapour lamps or high pressure sodium lamps.

The most used LED luminaires, plotted in this master's thesis, are made by Philips but also other manufacturer's luminaires are on the market. The users of these pedestrian ways (presented in Chapters 3.1-3.26) have mostly been satisfied with the LED lighted streets, however, many users have felt that the lights cause glare.

The most used luminaire power in the installations is 31 W. The used colour temperature in 50 % of the installations is 3000 K.

4 Luminance and illuminance measurements

Luminance measurements have been made of a LED lighted pedestrian way, a footway illuminated with high pressure sodium lamps and a pedestrian way illuminated with induction lamps. The streets are all situated in the Otaniemi district in Espoo, Finland.

4.1 Otakaari- Pedestrian way

The measurements were made on 30/10/2009 around 6 p.m. The asphalt was dry but covered with yellow leaves from the trees. The air was a few degrees below zero. Besides the pedestrian way lighting, there is also lighting from the street, the parking lots and the buildings nearby. The installation is on a hill and the luminance photograph (Figure 4.2) is taken from the top pointing down.

The installation is shown in Figure 4.1. The small red dots mark the LED luminaires. The measurement area between two luminaires is marked with larger red dots. The imaging luminance photometer (LMK 2000 Mobile Advanced) was placed at the blue dot.

Figure 4.1. The measurement area on Otakaari pedestrian way.

The imaging luminance photometer was placed 43 metres from the first luminaire of the measurement area. According to the European standard EN 13201-3 (Appendix 1) for road lighting the photometer should be placed 60 metres from the measurement area to get the right angle for the luminance meter. However, it was impossible to make a measurement any longer than 43 metres from the area. This should not be a problem as the 60 m in the standard indicates that then the viewing angle is between 0.5° and 1.5°, which it is also in this case, because the measurement is made downhill. The spacing between the luminaires is 21 metres and the pedestrian way is 3 metres wide.

The luminance distribution is shown in Figure 4.2. The luminances in the measurement area (the area between the two luminaires marked with larger dots in Figure 4.1) was calculated with the LMK 2000 mobile advance program. The mean luminance in this area (marked as area 1 in Figure 4.2) is 0.37 cd/m^2. The mean luminance on the ground under the luminaire (marked as area 2 in Figure 4.2) is 1.1 cd/m^2.

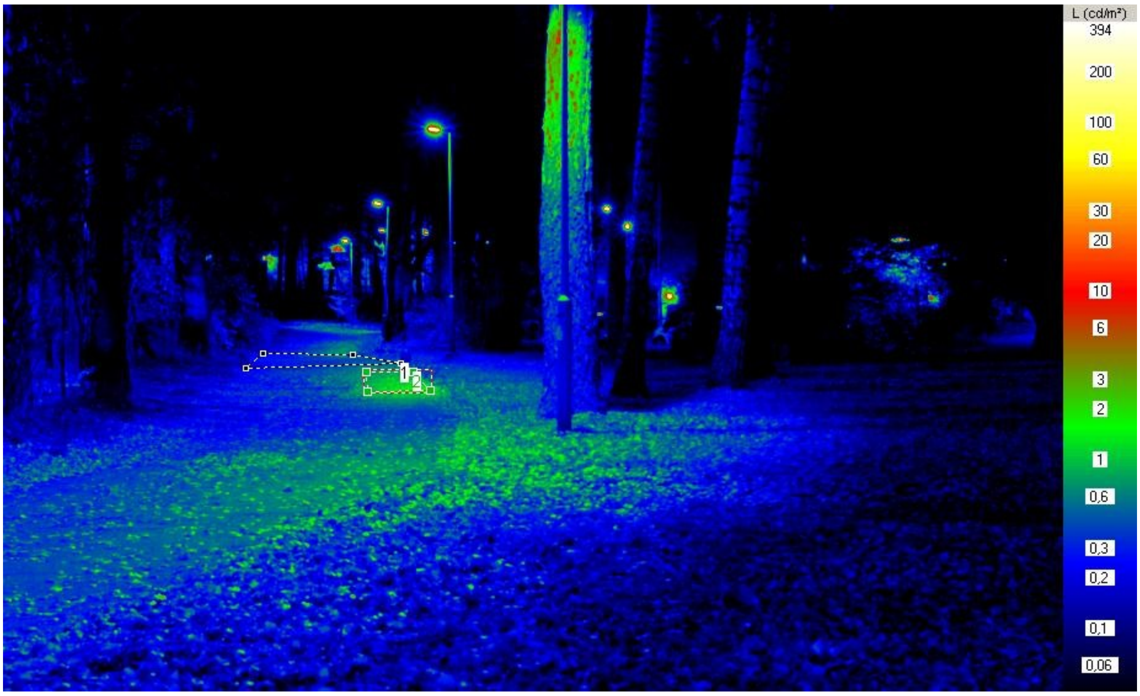


Figure 4.2. The luminance distribution of Otakaari pedestrian way in October.

The illuminance of the same area (between the two luminaires) was measured and it is shown in Figure 4.3. The measurement is made according to the European standard EN 13201-3 (Appendix 1).

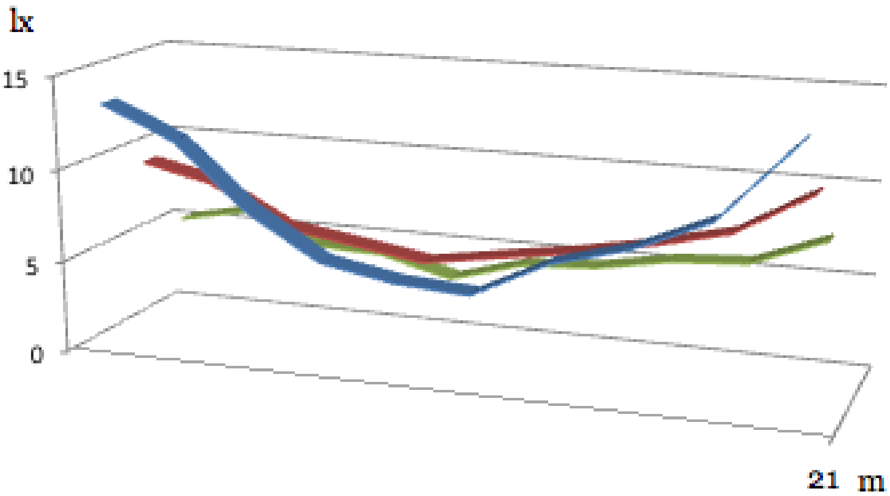


Figure 4.3. The illuminance of Otakaari pedestrian way in October. The blue line presents the measurement points nearest the luminaires, the red line presents the measurement points in the middle of the pedestrian way and the green line presents the measurement points in the pedestrian way on the opposite side of the luminaires.

The highest illuminance is 14.15 lx and the lowest 3.30 lx. The mean luminance of the area is 7.15 lx. The pedestrian street has a K5 K-class and according to Table 1.1, the class K5 requires a mean illuminance of 3 lx and a minimum illuminance of 0.6 lx. The pedestrian way is therefore perfectly in its class.

The luminances of this area were also measured in winter weather conditions because of the user study in Chapter 5. The measurement was made on 26/1/2010 at 6 p.m. The luminance distribution is shown in Figure 4.4. The mean luminance in snowy conditions between two luminaires (marked as area 1 in Figure 4.4) is 1.83 cd/m^2 , which is 5 times more than in autumn weather conditions. The mean luminance under a luminaire (marked as area 2 in Figure 4.4) is 1.9 cd/m^2 ,which is about 1.7 times more than in autumn weather conditions.

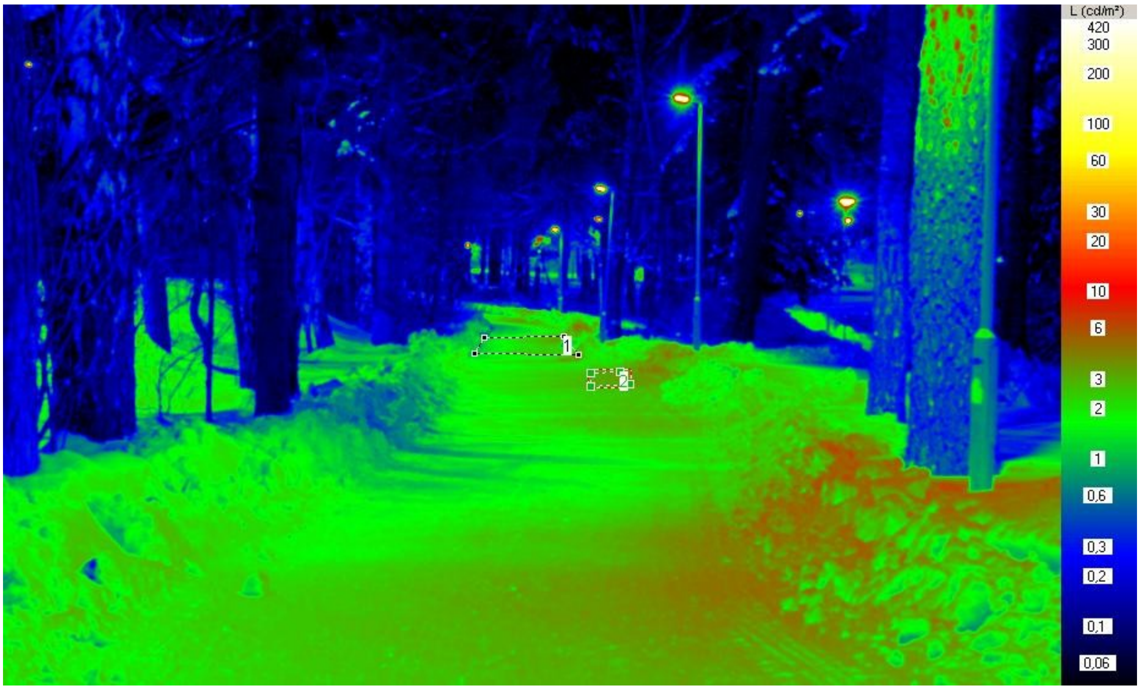


Figure 4.4. The luminance distribution of Otakaari pedestrian way in January.

4.2 Tietotie- Street with a footway

The measurement was made on 30/10/2009 around 7 p.m. on 110 W high pressure sodium lamps. The asphalt was dry and not covered by any leaves. The street lighting installation illuminates the driveway as well as the footway. The facades of the buildings nearby were illuminated. There is a zebra crossing in the driveway at the same position from where the footway luminance image is taken.

The measurement installation is shown in Figure 4.5. The small red dots mark the high preassure sodium lamp luminaires. The measurement area is made between the luminaires that are marked with bigger red dots. The imaging luminance photometer (LMK 2000 Mobile Advanced) was placed at the blue dot.

Figure 4.5. The measurement area of Tietotie.

The camera was placed 60 metres from the measurement area, according to the European standard for road lighting EN 13201-3 (Appendix 1). The luminaire spacing is 22 metres and the pedestrian way is 2.5 metres wide.

The luminance distribution is shown in Figure 4.6. The luminance in the measurement area (the area between the luminaires marked with larger dots in Figure 4.5) was calculated with the LMK 2000 Mobile Advance Program. The mean luminance in this area (marked as area

1 in Figure 4.6) is 0.6 cd/m^2 . The mean luminance on the ground under the luminaire (marked as area 2 in Figure 4.6) is 1.1 cd/m^2 .

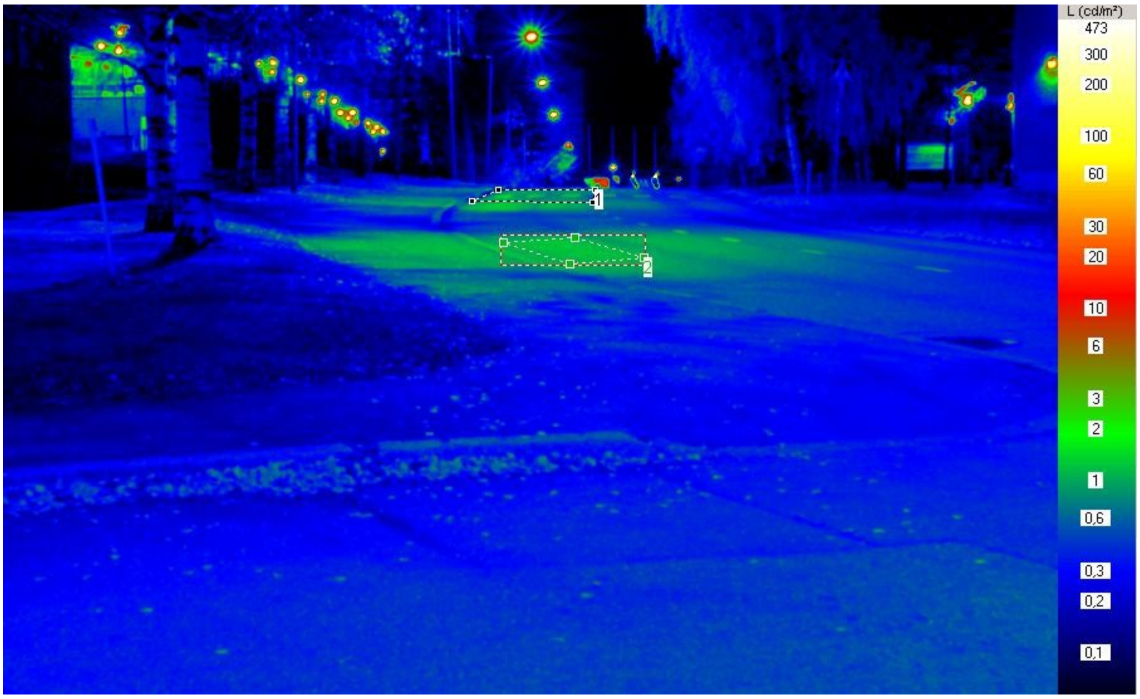


Figure 4.6. The luminance distribution of Tietotie in October. Area 1 shows the mean luminance between two luminaires and area 2 shows the luminance under a luminaire.

4.3 Otaniementie- Pedestrian way

The measurement was made on 12/11/2009 around 7 p.m. on 55 W induction lights. The asphalt was dry and the temperature was -3 degrees. Besides the pedestrian way lighting there is also lighting from the street and the buildings nearby.

The installation is shown in Figure 4.7. The small red dots mark the luminaires. The measurement area is that between the luminaires that are marked with larger red dots. The imaging luminance photometer (LMK 2000 Mobile Advanced) was placed at the blue dot.

Figure 4.7. The measurement area of Otaniementie pedestrian way.

The camera was placed 60 metres from the measurement area, according to the European standard EN 13201-3 (Appendix 1). The spacing between the luminaires is 20 meters and the pedestrian way is 3 metres wide.

The luminance distribution is presented in Figure 4.8. The luminance in the measurement area (the area between the luminaires marked with bigger dots in Figure 4.7) was calculated with the LMK 2000 Mobile Advance Program. The mean luminance in this area (marked as area 1 in Figure 4.8) is 0.29 cd/m^2. The mean luminance on the ground under the luminaire (marked as area 2 in Figure 4.8) is 0.35 cd/m^2.

Figure 4.8. The luminance distribution of Otaniementie pedestrian way in October.

The illuminance of the same area (between the two larger red dots) was measured and it is shown in Figure 4.9. The measurement is made according to the European standard EN 13201-3 (Appendix 1).

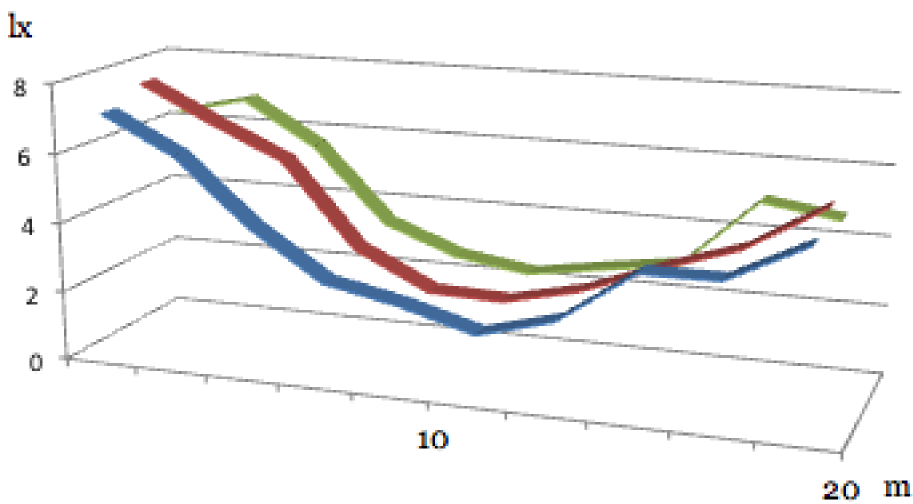


Figure 4.9. The illuminance of Otaniementie pedestrian way in October. The blue line presents the measurement points nearest the luminaires, the red line presents the measurement points in the middle of the pedestrian way and the green line presents the measurement points in the pedestrian way on the opposite side of the luminaires.

The highest illuminance is 7.59 lx and the lowest 1.80 lx. The mean luminance of the area is 4.18 lx.

4.4 Conclusions

The luminances measured on the ground, right under the luminaire are the same for both the 31 W Philips Mini Iridium LED luminaires and for the 110 W High Pressure Sodium lamps, that is 1.1 cd/m^2 . For the 55 W induction lamp the mean luminance right under the luminaire was notably smaller, only 0.29 cd/m^2 .

The mean lumninance in the measurement area is different for all of the lamp types. LED lights give a mean luminance value of 0.37 cd/m^2 , High Pressure Sodium lamps give a mean luminance value of 0.6 cd/m^2 and the induction lamps a mean value of only 0.29 cd/m^2 .

The illuminances of Philips' Mini Iridium LED lights and the 55 W induction lights were measured. The maximum illuminance for the LEDs was 14.15 lx, the minimum value 3.30 lx and the mean value 7.15 lx in the measurement area. The equivalent results for induction lights were 7.59 lx, 1.8 lx and 4.18 lx, respectively.

5 User Study

5.1 Objectives

The aim of the user study in this thesis is to get to know road user attitudes to LED lighting in pedestrian ways. The user study is executed by having test persons walking on an illuminated street and afterwards answering questions about their feelings and opinions that are aroused in them during their walk. The user study is made on a pedestrian way illuminated with LED luminaires and on a reference street illuminated with metal halide lamp luminaires.

5.2 Test sites

Both pedestrian ways are situated in the Otaniemi district in the city of Espoo. The pedestrian ways are shown in Figure 5.1. The red line indicates the pedestrian way illuminated with LED luminaires and the blue line indicates the pedestrian way illuminated with metal halide lamp luminaires.

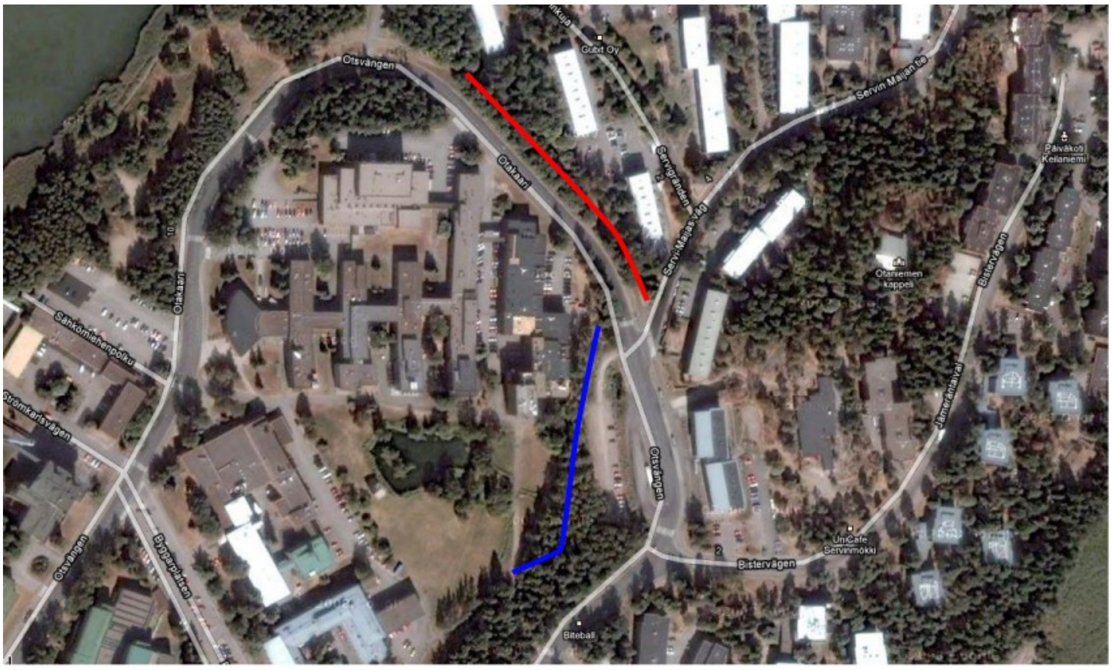


Figure 5.1. The pedestrian ways of the user study. Both ways are approximately 160 metres long.

Both pedestrian ways are situated next to the Otakaari street but on different sides of it. Both streets are situated with houses and parking areas next to them and surrounded by trees and bushes. However, it should be noted that the two streets are separate ways with different surroundings.

The LED luminaires used in the user study are 31 W Philips Mini Iridium with a driver that has Constant Light Output Functions (CLO). Due to the CLO the power is reduced to 23 W. The metal halide lamps are 70 W Osram Powerstar HCI-PAR 30 830 WDL FL. The metal halide lamps are in luminaires designed by the architect Alvar Aalto. The colour temperature (given by the manufacturer) of the LEDs and metal halide lamps is 3000 K. The luminaires are shown in Figure 5.2.

Figure 5.2. From left to right: Philips Mini Iridium LED luminaire, Luminaire designed by Alvar Aalto, OSRAM POWERSTAR metal halide lamp.

Both test sites are approximately 160 metres long and 3 metres wide. Pole spacing varies due to the uneven terrain. Pole spacing is between 22-25 metres of the LED illuminated pedestrian way and 17-23 metres on the pedestrian way illuminated with metal halide lamp luminaires. The pole height is 4 metres on both pedestrian ways. Both pedestrian ways are covered with asphalt. The K-class of the LED illuminated pedestrian way is K5.

The test in autumn weather conditions was made on the 26/11/2009 between 5.30 p.m. and 6.15 p.m. The asphalt was slightly humid but not wet. There was no precipitation during the test. Figure 5.3 shows the LED street on the autumn test day.

Figure 5.3. The LED street under autumn weather conditions.

The test under winter weather conditions was made on the 26/1/2009 between 5 p.m. and 7 p.m. The asphalt was covered by snow. There was no precipitation during the test. Figure 5.4 shows the LED illuminated street under winter weather conditions.

Figure 5.4. The LED street under winter weather conditions.

Unfortunately it was impossible to take pictures or make luminance measurements on the metal halide lamp illuminated street, because after the user test the lights stopped working due to an underground cable problem.

5.3 Test persons

Group 1 consists of 9 test persons, 2 women and 7 men. The mean age of Group 1 was 22 years (age distribution between 19-25 years). The same Group 1 did the tests under autumn weather conditions and winter weather conditions. Under winter weather conditions the 19 year old woman was not able to make the test, so then there were only 8 test persons. Group 2 consists of 6 test persons, 4 women and 2 men. The mean age of Group 2 was 23 years (age distribution between 20-27 years). Group 2 did the test under winter weather conditions.

The following three comparisons can be made between the groups:

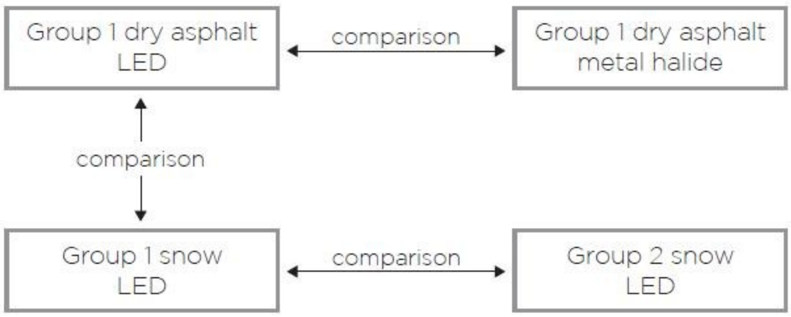


Figure 5.5. The comparisons that can be made between the groups.

The test persons were asked how often they use the pedestrian streets of the test sites. Tables 5.1-5.3 show their answers.

Table 5.1. How often the persons of Group 1 use the pedestrian street with LED lighting.

Testsite	autumn	winter
First time in the test	44 %	
A few times a year	44 %	75 %
A few times a month		12.5%
A few times a week		12.5%
Every day	11 %	

Table 5.2. How often the persons of Group 1 use the pedestrian street with LED or metal halide lighting.

Testsite	LED	MH
First time in the test	44 %	
A few times a year	44 %	78 %
A few times a month		11 %
A few times a week		
Every day	11 %	11 %

Table 5.3. How often the members of Group 1 and of Group 2 use the pedestrian street with LED lighting.

Testsite	Group 1	Group 2
First time in the test		50 %
A few times a year	75 %	17 %
A few times a month	12.5%	33 %
A few times a week	12.5%	
Every day		

5.4 Study design

The user study was made by two subject groups under two different weather conditions. Group 1 did the test under autumn weather conditions on a pedestrian street illuminated with LEDs and on a reference pedestrian street illuminated with metal halide lamp luminaires. Group 1 did also the test under winter weather conditions on the same LED illuminated pedestrian street. Group 2 did the test only under winter weather conditions on the LED illuminated pedestrian street. In this way comparison can be made in three ways, as Figure 5.5 shows:

1. Comparison between the lighting on the LED street and the reference street, within Group 1
2. Comparison between the lighting on the LED street for both autumn and winter weather conditions, within Group 1
3. Comparison between the lighting under winter weather conditions on the LED street between Group 1 and Group 2.

Before starting the test, the test persons were asked to list 1 to 5 factors that they feel are the most important criteria in pedestrian way lighting. After doing the test and answering all the questions, the test persons were asked to write how well the lighting of the test sites met their criteria. The test persons in Group 1 in autumn weather conditions were also asked to compare the LED illuminated street to the reference street.

The test sites were built up in the way Figures 5.5 and 5.6 indicate. Figure 5.5 describes the LED illuminated street and the metal halide illuminated street under autumn weather conditions. The test persons walk on a stretch of road that has seven luminaires. The Landolt-Cs (discussed in Chapter 5.5.5) and the actor (discussed in Chapter 5.5.2) are spaced as the illustrations (Figures 5.5 and 5.6) indicate. Figure 5.6 describes the LED illuminated street in winter weather conditions. The street is otherwise built up in the same way, but the black Cs are replaced by grey ones and the brown Cs are replaced by white ones. The spacing between the poles and therefore also the C letters is uneven, due to the surroundings. The pole spacing varies between 22-25 metres.

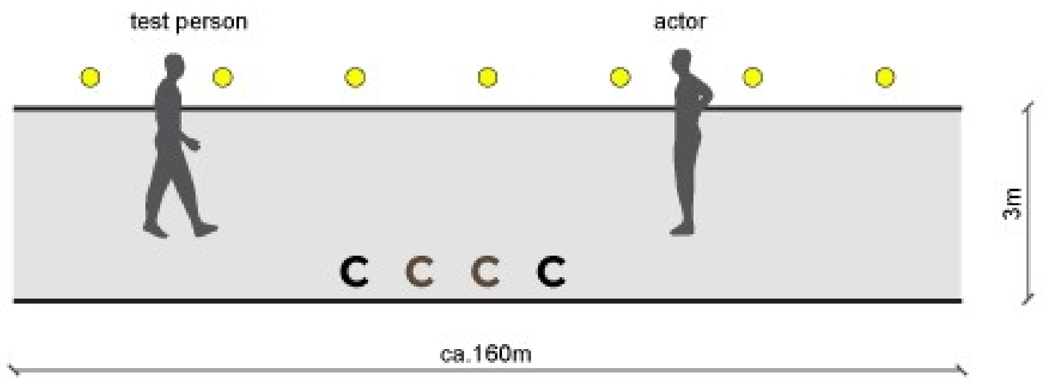


Figure 5.5. The test roads in autumn weather conditions. The streets were approximately 160 metres long and 3 metres wide.

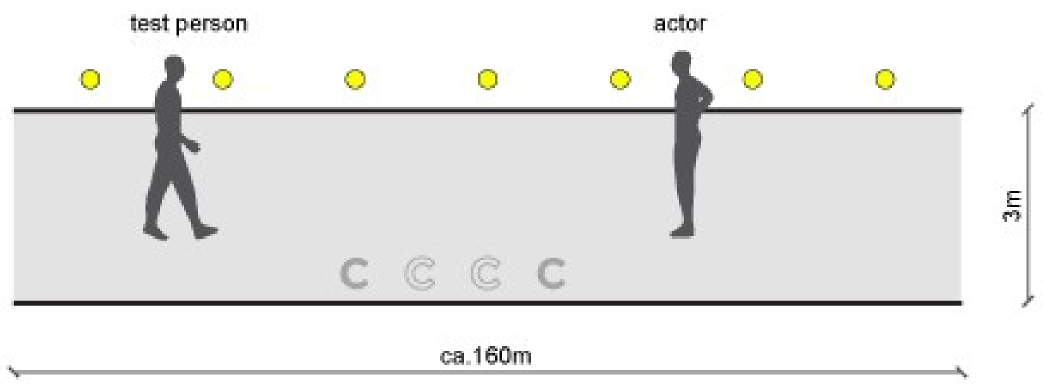


Figure 5.6. The test road in winter weather conditions. The street was approximately 160 metres long and 3 metres wide.

5.5 Questionnaires

The questions in the questionnaire cover the following topics:

- Do LED luminaires cause glare to the road users?
- Is it possible to recognize faces in the LED illumination?
- How does LED lighting have an impact on the feeling of safety?
- Is it possible to see obstacles on the road?
- Is the light from LEDs distributed evenly?

The questionnaires can be found in Appendix 2. The questionnaire in the executed test was in Finnish. The English translation of the questionnaires can be found in Appendix 3.

5.5.1 Feeling of safety

As previously stated, feeling of safety can only be measured through enquiries and interviews. This is the reason why feeling of safety is analyzed in this user study based on questions, not on performed tasks in the test road. However, facial recognition affects the feeling of safety and it is measured in the test with a visual task.

Two of the questions in the questionnaire are directly related to the feeling of safety. These questions are ”*Are you usually afraid to walk alone in the dark?* ” and ”*How safe did you feel walking on the pedestrian way you just walked on?* ”. Both questions have a scale, where the respondent can make a mark between *not at all- a lot* and respectively *really unsafe- really safe*.

Questions that have to do with the feeling of safety indirectly are the ”*Was the light evenly distributed on the street?* ” (answers *yes* or *no*), ”*Did the illumination feel too bright?* ” (answers on a scale *not at all- a lot*) and ”*Did the light cause you glare?* ” (answers on a scale *not at all- a lot*).

5.5.2 Facial recognition

Facial recognition is measured in the test by asking “*Did someone of the following persons walk towards you on the street?* ” followed by five pictures of faces of unknown people for the test person. One of the persons in the pictures is a hired actor, who really walked towards each test person. The test sites had different actors.

Figures 5.5 and 5.6 show where the test person is located on the street. The actors walks in his/her usual clothes and in a normal way, like any other road user. The actor walks towards the test persons always at the same place, between two lamps, where there is not placed a Landolt-C. Test persons are sent to walk on the street every two minutes, so that only one test person walks on the street at a time. In this way the actor has the possibility to walk towards each test person at the same place.

5.5.3 Light distribution

An even street luminance distribution makes the use of the street comfortable for the user (Kyttä et. al, 2008). Blindspots and shadows can make the environment feel unsafe. An even distribution of light makes also the environment on the pedestrian way and its neighbourhood visually more aesthetic (Kyttä et. al, 2008). The test persons were asked ”*Was the light evenly distributed on the street?* ” with the possible answers *yes* or *no*.

5.5.4 Glare

The test person was asked “*Did the light cause you glare?* ” and the question is provided with a scale *not at all- a lot*. To be able to know that all the test persons understand the concept of glare is also another question was also asked: “*Was the lighting too bright in your opinion?* ” provided with the scale *not at all- a lot*.

5.5.5 Landolt-C recognition

The Landolt-C optotype is used frequently in the clinical evaluation of visual acuity. In vision acuity testing, the Landolt-C is presented at one of several orientations, and the observer’s task is to judge the location of the gap.

The thickness W of the Landolt-C measures 1/5 of its outer diameter D and gap G measures 1/5 of its outer diameter D (See Figure 5.7).

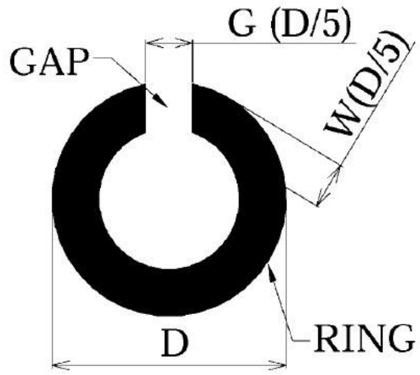


Figure 5.7 The Landolt-C optotype (Muraoka, Ikeda, 2007)

The Landolt-C was used in the test partly because it is commonly used in visual testing and partly because it is an easy object to use in this test because of its shape. The aim of using the Landolt-C was to measure how well the test persons can see obstacles on the pedestrian street.

Pedestrian ways may have bumps, potholes and other uneven formations in the asphalt. The lighting of the street should be of such design that thus unevenness or other possible obstacles are noticeable and will not cause accidents to the road users. In the user study this is measured with four pieces of Landolt Cs. The Cs were manufactured of painted wood and had a diameter of 20 centimetres and are of two different contrasts in each test sites.

The placing of the Landolt-Cs is shown in Figures 5.5 and 5.6. The idea is to have the Cs of both contrasts placed in two ways: right under a luminaire and in the exact middle of two luminaires. The Cs are situated on the pedestrian way, exactly where the test persons walk.

The test person is asked in the questionnaire to tell how many Landolt-Cs he/she detected on the street. Options are 0, 1, 2, 3 and 4. In the following question the test person is asked to choose to which direction the gap of the C was pointing to. All the Cs on the street are pointing in the same direction. However, the Landolt-Cs on the LED illuminated pedestrian street and the reference pedestrian street under autumn weather conditions are pointing in different directions as well as on the LED illuminated pedestrian street under winter weather conditions.

5.5.6 Amount of light

The test persons were asked to mark on a scale if there was enough light on the pedestrian street. The scale went from *too little light* to *too much light*.

5.5.7 Colour of light

The test persons were asked to mark on a scale how the colour of the light is. The scale went from *very unpleasant* to *very pleasant*.

5.5.8 Fake questions

The test persons are asked to answer the exact same questions after walking on the streets of each test site. To prevent the test persons to be too focused on the Landolt-Cs, the faces of the other road users and on the distribution of the light, some fake questions were added to the questionnaire. The aim of these questions was to get the test persons not to concentrate on the above issues while walking thus making the answering to the "real" questions more natural.

The fake questions were "*Was the poles made of a) metal b) wood c) I didn't pay attention*" and "*Was the road slippery?* ". The previous question was provided with a scale where the test person can make a mark between *not at all* - *really slippery*.

5.6 Results

5.6.1 Feeling of safety

The test persons were asked to mark on a scale if they are usually afraid to walk in the dark and how safe they felt walking on the test street. The answers on the continues scale are transferred to corresponding numerical values and the mean values are shown in Figures 5.8-5.9.

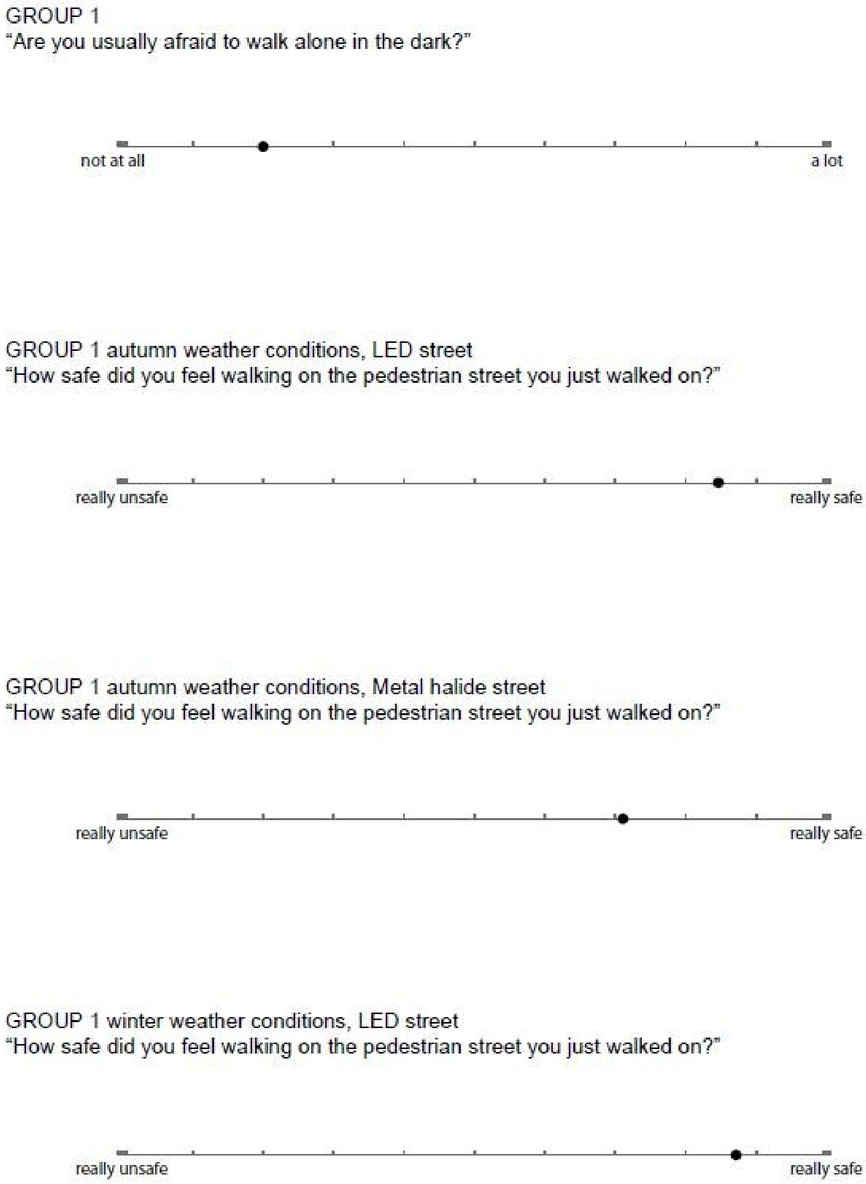


Figure 5.8. The mean values of Group 1's answers to the questions about feeling of safety.

Group 1 answered the question "*Are you usually afraid to walk in the dark?*" three times, since it was asked at all test sites. The mean value of the answers was the same every time.

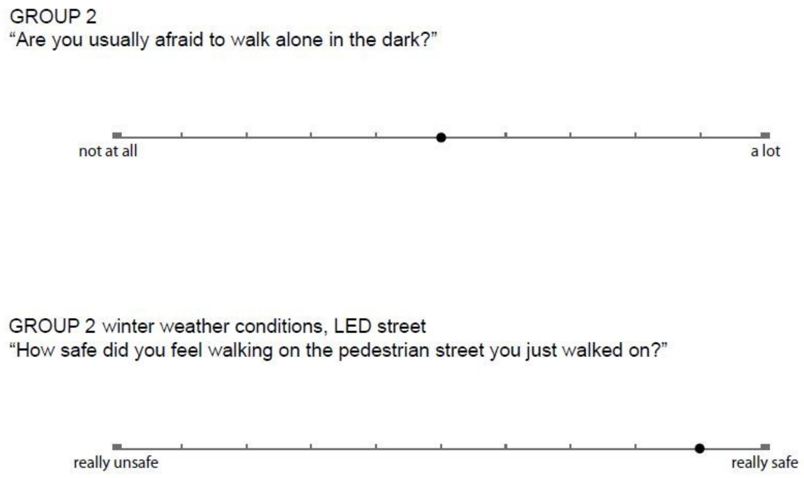


Figure 5.9. The mean values of Group 2's answers to the questions about feeling of safety.

As stated before, darkness, disorder and finding oneself alone or in the presence of others who are perceived to be threatening are the three cues which indicate potential risk and heighten fear for personal safety (Painter, 1996, Kyttä et. al, 2008). The feeling of safety can only be measured through enquiries and interviews.

As seen in Figure 5.8, the test persons in Group 1 do not usually feel afraid in the dark. They answered three times the same question and the mean value of the group was always the same. Group 1 lies on the scale near "*really safe*" under both weather conditions when the test persons were asked how safe they felt on the LED illuminated street. The answers of the metal halide illuminated street lie on the scale also in the "*safe*" end but not as close to the "*really safe*" results like the street illuminated by LED luminaires. As seen in Figure 5.9, the test persons in Group 2 felt usually more afraid to walk in the dark than Group 1 but they placed on the scale nearer to "*really safe*" than Group 1 under any weather condition.

The distribution of light can also have an effect on the feeling of safety. As noted in Figure 5.10, 78 % of the test persons in Group 1 felt that the light was evenly distributed on the LED illuminated street under autumn weather conditions and 88 % under winter weather conditions. Only 33 % of the test persons in Group 1 felt that the light was evenly distributed on the metal halide lighted street. These results attest that Group 1 felt safer on the LED illuminated street than the metal halide illuminated street. 83 % of the test persons in Group 2 felt that the light was evenly distributed (see Figure 5.10) on the LED illuminated street under winter weather conditions. This attests that Group 1 felt safer than Group 2 even though both groups felt safe on the streets.

Also the opinions of road users on street lighting confirm previous results concerning the feeling of safety. "*No blackspots*" was listed as the most positive feature of the LED illuminated street under both weather conditions with the index 5 (see Figures 5.16 and 5.17), while the metal halide illuminated street only had the index 2 (see Figure 5.21). The index indicates to the amount of answers. The most negative features of the LED illuminated street were brightness and glare in both weather conditions as the most negative features of the metal halide illuminated street were that the road was too dark and that the test persons felt unsafe.

Facial recognition plays an important part in the feeling of safety. Facial recognition is discussed in Chapter 5.6.2.

5.6.2 Facial recognition

The test persons were asked how many pedestrians walked towards them on the street with a follow up question provided by five pictures of unknown faces for the test user. The test user was asked to make a mark if the person in the picture walked towards him/her or not.

The results are listed in Table 5.4. Group 1 in autumn weather conditions had the average of 1.1 pedestrians walking towards them in the LED illuminated street and 2.8 pedestrians on the metal halide illuminated street. On the LED illuminated street in winter weather conditions Group 1 had the average of 2.2 pedestrians walking towards them and Group 2 1.5 pedestrians. There were on all streets only one actor and the picture of this actor was in the questionnaire.

If the test person recognized the face of the actor they are listed in Table 5.4 as "recognized", if the test person picked the wrong person or said that the actor did not walk on the street they are listed as "not recognized". 11 % of the answers in Group 1 on the autumn test day on the LED illuminated street recognized the face of the actor while 89 % did not. On the metal halide illuminated street only 8 % recognized the actor and 92 % did not. In Group 1 on the winter test day on the LED illuminated street 80 % recognized the face of the actor and 20 % did not. In Group 2 everybody recognized the actor.

Table 5.4. The amount of persons walking towards the test person and the percentage of recognized actor.

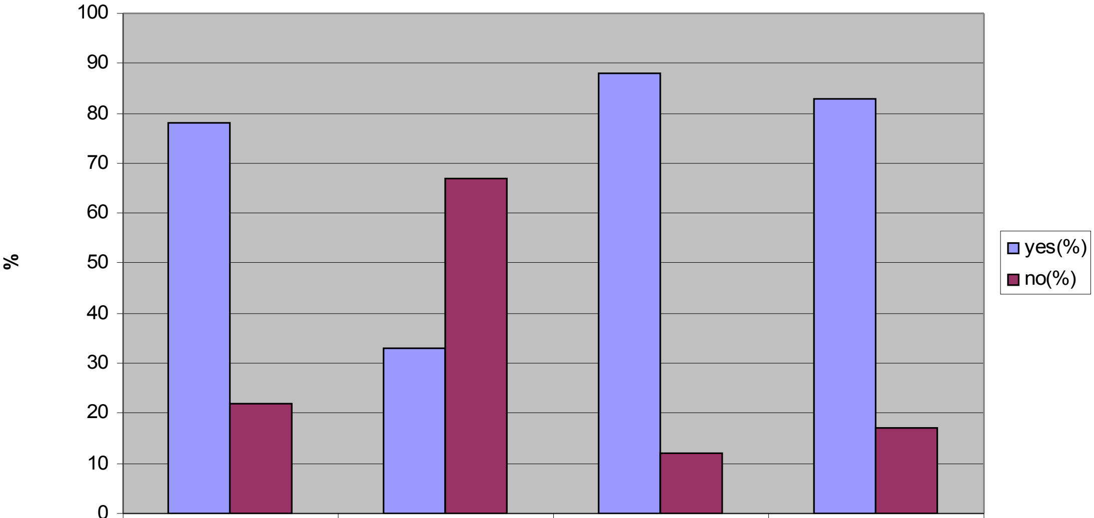
Group and weather condition	How many pedestrians	Recognized	Not recognized
GROUP 1, Autumn LED	1.1	11 %	89 %
GROUP 1, Autumn, MH	2.8	8 %	92 %
GROUP 1, Winter, LED	2.2	80 %	20 %
GROUP 2, Winter, LED	1.5	100 %	0 %

These results do not confirm that the LED illuminated street was safer than the metal halide illuminated street as the difference between the facial recognitions on the streets is not as big as the difference between the feelings of safety on the streets.

Under winter weather conditions 80 % of the persons of Group 1 correctly identified the actor on the LED illuminated street. The reason for the big difference to autumn weather conditions cannot only be that the group learned the first time they made the test to stare more at the faces, because in Group 2 every member recognized the right face. It seems like both the LED lighting as well as the metal halide lamp lighting do not allow facial recognition under autumn weather conditions. It seems that there is not a problem to recognize a face in winter time in the LED lighting of this test site.

5.6.3 Light distribution

The distribution of light was measured with the question "*Was the light evenly distributed on the street?* " with the possible answers *yes* and *no*. Figure 5.10 shows the answers. In Group 1 under autumn weather conditions 78 % felt that the light was evenly distributed on the LED illuminated street while 22 % felt that it was not. 33 % of the same group felt on the metal halide illuminated street that the light was evenly distributed while 67 % felt that it was not. Under winter weather conditions on the LED illuminated street 88 % of Group 1 felt that the light was evenly distributed and 12 % felt that it was not and respectively for Group 2 83 % felt that it was evenly distributed that 17 % answered and it was not.



	GROUP 1,autumn,LED	GROUP 1,autumn,MH	GROUP 1,winter,LED	GROUP 2,winter,LED
yes(%)	78	33	88	83
no(%)	22	67	12	17

Figure 5.10. The percentage of yes and no answers to the question "Was the light evenly distributed on the street?".

These results confirm that the metal halide illuminated street was perceived darker than the LED illuminated street and they also back up the fact that the LED illuminated street felt safer than the metal halide illuminated street in autumn weather conditions.

In Figures 5.16, 5.17, 5.18, 5.19, 5.20 and 5.21, where the test persons were asked to analyze how well the lighting in the test streets met their criteria of good pedestrian way lighting, an "even distribution of light without blackspots" was chosen as a positive feature for the LED illuminated street in both weather conditions with the index 5. On the same street under the same weather conditions an "uneven distribution of light" was chosen as a negative feature with the index 1. On the metal halide illuminated street under autumn weather conditions an "even distribution of light without blackspots" was chosen as a positive feature with the index 2 and an "uneven distribution of light" was chosen as a negative feature also with the index 2. These results also confirm the distribution of light on the LED illuminated street in all weather conditions was considered better than on the reference street.

5.6.4 Glare

The test persons were asked to mark on a scale if they felt that the lighting was too bright. The mean values of the groups are shown in Figure 5.11.

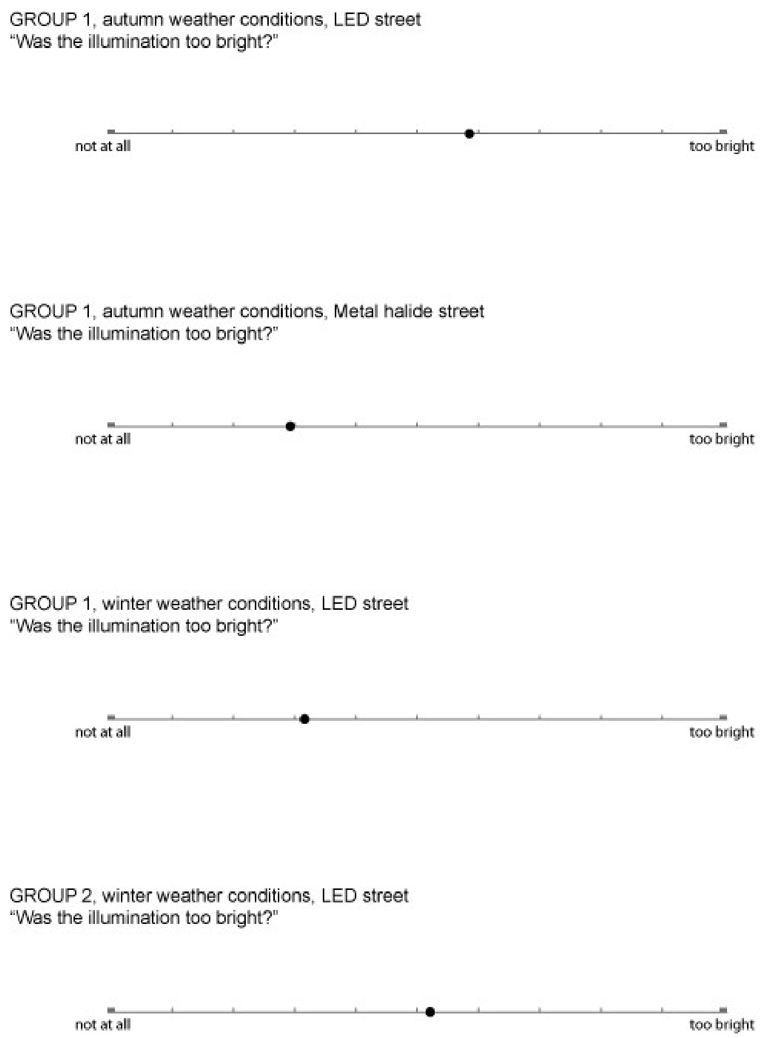


Figure 5.11. The mean values of the answers to the question "Was the illumination too bright?".

The test persons were asked to mark on a scale if they felt that the lighting caused them glare. The mean values of the groups are shown in Figure 5.12.

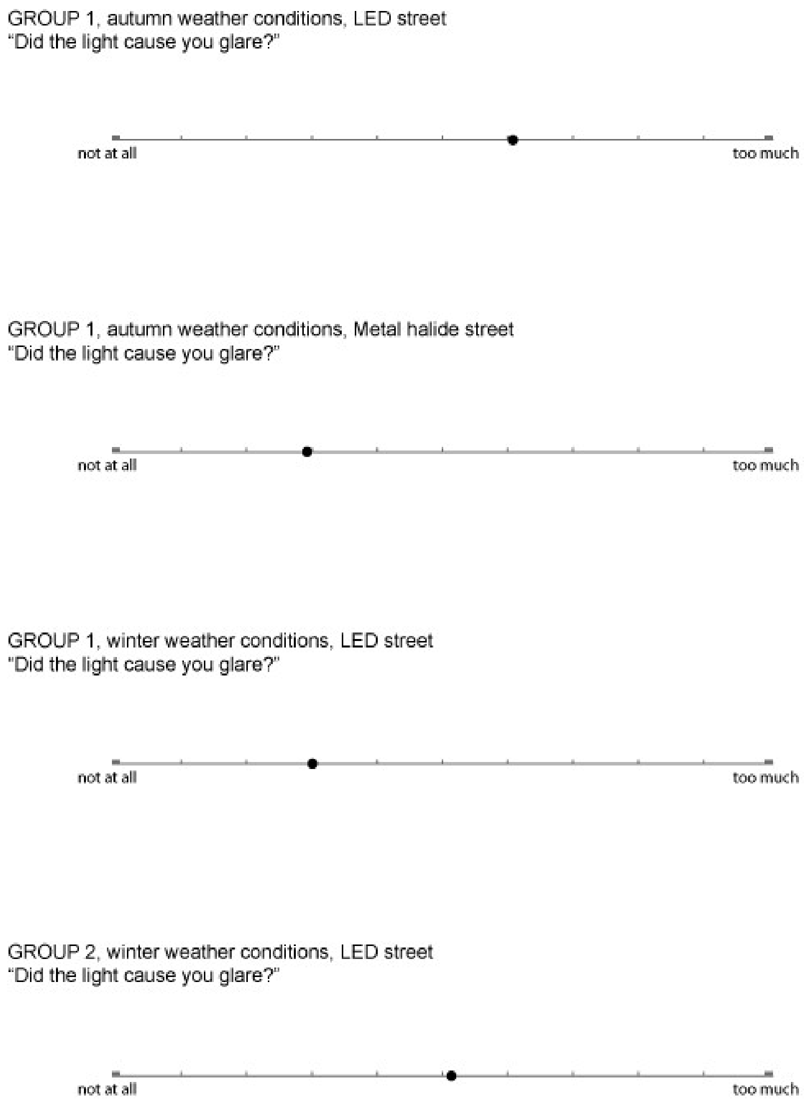


Figure 5.12. The mean value of the answer scales to the question "Did the light cause you glare?".

The concept *glare* is not always understood correctly and that is why two different questions were asked, "*Did the light cause you glare*" and "*Was the lighting too bright in your opinion*". As noted in Figures 5.11 and 5.12, Group 1 under autumn weather conditions felt that the lighting on the LED illuminated street was perceived slightly too bright and that it also felt to cause glare. The scale for the same group in the same weather conditions in the metal halide illuminated street indicates that the lighting felt less bright than the LED illuminated street and that the lighting did not cause as much glare.

Under winter weather conditions Group 1 felt that the lighting was not too bright and that it did not cause too much glare on the LED illuminated street. Group 1 felt that the brightness and the perception of glare were at the same levels with the metal halide illuminated street under the autumn weather conditions. Group 2 felt that the brightness on the LED illuminated street in winter weather conditions was in the exact middle of "*not at all*" and "*too bright*" as well as lying in the exact middle between "*not at all*" and "*too much*" on the glare question.

In Figures 5.16, 5.17, 5.18, 5.19, 5.20 and 5.21 are the answers, when the test persons were asked to analyze how well the lighting in the test streets met their criteria of good pedestrian way lighting. "Too bright" was chosen as a negative feature with the index 2 for the LED illuminated street in autumn, with index 3 for the LED lighted street in winter and with the index 2 for the metal halide illuminated street in autumn. These results are the opposite of the results in the scales in Figures 5.11 and 5.12. However, "the lights were bright enough" was chosen as a positive feature with the index 3 in the LED illuminated street in winter, with the index 3 in autumn and not at all for the metal halide illuminated street in autumn.

"The lights did not cause glare" was chosen as a positive feature with the index 1 for the LED illuminated street and with the index 2 for the metal halide illuminated street in autumn and with the index 1 for the LED illuminated street in winter-time. "The lights caused glare" was chosen as a negative feature with the index 3 for the LED illuminated street in autumn time and with the index 2 for the LED illuminated street in winter-time. The metal halide illuminated street was not chosen at all in this category.

These results indicate that the LED lighting is considered too bright and to cause glare, but weather this is a positive or a negative feature varies betweens individual answers.

5.6.5 Landolt-C recognition

The test persons were asked how many Landolt-Cs they detected on the test road and to recognize in which direction the gap was pointing to. There were four Landolt-Cs on every test site. The gap openings were pointing towards the walking direction under the autumn weather conditions on the LED illuminated street and backwards the walking directions under winter weather conditions. The gap openings on the metal halide illuminated street under autumn weather conditions were pointing right in the walking direction. The answers are listed in Table 5.5.

Table 5.5. The percentage of the recognition of Landolt-Cs.

Group and weather conditions	0 C	1 C	2 C	3 C	4 C	Right direction
Group 1, autumn, LED	89 %	11 %	0 %	0 %	0 %	0 %
Group 1, autumn, MH	33 %	11 %	33 %	22 %	0 %	44 %
Group 1, winter, LED	12.5%	12.5%	12.5%	37.5%	25 %	63 %
Group 2, winter, LED	83 %	0 %	0 %	0 %	17 %	0 %

Group 1 did the test for the first time on the street illuminated by LED luminaires under autumn weather conditions. As noted in Table 5.5, nobody recognized the direction of the gap and 89 % of the test persons did not detect a C at all. 11 % detected one of the four Cs. A few minutes later when the same test persons walked under the same weather conditions on street illuminated by metal halide lamps 44 % of the test persons were able to recognize the direction of the C, even though nobody detected all of them. 22 % detected three, 33 % detected two, 11 % detected one and 33 % did not detect a C at all. These results indicate that the test persons learned at the first test site the need to search for the Cs in the second test site.

Two months later when the same group was asked to walk on the same LED illuminated street under winter weather conditions 63 % of the test persons were able to recognize the right direction of the gap and this time 25 % detected all of the Cs. 37,5 % detected three, 12.5 % detected two, 12.5 % detected one and only 12.5 % did not detect a C at all. This indicates, again, that the persons remembered to search for the targets because when Group 2 walked on the same LED illuminated street at the same time, 83 % of them did not detect a C at all. 17 % detected all of them but no one was able to recognize the right direction.

The results of Group 1 between the metal halide illuminated street under autumn weather conditions and the LED illuminated street under winter weather conditions are comparable. In both cases the test persons had apparently learned that there could be some C letters on the ground. However, they did not know how many or to what direction the gap would point. Even if the test persons knew about the C letters, they were not able to detect all of them. Table 5.5 shows that test persons were able to note these C letters much better on the LED illuminated street under winter weather conditions than on the metal halide illuminated street under autumn weather conditions.

5.6.6 Amount of light

Figure 5.13 shows the mean value of the answers to the question "*Was there enough light* ?". In autumn weather conditions Group 1 answered that the LED illuminated street had a good amount of light, almost too much light. On the metal halide lamp illuminated street Group 1 answered the street to have too little light. In winter weather conditions both groups answered that the LED illuminated street had almost too much light.

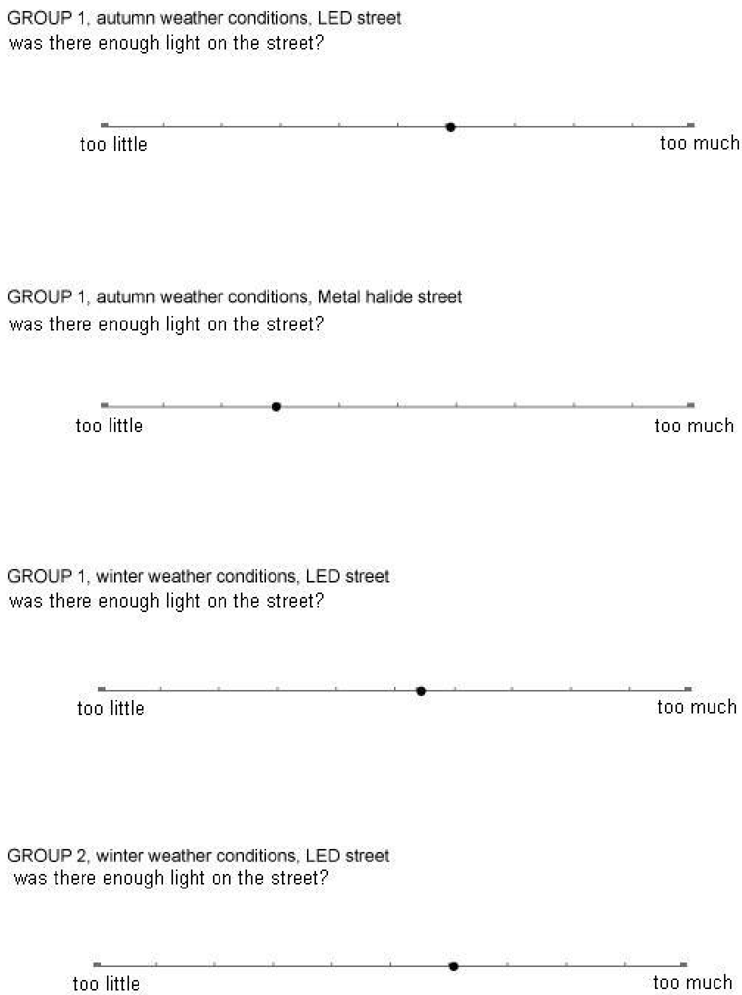


Figure 5.13. The mean value of the answer scales to the question " *Was there enough light on the street* ?"

"Enough light" was chosen as the most important criterion, with the index 12 (see Figure 5.15), when the test users were asked to list their opinions of most important features in pedestrian street lighting. According to this opinion and the fact that the test users considered there to be almost too much light on the LED illuminated street (see Figure 5.13) it could be stated that the LED illuminated street is a successfully lighted street, in the test person's opinion. However, the amount of light on the metal halide lamp illuminated street was considered to be too little and as "Enough light" was chosen as the most important criterion (see Figure 5.15) it could be stated that the metal halide lamp illuminated street is not a very successfully lighted street in the test person's opinion.

5.6.7 Colour of light

Figure 5.14 shows the mean value of the answers to the question about the colour of the light.

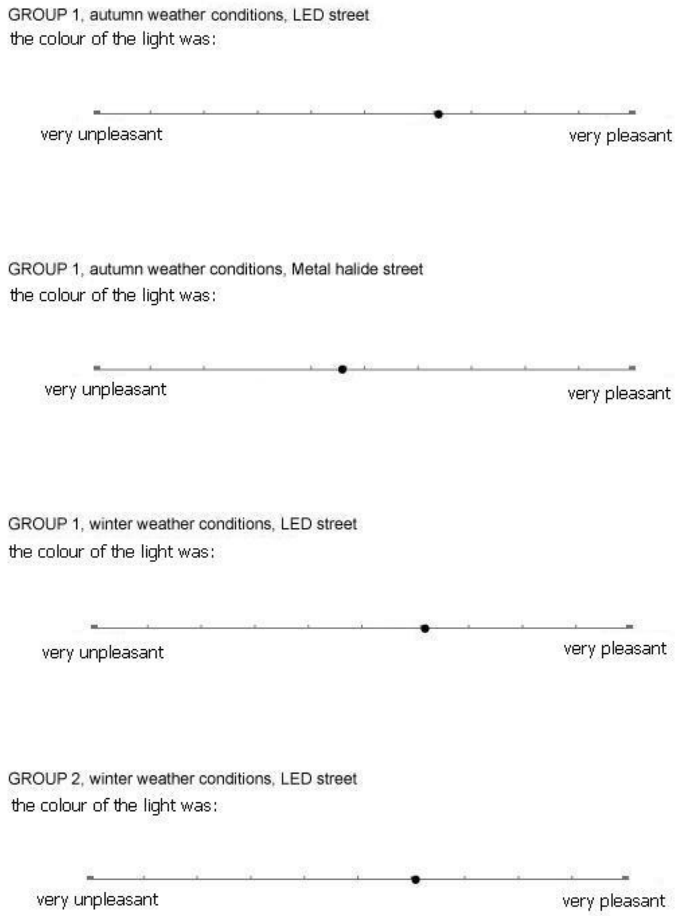


Figure 5.14. The mean value of the answer scales to the question about the colour of the light.

The colour temperature, given by the manufacturer, of the LEDs and metal halide lamps is the same, 3000 K. Even if the colour temperature is said to be the same, a difference can be noticed in the answers in Figure 5.14. The colour of the LED illuminated street is considered in all weather conditions and by both groups to be more near to *very pleasant* than to *very unpleasant*. The colour of the light on the metal halide lamp illuminated street is considered to be more near to *very unpleasant* than to *very pleasant*. Since the scales of the colour of light (Figure 5.14) and the scales of amount of light (Figure 5.13) are almost identical, it seems like the amount of light has an impact on how the test persons have perceived the colour of the light.

5.6.8 Opinions of the test persons

It is important here to note that the test persons are not studying or working with light engineering. All of the chosen test persons have made the test as "normal road users" without any prejudices.

The test persons were asked to list 1-5 factors that they feel are the most important criteria in pedestrian way lighting. The factors they (no matter of the group or when the test is made) listed are showed in Figure 5.15. The numbers in the following Figures indicate the amount of answers. If a person from Group 1 listed the same criterion many times, it was only noted once in the table.

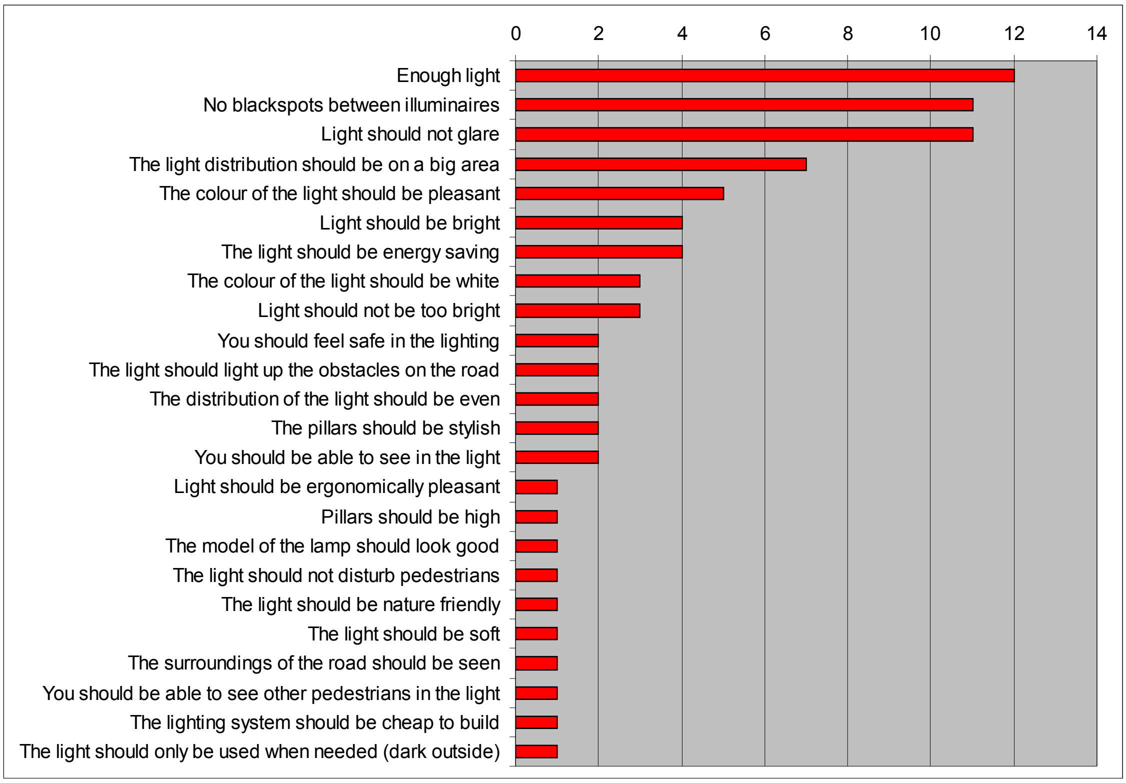


Figure 5.15. The most important criteria in pedestrian way lighting, listed by the test persons.

In winter weather conditions both groups, after answering the questionnaire, were asked to analyze how well the test street equalled their criteria of good pedestrian way lighting. Under autumn weather conditions Group 1 was asked to analyze how well both the LED illuminated street and the metal halide illuminated street equalled their criteria. The positive feedback of the LED illuminated street on the winter test day is listed in Figure 5.16 and the negative feedback in Figure 5.17.

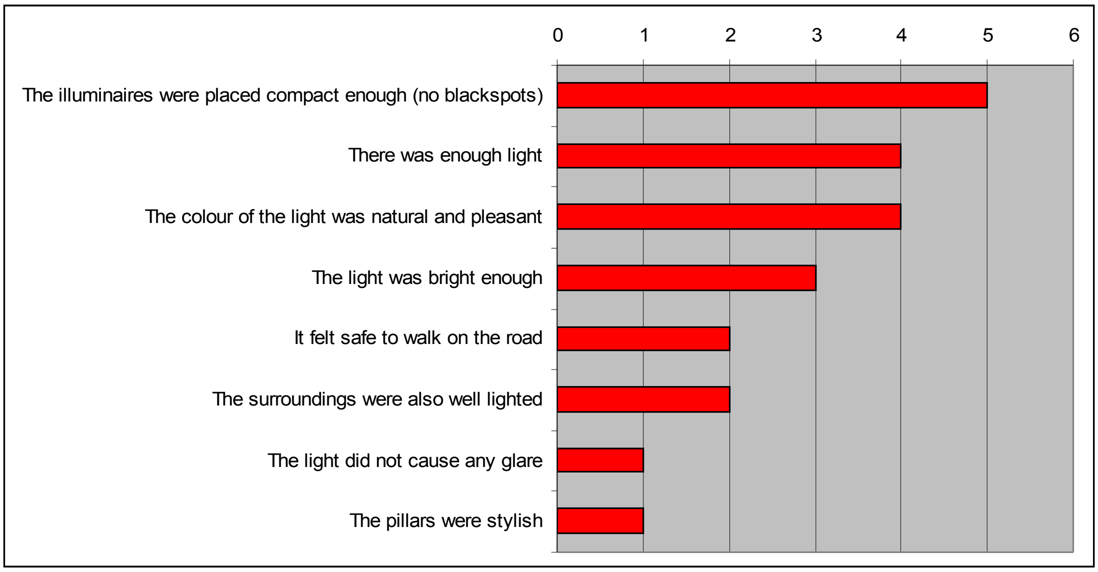


Figure 5.16. Positive features of the LED lighting under winter weather conditions, evaluated by test persons.

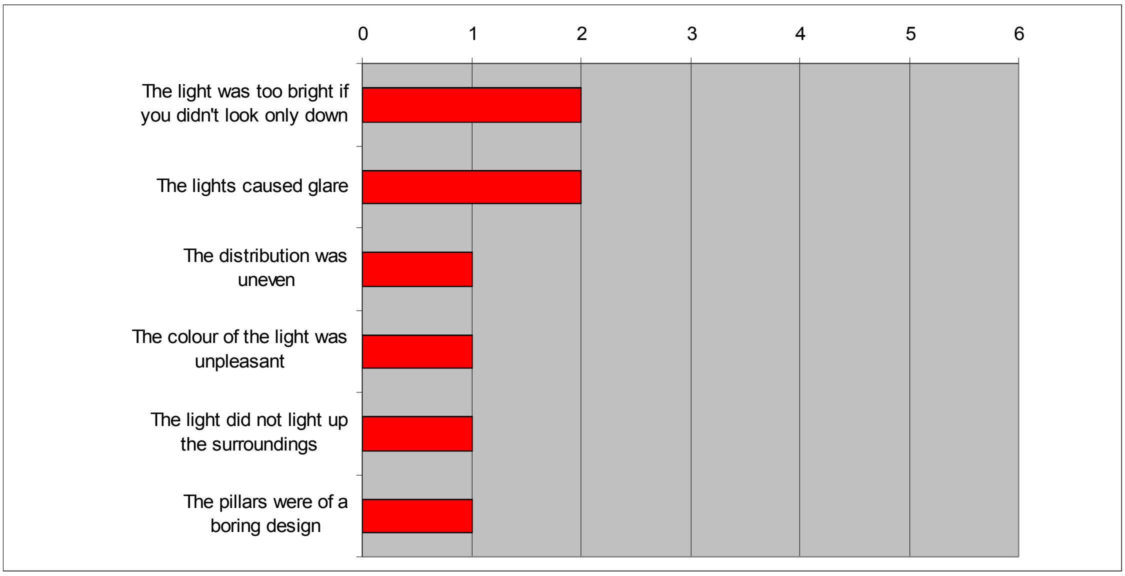


Figure 5.17. Negative features of the LED lighting under winter weather conditions, evaluated by test persons.

The positive feedback for the LED illuminated street under autumn weather conditions is listed in Figure 5.18 and the negative feedback in Figure 5.19. The positive feedback of the metal halide illuminated street is listed in Figure 5.20 and the negative in Figure 5.21.

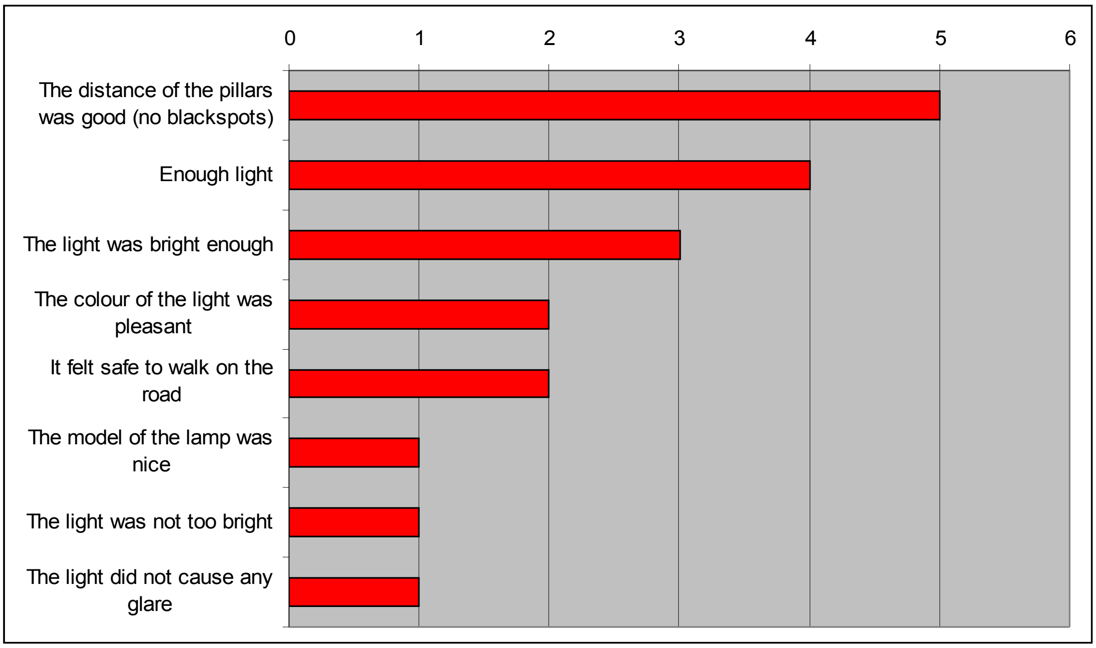


Figure 5.18. Positive features of the LED lighting under autumn weather conditions, evaluated by test persons.

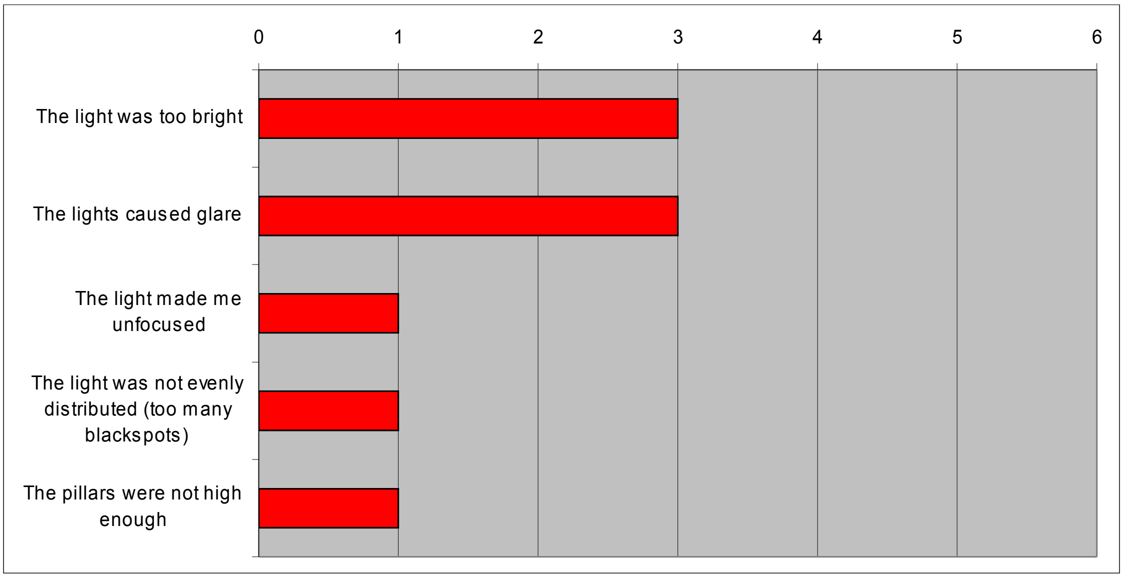


Figure 5.19. Negative features of the LED lighting under autumn weather conditions, evaluated by test persons.

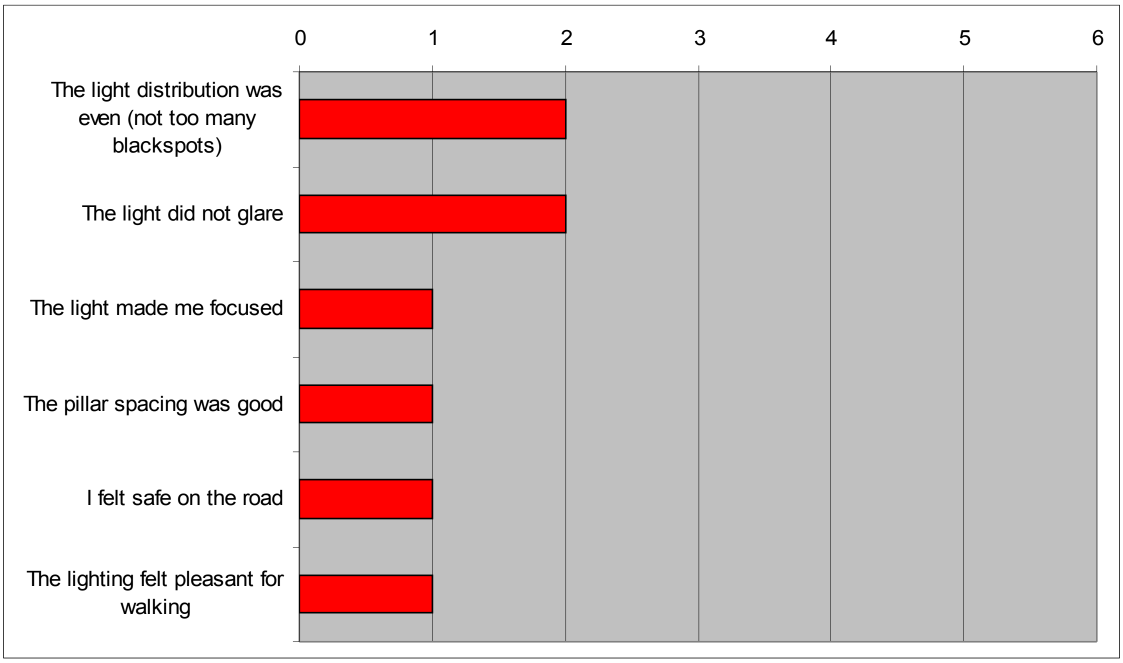


Figure 5.20. Positive features of the metal halide lighting under autumn weather conditions, evaluated by test persons.

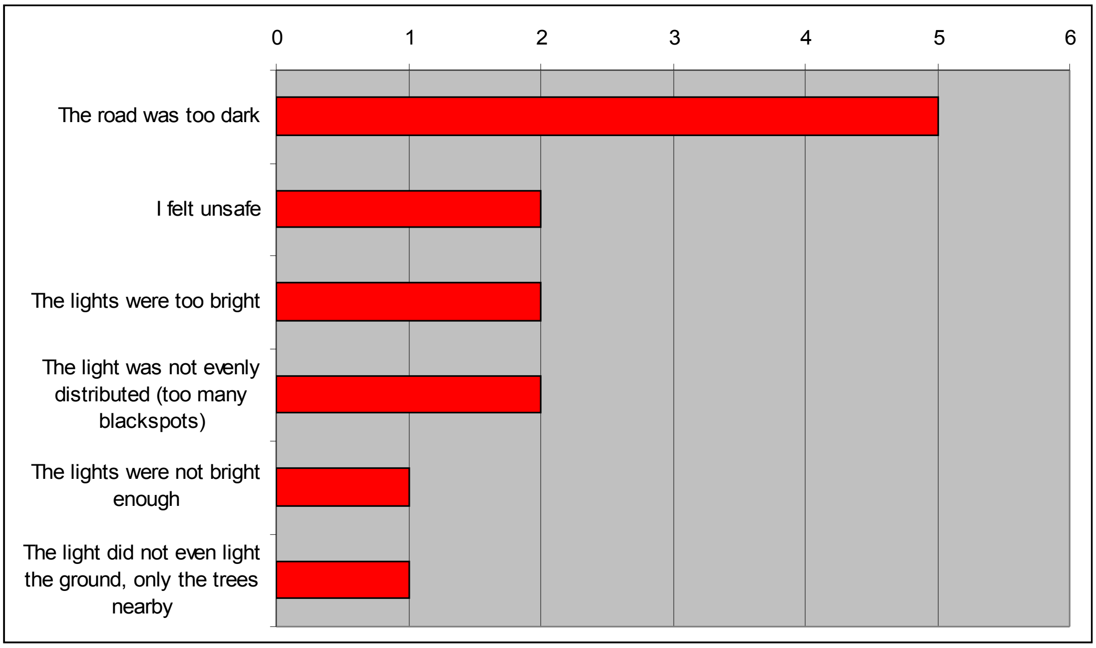


Figure 5.21. Negative features of the metal halide lighting under autumn weather conditions, evaluated by test persons.

Test persons in Group 1 were also asked to compare the lighting of the metal halide illuminated street to the LED illuminated street in autumn weather conditions. Besides the criteria listed in previous tables only 44 % of the group members felt that the LED street was more pleasant and "better". Only 22 % felt that the metal halide street was more pleasant.

When the test persons, as "normal road users" were asked to list what they felt were the most important criteria in pedestrian way lighting they listed "enough light" as the most important one. "No blackspots between luminaires","light should not glare" and "the light distribution should be on a large area" were also found to be important criteria.

When the test persons were asked to analyze how well the test roads met these criteria, the majority felt that the metal halide illuminated street was too dark in autumn. There were equally as many test persons considering the light distribution to be even and uneven as well as there were equally as many test persons considering the light to cause glare and not to be bright enough.

The LED illuminated street under autumn weather conditions was considered to have enough light without any blackspots. There were equally as many test persons considering the lighting to be bright enough and the lighting to be too bright. However, there were three times more test persons feeling the light to cause glare than not to cause glare. The test persons felt almost the same of the LED illuminated street under winter weather conditions as under autumn weather conditions.

5.7 Proposals for improvements

Based on the test sites in this user study some ideas of improvements for pedestrian street luminaires are given. When designing a luminaire for outdoor areas like pedestrian streets, parks and parking areas following aspects should be considered:

- the luminaire should give enough light but not only on a small area under the luminaire creating blackspots between poles but also in the closest neighborhood. This kind of lighting would have a positive impact on the feeling of safety for the road user.
- the luminaire should not only provide light in a vertical direction but also from the sides, without causing glare. If the luminaire provides only light in a vertical direction, may it cause shadows on the faces of road users and that in turn makes facial recognition hard. As noted in Chapter 5.6.2 it was remarkably easier to recognize faces in snowy weather than in dark autumn weather without snow as then the light

was not only provided from the luminaire in vertical direction but also from the snow lying in trees and bushes all around.

- the light of the luminaire may be bright but not causing glare. Since the terrain on pedestrian streets, parks and parking areas can alternate a lot, should the luminaire be designed in a way that the light source or light sources could be adjustable.

An idea of a luminaire according to these aspects is presented in Figures 5.22, 5.23 and 5.24.

Figure 5.22. A model of a luminaire made as an arch. The luminaire has four light sources; two adjustable and two made in a twist.

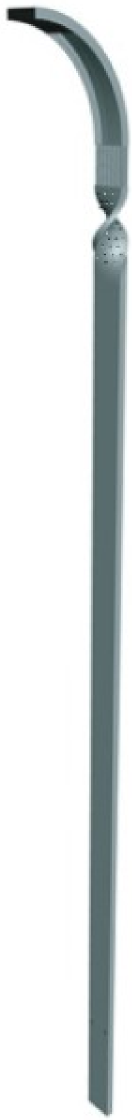


Figure 5.23. The same luminaire as in Figure 5.22 but made as a half arch.

Figure 5.24. The adjustable light source used in the luminaires presented in Figures 5.22 and 5.23.

The design of the luminaire is an arch (see Figure 5.22) with four sources of light. The light sources consist of LED modules. The twists on the sides provide light on the ground *around* the luminaire in the closest neighborhood. The two other light sources are also LED modules but they are adjustable. Figure 5.24 shows the adjusting possibilities. The luminaire can therefore be used in hills or other difficult terrains without causing too much glare, assuming the source is placed in optimal angles. The sources can also be adjusted so that they increase the vertical illuminance, which in turn increases the possibility for facial recognition. Figure 5.23 shows a variant to the luminaire presented in Figure 5.22. The variant is a half arch with only two sources of light. The idea of the luminaire with its light sources is the same, but together the arch and the half arch can create nicely lighted scenes in almost any urban area.

The LEDs used in the luminaires should be provided with integrated lenses giving an oval radiation pattern instead of a direct light. When the luminaires (in Figures 5.22 and 5.23) with the light sources are adjusted in the optimal way for the terrain where they are used and provided with LEDs that have integrated lenses, the light can be directed in the exact places where they are needed and with minimum light pollution and without causing glare. Because of the many light sources the luminaires should provide light on a big area without causing blackspots.

5.8 Conclusions

The majority of the test persons felt the LED lighting to be too bright and to cause glare but this was not always considered as a negative feature. According to the test users, the pedestrian street illuminated by LED luminaires was safer to use than the reference street that was illuminated by metal halide lamps. The main reason to the lack of feeling of safety seemed to be that the metal halide illuminated street was felt to be too dark. Even though the LED lighting was considered to cause glare and to be too bright, these features did not impact negatively on the feeling of safety.

There was a remarkable difference between facial recognition under autumn and winter weather conditions. In winter the snow, that was laying both on the ground as in the trees, increased the overall illumination to that extent that faces were easy to recognize. In autumn weather conditions it was not only darker but also shadows were formed, which made the recognition harder. Even though facial recognition is considered to have an impact on the feeling of safety, this could not be confirmed in this user study.

The Landolt-Cs were hard to detect in any weather condition on both roads. Group 1, who walked on test sites three times learned to search for them but they did not anyway recognize all of the Cs. The aim of having the Landolt-Cs lying on the test streets was to find out whether it is possible to notice obstacles on the street in different lighting and weather conditions.

When the test persons, as “normal road users” were asked to list what they felt were the most important criteria in pedestrian way lighting they listed “enough light” as the most important one. “No blackspots between luminaires”,“light should not glare” and “the light distribution should be on a large area” were also important criteria.

6 Conclusions

Lighting of outdoor areas such as streets, roadways, parking lots and pedestrian areas are currently dominated in Finland by mercury vapour and high pressure sodium light sources. The percentage of mercury vapour lamps is about 51.3 % of all outdoor light sources and respectively 44.5 % for high pressure sodium lamps.

The Ecodesign Directive provides with consistent EU-wide rules for improving the environmental performance of energy-using products (EuPs) through ecodesign (European Commission). The Ecodesign Directive will forbid the placement of mercury vapour lamps to the EU market by 2015 because of its unacceptably low system efficacy (European Commission). It is estimated that there is about 664 000 mercury vapour lamps in outdoor lighting in Finland (Sippola, 2010).

This current work documents the LED installations in pedestrian ways, parks and smaller residential area streets in Finland that have existed at the time of making this Master's thesis. The majority of the installations are experimental installations. The experimental installations are made mostly in destinations where it has been topical to update or change old installations of mercury vapour lamps or high pressure sodium lamps. However, there are also new LED installations that have not replaced any old lamps.

Luminance and illuminance measurements were made on a LED illuminated pedestrian way, a high pressure sodium lamp luminaire illuminated footway and a pedestrian way illuminated with induction lamps. The luminances measured on the ground, right under the luminaire, are the same for both the 31 W Philips Mini Iridium LED luminaires and for the 110 W High Pressure Sodium lamps, that is 1.1 cd/m^2 . For the 55 W induction lamp the mean luminance right under the luminaire was notably smaller, only 0.29 cd/m^2. The mean lumninance in the measurement area was different for all of the lamp types. LED lights gave a mean luminance value of 0.37 cd/m^2, High Pressure Sodium lamps 0.6 cd/m^2 and the induction lamps 0.29 cd/m^2. The maximum illuminance for the LEDs was 14.15 lx, the minimum value 3.30 lx and the mean value 7.15 lx in the measurement area. The equivalent results for induction lights were 7.59 lx, 1.8 lx and 4.18 lx, respectively.

The results of the user study indicate that even though the LED lighting was considered to cause glare and to be too bright, they did not seem to be negative features. According to the test users, the pedestrian street illuminated by LED lamps felt safer to use than the reference street that was illuminated by metal halide lamps.

There was a remarkable difference between facial recognition in pedestrian street lighting under autumn and winter weather conditions. In winter weather the snow, that is situated both on the ground as in the trees, increases the luminance levels from every direction to that extent that faces are easy to recognize. In autumn weather conditions it is not only dark but also the lack of snow creates different kinds of shadows on the faces and they are not as easy recognizable.

When the test persons, as "normal road users" were asked to list what they felt were the most important criteria in pedestrian way lighting they listed "enough light" as the most important one. "No blackspots between luminaires","light should not glare" and "the light distribution should be on a large area" were also important criteria.

Based on the test sites in this user study some ideas of improvements are given for pedestrian street luminaires. The luminaires should not only give light on small areas under the luminaire but also in the closest neighborhood. The luminaire should not only provide light in a vertical direction, because it cause shadows on the faces of road users and that in turn makes facial recognition hard. It was noted in the user study that it was remarkably easier to recognize faces in snowy weather than in dark autumn weather without snow as then the light was not only provided from the luminaire in vertical direction but also from the snow lying in trees and bushes all around. Therefore, the luminaire should provide light also in a horizontal direction on faces of road users. If the light sources in horizontal direction are provided with good lenses, the light can be directed in a way without causing glare. Also to prevent glare, luminaires could be provided with adjustable light sources making them optimal for any kind of terrain and environment.

References

Books

Liisa Halonen. Jorma Lehtovaara. 1992. ”Valaistustekniikka”. Otatieto.
ISBN 951-672-145-1

Martti Paakkinen.2008. Diplomityö ”Led-tekniikan mahdollisuudet osana valaistusjärjestelmää”. Elektroniikan laitos/ Valaistusyksikkö. A Master’s thesis.

Lars Starby. 2003. ”En bok om belysning”. Ljuskultur. ISBN: 91-631-3529-9. Fingraf Tryckeri AB Södertälje 2003.

Marketta Kyttä, Sari Puustinen, Jukka Hirvonen, Anna Broberg, Hilkka Lehtonen. 2008. “Turvallinen asuinalue –Tampereen Muotiala suunnitelmissa ja kokemuksissa” Yhdyskuntasuunnittelun tutkimus- ja koulutuskeskuksen julkaisuja B93. Yliopistopaino Espoo 2008. Teknillinen korkeakoulu. ISBN 978-951-22-9409-1.

John E Kaufman, Howard Haynes 1981. ”IES LIGHTING Handbook Application Volume”. Published by Illuminating Engineering Society of North America. ISBN 0-87995-008-0. Composed and printed by Waverly Press.Inc., Baltimore.

H. Hewitt, A.S. Vause 1966. “Lamps and Lighting”. British Lighting Industries. Printed in Great Britain by William Clowes and sons, Limited, London and Beccles.

Vesa Sippola 2010. Diplomityö “Eco-design- direktiivin täytäntöönpanotoimenpiteiden vuoksi poistuvien lamppujen korvaaminen ulkovalaistuksessa”.

Suomen stadardisoimisliitto SFS 1992. ”Sähköteknillinen sanasto. Valaistus. Electrotechnical vocabulary. Lighting” SFS-IEC 50(845).

Articles and publications

Marjukka Puolakka, Anne Ylinen, Aleksanteri Ekrias, Liisa Halonen. 2009. Raportti 55. ”Tievalaistuksen optimointi- ohjaus, näkyvyys, mittaukset, tien päällyste”. Teknillinen korkeakoulu. Elektroniikan, tietoliikenteen ja automaation tiedekunta. Elektroniikan laitos, Valaistusyksikkö. 2009.

Meri Viikari, Aleksanteri Ekrias, Marjukka Eloholma, Liisa Halonen 2008. “Modeling spectral sensitivity at low light levels based on mesopic visual performance”. Lighting Laboratory, Helsinki University of Technology, Finland. Clinical Ophthalmology 2008:2(1) 173–185. © 2008 Viikari et al, publisher and licensee Dove Medical Press Ltd.

Meri Viikari 2007. Doctoral dissertation ”Analysis of the existing visual performance based mesopic models and a proposal for a model for the basis of mesopic photometry”. ISBN:978-951-22-9122-9.

CIE 2009. CIE TC 4-48 ”White light under mesopic conditions in road lighting”. Report of TC 4.48.

Risto Näsänen 2004. ”Käyttöliittymien visuaalinen käytettävyys” Työterveyslaitos, Fysiikan osasto, Aivotyölaboratorio, Helsinki Työ ja ihminen 18 (2004):3, 90–99

Y. A. W. de Kort, W. A. IJsselsteijn, I. M. L. C. Vogels, M. P. J. Aarts, A. D. Tenner, & K. C. H. J. Smolders 2009. “Proceedings EXPERIENCING LIGHT 2009 International Conference on the Effects of Light on Wellbeing”. Keynotes and selected full papers Eindhoven University of Technology. ISBN: 978-90-386-2053-4.

Tetsuya Muraoka, Hiroaki Ikeda 2007. “Experimental Study on Distances of Objects Seen on Flat Panel Display Evaluated in Terms of Human Factors”. Polytechnic University in Tokyo. IKEDA Technologies, Inc.

Aleksanteri Ekrias, Marjukka Eloholma, Liisa Halonen, Xian-Jie Song, Xian Zhang, Yan Wen. 2007. ”Road Lighting and Headlights: Luminance measurements and automobile lighting simulations”. Building and Environment 43 (2008) 530-536.

Kate Painter. 1996. ”The influence of street lighting improvements on crime, fear and pedestrian street use, after dark” Institute of Chriminology, Cambridge University. Landscape and Urban Planning 35 (1996) 193-201.

British Standards Institution (1987-1990). “Road Lighting: BS 5489”. 10 parts. London.

Colette Knight and Johan van Kemenade. 2007. ”Effect of outdoor lighting on perception and appreciation of end-users” Philips Lighting B.V. 5600 JM Eindhoven. The Netherlands.

An interview of Marjukka Puolakka made by Tapio Kallonen. 2009. Magazine: Sähköala. “ledien käyttö tie- ja katuvalaistuksessa”. 8/2009. Pages 34-36.

Commission Internationale de l’Éclairage (1987). CIE/IEC. “International Lighting Vocabulary”. CIE 1987; 17:4.

Naomi Miller/U.S. department of Energy. 2008. Outdoor Area Lighting. Building Technologies Program. PNNL-SA-60645.

Caminada, J. F. and van Bommel, W. J. M. (1980) Residential area lighting. ”Engineering Report 43” , Lighting Design and Engineering Centre. Eindhoven, The Netherlands: NV Philips Gloeilampenfabrieken.

Road lighting—Part 3: “Calculation of performance”. European standard EN 13201-3. Publication 270-2003. Ref. No. EN 13201- 3:2003 E.

IESNA light Sources Committee. 2005. “IESNA Technical Memorandum on Light Emitting Diode (LED) Sources and Systems”. IESNA TM-16-05. ISBN 0-87995-206-70

Mathias Wendt. 2006. “Historical Luminous Efficacy Evolution of Light Sources”. Research laboratory, Aachen. COST Meeting.

Interviews

Knight Colette. 2009. Philips Lighting B.V. The Netherlands. Interview by e-mail during November 2009.

Aki Mäkirinta. 2009. Maintenance of outdoor lighting. Kerava. Interview by e-mail during autumn 2009.

Olli.Markkanen. 2009. Product Manager Helen Outdoor Lighting. Helsinki. Interview by e-mail during autumn 2009 and winter 2010.

Antero Talja. 2009. General designer, Lahtienergia. Lahti. Interview by e-mail during autumn 2009 and winter 2010.

Tapio Nikkinen. 2009. General designer, Lahtienergia. Lahti. Interview by e-mail during autumn 2009 and winter 2010.

Markku Toivonen. 2009. Designer of outdoor lighting, Turku Energia Urakointipalvelut. Turku. Interview by e-mail during autumn 2009 and winter 2010.

Mika Heikkilä. 2009. Manager of the use of streetlights, the city of Tampere. Interview by e-mail during autumn 2009 and winter 2010.

Stig-Göran Lindholm. 2009. Emgineer of Building Services, Vantaan Energia Sähköverkot Oy. Vantaa. Interview by e-mail during autumn 2009 and winter 2010.

Harri Heino. 2009. Electrician, the city of Vaasa. Interview by e-mail during autumn 2009 and winter 2010.

Ari Piippo. 2009. Designer, Jyväskylän Energia. Jyväskulä. Interview by e-mail during autumn 2009 and winter 2010.

Ate Korkalainen 2009. Project Manager, Oversol Oy. Interview by e-mail during autumn 2009 and winter 2010.

Kati van Heerden 2009. Marketing director, Oversol Oy. Interview by e-mail during autumn 2009.

Pekka Sillanpää 2009. Leader of lighting, the city of Espoo. Interview by e-mail during autumn 2009 and winter 2010.

Petri Virtanen 2009. Manager of technical matters in the community, the city of Salo. Interview by e-mail during autumn 2009 and winter 2010.

Mika Nummenpalo. 2009. Manager of Research and Development, EasyLed Oy. Telephone conversation in November 2009.

Jari Kinnunen. 2009. Street manager. the commun of Kittilä. Interview by e-mail during autumn 2009.

Toivo Vilmi. 2009. CEO, Valopaa Oy. Interview by e-mail during autumn 2009 and winter 2010.

Hannu Kaikkonen. 2009. Maintanance manager, the city of Äänekoski. Interview by e-mail during autumn 2009 and winter 2010.

Emilia Rautkylä. 2009. Technical product manager, Philips Oy. Interview by e-mail during autumn 2009.

Juhani Ramberg 2009. Technical manager, the city of Harjavalta. Interview by e-mail during autumn 2009.

Tapio Pesu 2009. Manager of the electrical network department, Seinäjoen Energia Oy. Interview by e-mail during autumn 2009.

Lauri Aspblom 2010. Designer, Porin Enrgia Oy. Interview by e-mail during winter 2010.

Jorma Lusikka. 2009. Tiehallinto. . Interview by e-mail during autumn 2009.

Internet

European commission: http://ec.europa.eu/index_en.htm

Tiehallinto. Matti Piispanen. Kari Lehtonen. 2006. Tievalaistuksen suunnittelu. Verkkojulkaisu www.tiehallinto.fi/julkaisut ISBN 951-803-553-9 TIEH 2100034-v-06

Philips Lumileds. 2010. /www.philipslumileds.com

Osram Opto Semiconductors. 2010. www.osram-os.com

Appendix 1

European standard EN 13201-3.

The European standard for road lighting calculations (EN 13201-3) describes methods for luminance calculations and measurements. Because road lighting calculations are made for optimizing lighting conditions for drivers, the observation point is placed 1.5 m above the road surface (Figure 1). Measuring points are taken 60m ahead of the observer so that the viewing angle lies between 0.51° and 1.51°. The longitudinal measuring area is taken from the first luminaire 60m ahead to the following one on the same side of the road. The transverse measuring area is defined by borders of a driving lane.

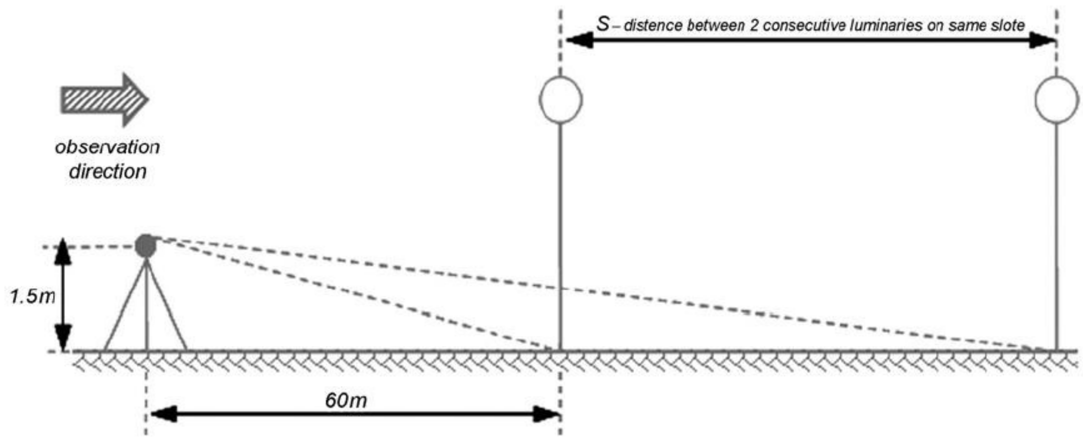


Figure 1. Observation point of road lighting calculations and measurements

According to the European standard EN 13201-3, the luminance points should be evenly spaced in the measuring field and located as indicated in Figure. 2.

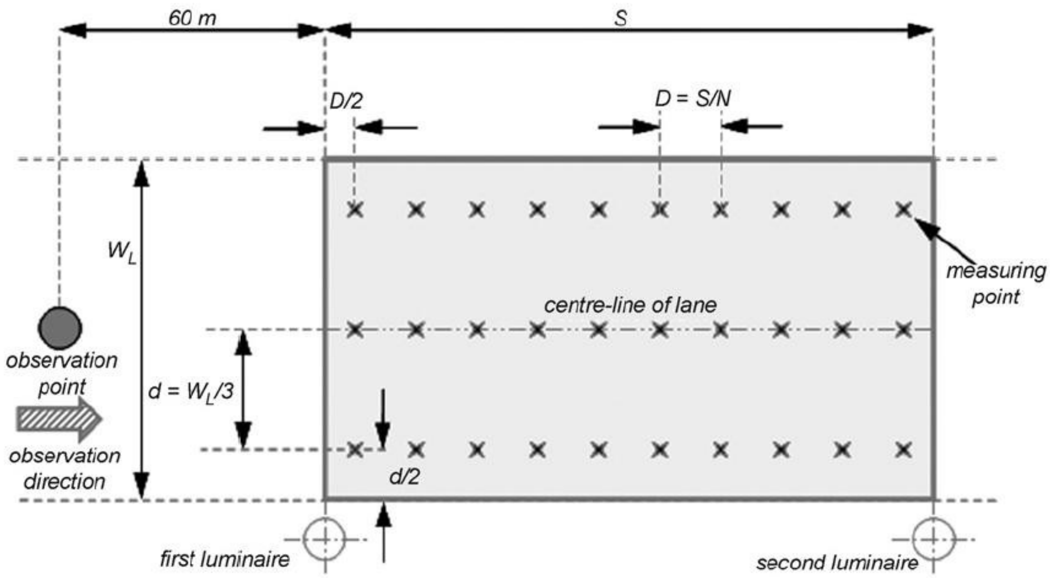


Figure 2. Placement of measurement points of road luminance measurements.

The number of points to be concerned depends on the measurement area. The spacing of luminance points in the longitudinal direction is determined from the equation:

$$D = \frac{S}{N}$$

where D is the spacing between points in the longitudinal direction, S is the spacing between luminaires and N is the number of calculation points in the longitudinal direction with the following values: for S≤30 m, N=10; for S>30 m, the smallest integer giving D≤3m.

Appendix 2

Questionnaire used in the user study in Chapter 5.

LOMAKE 1

Olen: mies ❑
nainen ❑

Olen ________ vuotta vanha

Mitkä ovat mielestäsi kaikista tärkeimmät ominaisuudet kävely- ja pyörätien valaistuksessa? Listaa 1-5 asiaa:

LOMAKE 2

Tietä, jota pitkin äsken kävelin, käytän:

- tänään ensimmäistä kertaa ❑
- muutaman kerran vuodessa ❑
- muutaman kerran kuukaudessa ❑
- muutaman kerran viikossa ❑
- joka päivä ❑

Merkitse asteikkoon: Oliko tiellä valoa?

|---|

liian vähän liikaa

Oliko valo tasaisesti jakautunut tielle? kyllä ❑
ei ❑

Merkitse asteikkoon: oliko valaistus mielestäsi liian kirkas?

|---|

ei laisinkaan hyvin paljon

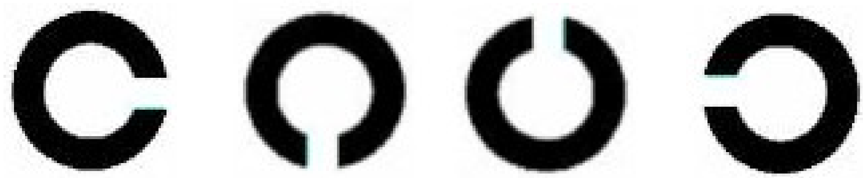
Olivatko valaisinpylväät:

- metallisia ❑
- puusta tehtyjä ❑
- en kiinnittänyt huomiota materiaaliin ❑

Montako merkkiä näit tiellä?

0 ☐
1 ☐
2 ☐
3 ☐
4 ☐

(Vastaa tähän jos valitsit edellisessä 1-4)
Valitse mihin suuntaan -merkin aukko osoitti?



oikealle ☐ taaksepäin ☐ eteenpäin ☐ vasemmalle ☐ en muista ☐

Merkitse asteikkoon: Oliko tie liukas?

|--|

ei laisinkaan hyvin liukas

Merkitse asteikkoon: Pelottaako sinua ***yleensä*** kävellä yksin pimeän aikaan?

|--|

ei laisinkaan hyvin paljon

Merkitse asteikkoon: Kuinka turvallinen olo sinulla oli äsken kävellessäsi tiepätkällä?

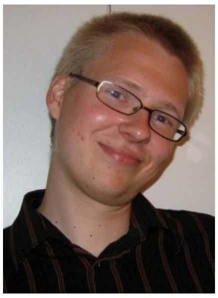
|--|

hyvin turvaton hyvin turvallinen

Sinua tuli vastaan seuraava määrä vastaantulijoita:

0	❑
1	❑
2-3	❑
4-10	❑

Kävelikö joku seuraavista henkilöistä sinua vastaan?

kyllä ❑	kyllä ❑	kyllä ❑	kyllä ❑	kyllä ❑
ei ❑	ei ❑	ei ❑	ei ❑	ei ❑

Merkitse asteikkoon: Oliko valon värisävy mielestäsi

|---|

hyvin epämiellyttävä hyvin miellyttävä

Merkitse asteikkoon: häikäisikö valo sinua?

|---|

ei laisinkaan hyvin paljon

LOMAKE 3

Oliko tienpätkissä eroja? Kerro omin sanoin millaisia eroja huomasit. (*Voit kutsua tiepätkiä esim. nimillä "tie 1" ja "tie 2"*):

Lomakkeessa 1 sinua pyydettiin listaamaan kaikista tärkeimmät ominaisuudet kävely- ja pyörätien valaistuksessa. Miten tiepätkät vastasivat näitä kriteerejäsi? Kerro vapaasti muutamalla sanalla:

Appendix 3

Questionnaire used in the user study in Chapter 5, translated to English

FORM 1

I am a:	man	❑
	woman	❑

I am ________ years old

In your opinion, the most important features in pedestrian street lighting are: (list 1-5 features)

____

____

____

____

____

____

FORM 2

The street that I just walked on, I use:

- today for the first time ❑
- few times a year ❑
- few times a month ❑
- few times a week ❑
- every day ❑

Put a mark on the scale: Was there enough light on the street?

|--|

too little too much

Was the light evenly distributed on the street? yes ❑
no ❑

Put a mark on the scale: was the lighting too bright in your opinion?

|--|

not at all a lot

The poles were:

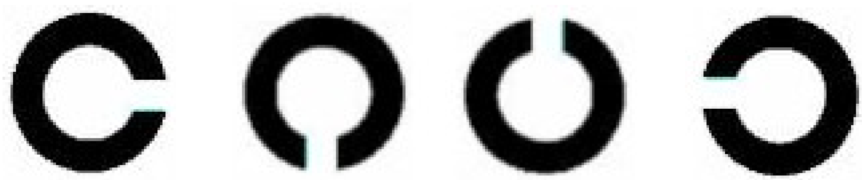
- metallic ❑
- wooden ❑
- I did not pay attention to the material ❑

How many  signs did you see on the road?

0 ❑
1 ❑
2 ❑
3 ❑
4 ❑

(Answer if you chose in the previous 1-4)

Choose in which direction the  letters gap was pointing to?



right ❑ backwards ❑ forwards ❑ left ❑ I don't remember ❑

Put a mark on the scale: was the road slippery?

|--|

not at all very slippery

Put a mark on the scale: Are you ***usually*** afraid to walk alone in the dark?

|--|

not at all a lot

Put a mark on the scale: How safe did you feel on the pedestrian street you just waked on?

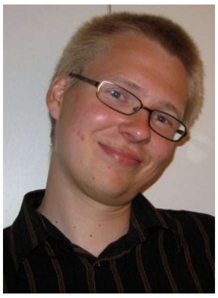
|--|

really unsafe really safe

The following amount of persons walked towards you:

0	❑
1	❑
2-3	❑
4-10	❑

Did any of the following persons walk towards you?

				
yes ❑	yes ❑	yes ❑	yes ❑	yes ❑
no ❑	no ❑	no ❑	no ❑	no ❑

Put a mark on the scale: the colour of the light was

|---|

very unpleasant   very pleasant

Put a mark on the scale: did the light cause you glare?

|---|

not at all   a lot

FORM 3

Were there differences in the pedestrian streets? Explain in own words what kind of differences you noticed. (*You may call the pedestrian streets for example "street 1" and "street 2"*):

____

____

____

____

____

____

In FORM 1 you were asked to list the most important criteria in pedestrian street lighting. How well did the pedestrian streets meet your criteria? Explain in your own words:

____

____

____

____

____

____