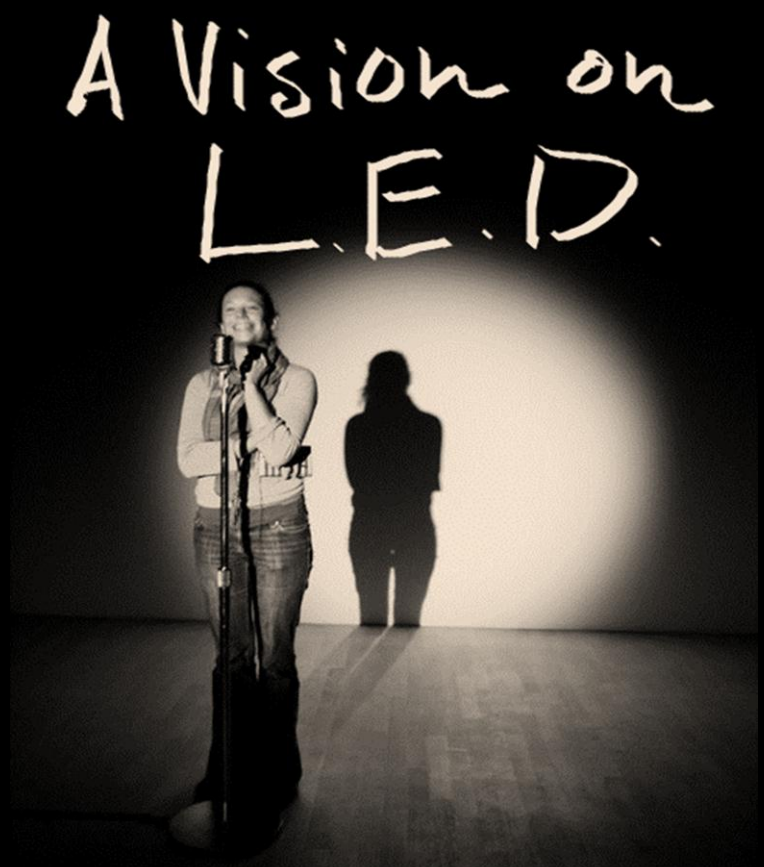


A thesis on LEDs for museum exhibition purposes

Sjoukje Kerman
Reinwardt Academie,
Amsterdamse Hogeschool voor de Kunsten
Cultuurbelicht@gmail.com

Amsterdam, June 1 2011

Foreword

After breathing in the air of museology for the past five years, this piece, this topic, you are holding in your hands right now, is what I find highly interesting and worth sharing with those in the field of cultural heritage and beyond.

Throughout this process, my research has led me to realize the power of semiotics within lighting design, the essence of choice-making and the effect they have on our collective and individual perceptions of cultural heritage. It has opened my eyes even more to the importance of knowledge and consistency, time management, craftsmanship, clear communication skills, creativity and courage when creating a vivid and innovative museum experience using LED.

I would like to acknowledge and thank the following people for their time, expertise and willingness:

Joris Krol
ERCO
Proliad/ Xicato
UvAErfgoedLab
Marysa Otte
Scott Geffert
Joost DeBeij
Taco de Bie
Henk van der Geest
Jack van Elewout
Ludmila Pechaczek
Katie O'Neill
Robert Kerman
Mario Jellema
Leontine Meijer- van Mensch
Gerdie Borghuis

Ever wonder why we use the light bulb as a symbol for a good idea or insight?

Summary

English

Sometimes people and institutions are so busy just staying alive that they do not have time to improve details. Over the past few years of working in museums I have often stumbled upon insufficient lighting design. Light is what gives us sight and lighting design gives us a specific perception of what it is we see. Due to my personal fascination for light in general, I want to share an innovative lighting source with you, that may facilitate a new and vivid collective aesthetic perception of your collection years to come. I am talking about LEDs for your museum exhibit lighting design.

This report describes the process and results of desk- and empirical research of LED lighting and lighting design with LEDs for museum exhibition purposes, under the Reinwardt Academy curriculum. This report offers professionals in the field of cultural heritage an understanding of the effects LED can provide its artifacts and its audiences during museum exhibitions. This report is based on the following question: Is it true that LED lighting can be a valuable asset to an innovative and vivid collective museum experience?

The answer to this question has two sides, yes and no. The answer you choose to acknowledge, depends on how you or your institution values the six motivation aspects concerning LED implementation used during this research. These six motives are presented in the image bellow on the far left column from top to bottom. The results listed in the columns are based on the opinion of two leading lighting distributers and two lighting designers. These opinions where then tested in the testing facility at the UvAErfgoedLab.

Motivation	Halogen	Fluorescent	Gas discharge	Fiber light	LED
Financial Average	2,9	3,8	3,1	2,8	3,8
Sustainability	2,3	3,0	3,0	2,7	4,3
Pre- conservation	3,5	3,0	2,8	3,0	4,5
Presentation/Aesthetics	4,3	2,3	3,0	2,7	2,5
Health issues	4,0	2,8	2,8	3,3	3,5
Try new technology	2,5	2,3	3,0	2,0	5,0
Average score per source	3,2	2,9	2,9	2,8	3,9
Result (round figures)	**3**	**3**	**3**	**3**	**4**

score is based on 4 respondents
score is based on 3 respondents
score is based on 2 respondents

Overall, LEDs score the highest results. From a Financial motive it is clear that LEDs are the most expensive lighting source to purchase. But LEDs use less electricity and need less maintenance than current leading lighting sources. Which makes them beneficial to long term financial planning. They are to this respect also the most suitable for maintaining a sustainable approach.

Concerning the preventive conservation issues on museum settings, LED also scores the highest. LEDs have minimal impact on damaging museum artifacts compared to current leading lighting sources in museum settings. This report does however score the lowest on aesthetical presentation. Though this does not agree with the results through tests in the testing facility in UvAErfgoedLab. The results in the image above have been filled out by leading lighting distributers and two lighting designers. Both have little experience with lighting design and therefore, based on this research are not sufficient.

However, through tests at the facility LEDs have proven to have potential to raise an emotional museum experience . LEDs offer a huge scale of colors without using any filters, which gives a museum the possibility to tune the exact lighting design that is desired. Therefore LEDs have the potential to create more scope for the imagination, which often triggers curiosity and therefore may indirectly inspire its audiences to accumulate more knowledge.

Regarding the health issues LED has scored lower than halogen lighting. This is still being questioned by scientists. Although halogen distributes light that allows us to feel comfortable, LEDs need far less lux to make a surface visible. This will be explained on a much more detailed level in 3.4.

Applying new technology in museums has been added as motive, because the museum is often said to reflect our current society. Therefore it can be important for museums to invest in the leading technologies to sustain this social role.

LED implementation is not always the right choice to make. LEDs are less reliable than other lighting sources due to the fact that LEDs have a high voltage sensitivity. And it is also important to state that not every lighting designer knows how to or wants to work with LEDs.

By simply replacing a LED into a fitting where a different lighting source has been taken out will not give the quality that LEDs are said to have. This new lighting source must be seen and treated as a completely new lighting source to be able to make use of its actual lighting qualities.

From this research five recommendations have been made to help professionals in the field of cultural heritage make the right decisions when dealing with their lighting choices.

First of all this report should *not* be used as a checklist when deciding to invest in LED. This thesis should be used as a source to read up on the issues that are paired with LED implementation used specifically for museum exhibit lighting design.

After reading this paper and before deciding to invest in LEDs for museum exhibition purposes, heritage professionals should recollect which motivations are valued by the mission statement of their museum. That way the museums choice will be backed up by its mission. It will make choice making quicker and it will amplify its mission.

And *please* ask for a screening of your chosen LED before investing in it. You do not want to end up with, for instance insufficient CRI ratings[1]. For your screening you should contact: **OLINO.org**

[1] See Glossary fort the definition of CRI ratings.

Samenvatting

Dutch

Soms zijn mensen en instellingen zo druk bezig met overleven dat zij geen tijd hebben zich te verdiepen in het verbeteren van details. De afgelopen jaren werd ik tijdens mijn werk in musea vaak geconfronteerd met onvoldoende lichtontwerp. Licht verschaft ons zicht en lichtontwerp geeft ons een specifieke perceptie van hetgeen we zien. Omdat ik op persoonlijk vlak gefascineerd ben door licht in het algemeen, wil ik een innovatieve lichtbron met u delen; een lichtbron die wellicht in de toekomst een nieuwe en levendige collectieve esthetische perceptie op uw collectie zal doen schijnen. Ik heb het over LEDs voor uw museumtentoonstelling lichtontwerp.

Deze scriptie beschrijft het proces en de resultaten van literatuur en empirisch onderzoek naar LED verlichting en lichtontwerp met LEDs voor museum tentoonstellingsdoeleinden als onderdeel van het curriculum van de Reinwardt Academie. Deze scriptie biedt professionals op het vakgebied van cultureel erfgoed een begrip van de effecten die LED tijdens een museumtentoonstelling kan hebben op zowel de kunstvoorwerpen als op de bezoekers. Deze scriptie is gebaseerd op de volgende vraag: Is het waar dat LED verlichting een waardevolle bijdrage kan zijn voor een innovatieve en levendige collectieve museumervaring?

Het antwoord op deze vraag is tweezijdig, ja en nee. Het antwoord dat u kiest hangt nauw samen met de waarde die u of uw instelling toekent aan de zes beweegredenen voor LED implementatie die voor deze scriptie gehanteerd zijn. Deze zes beweegredenen worden in de uiterst linkse kolom in onderstaande afbeelding van boven naar onder genoemd. De resultaten die in de kolommen vermeld worden, zijn gebaseerd op de mening van twee vooraanstaande lichtdistributeurs en twee lichtontwerpers. Deze meningen zijn daarna getest in de proefopstelling van het UvAErfgoedLab.

Over het algemeen genomen behalen LEDs de hoogste score. Vanuit de financiële kant bekeken is het duidelijk dat LEDs bij aanschaf de duurste lichtbron zijn. Maar LEDs gebruiken minder elektriciteit en vergen minder onderhoud dan de huidige voornaamste lichtbronnen. Dat biedt weer een voordeel voor een lange termijn financiële planning. Zij zijn ook het meest geschikt als je een duurzame aanpak beoogt.

Motivation	Halogen	Fluorescent	Gas discharge	Fiber light	LED
Financiele gemiddelde	2,9	3,8	3,1	2,8	3,8
Duurzaamheid	2,3	3,0	3,0	2,7	4,3
Passieve conservaering	3,5	3,0	2,8	3,0	4,5
Esthetiek	4,3	2,3	3,0	2,7	2,5
Gezondheid	4,0	2,8	2,8	3,3	3,5
Nieuwe technologie	2,5	2,3	3,0	2,0	5,0
Percentage per bron	3,2	2,9	2,9	2,8	3,9
Resultaat afgerond	**3**	**3**	**3**	**3**	**4**

score van 4 respondenten
score van 3 respondenten
score van 2 respondenten

Wat passieve conservatie issues in een museumcontext aangaat, scoren LEDs ook het hoogst. LEDs hebben een minimale impact voor wat betreft de beschadiging van museale kunstvoorwerpen als je ze vergelijkt met de huidige meest gebruikte lichtbronnen binnen musea. Uit deze scriptie blijkt echter dat LEDS voor wat betreft de esthetische presentatie het laagst scoren. Dit komt echter niet overeen met de resultaten van de testen die in de proefopstelling in het UvAErfgoedLab zijn gedaan. De weergegeven resultaten uit bovenstaande afbeelding zijn aangeleverd door toonaangevende lichtdistributeurs en twee lichtontwerpers.

Door testen in de proefopstelling is gebleken dat LEDs de potentie hebben een emotionele museumervaring op te roepen. LEDS bieden, zonder filters te gebruiken, een uitgebreid scala aan kleuren. Hierdoor krijgt het museum de gelegenheid om het exact gewenste licht in te stellen. Daarom hebben LEDs de potentie meer ruimte voor de verbeelding te creëren, hetgeen weer de nieuwsgierigheid aanwakkert en daarmee indirect het bezoek kan inspireren meer kennis te verwerven.

Voor wat betreft gezondheidsissues scoort LED lager dan halogeenverlichting. Wetenschappers doen hier nog volop onderzoek naar. Ofschoon halogeen licht verspreidt waarbij we ons comfortabel voelen, hebben LEDs veel minder lux nodig om een oppervlak zichtbaar te maken. Dit wordt uitvoerig en gedetailleerd toegelicht in 3.4

Het toepassen van nieuwe technologie in musea is als beweegreden toegevoegd, omdat men vaak zegt dat het museum een afspiegeling is van onze huidige maatschappij. Als musea deze sociale rol willen blijven vervullen, kan het belangrijk zijn dat zij in toonaangevende technologieën investeren.

Kiezen voor LED implementatie is niet altijd de juiste keuze. LEDs zijn minder betrouwbaar dan andere lichtbronnen omdat LEDs een hoge Voltage gevoeligheid hebben. En het is belangrijk te vermelden dat niet iedere lichtontwerper voldoende kennis heeft van LEDs of ermee wil werken.

Het simpelweg vervangen van een lichtbron door een LED in een fitting van een andere lichtbron te draaien levert niet die kwaliteit op die LEDs verondersteld worden te hebben. De nieuwe lichtbron moet gezien en behandeld worden als een

totaal nieuwe lichtbron om zo optimaal mogelijk gebruik te maken van de eigenlijke lichtkwaliteiten.

Dit onderzoek levert vijf aanbevelingen op die professionals op het gebied van cultureel erfgoed moeten helpen om de juiste beslissing te nemen als het gaat om lichtkeuzes.

Allereerst moet deze scriptie niet gebruikt worden als een checklist wanneer men besluit in LED te investeren. Deze scriptie kan als bron geraadpleegd worden wanneer het gaat om de issues die gepaard gaan met LED implementatie om specifiek gebruikt te worden voor lichtontwerp voor een museumtentoonstelling.

Na het lezen van dit verslag en voordat u besluit om in LED te investeren voor tentoonstellingsdoeleinden, kunt u zich bezinnen op de beweegredenen waarop de missie van uw museum/ erfgoedinstelling is gebaseerd. Hecht uw instelling veel waarde aan een van de beweegredenen om over te stappen op LED dan wordt het maken van uw keuze makkelijker. Op die manier wordt uw keuze door de missie ondersteund en wordt de missie versterkt.

Vraag, a.u.b., om een screening van uw gekozen LED voordat u erin investeert. U wilt tenslotte toch niet eindigen met onvoldoende CRI ratings. Voor een screening kunt u contact opnemen met: **OLINO.org**

Content

Chapter 1

Introduction

1.1
The structure of this report

In **chapter 1 Introduction** the reasons for doing research on LED implementation for museum exhibition purposes are stated (1.1). These reasons are based on 3 aspects. The first is the current worldwide hype on LED investments in general. Second, my attempt to enlarge the awareness of the power of lighting design using LEDs under professionals in the field of cultural heritage, museums in particular. Third, the assumption that there is a correlation between a current shifting collective museum philosophy and the booming technology of LEDs.

Following chapter 1 is a short intermezzo in which a **comic strip 'What is LED?'** is presented which briefly explains the history, development and a definition of LED.

When playing with the idea of implementing LED for your museum exhibition settings it is important to have an understanding of the influence lighting design can have on your perception of cultural heritage when displayed in museum settings. **Chapter 2 Functions of artificial lighting to fit museum standards**, Therefore describes the functions and controllable properties for artificial lighting in general and LED in particular. This paragraph is based on a visit to the permanent museum exhibition 'Papiria', at the Kinderboekenmuseum in The Hague. Secondly the technical and aesthetic setbacks and benefits of LEDs, which lighting designer Joost DeBeij experienced while working on 'Papiria' are listed (2.2). This will give a realistic view on LED implementation and usage within the museum setting.

Third, lighting design for museum purposes have extra standards than for example stage lighting design has. For a museum must apply damage control when displaying its valuable artifacts. Museum standards concerning lighting based on a *compromise* or as some may say a *conflict*, between preventive conservation and an aesthetical presentation are described and questioned, this is argued and explained in paragraph 2.3.

Fourth (2.4) a comparison of LED to current leading lighting sources can be found. The results in the image below are explained in detail within this paragraph .The data accumulated for this comparison is based on the debate: Led's Talk Light that was specially facilitated for this thesis as well as through interviews per email and tests run at the testing facility.

Then in **chapter 3 Led's invest** six motivations from paragraph 2.3 are discussed on a more detailed level . This chapter is meant to give insight in the pros and cons of each motivation.

In **Chapter 4 Conclusion and Recommendation** a list of the results from this study is presented based on the motivations listed in paragraph 2.3. The conclusions and recommendations are listed as well.

Please take notice that in the back a **Glossary** has been attached to guide you through the terminology.

1.2
LED. A hype with prospects

In today's society there lies a worldwide hype amongst LED lighting. Governments, schools, cultural institutions, traffic management, etc. are fixed on investing in this innovative lighting source. Our collective society has become very aware of the importance of sustainability as well as of a growing aesthetic awareness. LED is said to have many benefits on these issues.

Although LED is a hot topic for discussion, many questions on the value of LED, for museum exhibits in particular, stay unanswered. This has resulted in uncertainty towards LED implementation for museum exhibit purposes. This thesis is meant to give some insight on why museums are uncertain when considering LED implementation and to question if their uncertainty is valid.

While observing the development of this LED- hype it has become clear that innovation often seems to have a dualistic undertone. Some people and institutions will approach innovative products such as LED progressively, while others will stay hesitant and conservative. In the end the *combination* of these two approaches may possibly define the actual value of a product.

It is found that in the field of museums this dualism on terms of innovation also exists. Both the conservatives and the progressive are able to underline their statements towards LED implementation. Researching both approaches and taking their arguments into consideration, one can observe how museums in the Netherlands have different points of view on LED for museum purposes.This research has found an answer to which extent LED lighting can be of value to the museum, its artifacts and its audiences during exhibitions.

This thesis describes the benefits and setbacks of LED investment for museum exhibition purposes viewed from different viewpoints. And emphasizes six different values one can consider as a motivation when investing in LED. These are; Greening, preventive conservation, aesthetic presentation, finance, health issues and implementing new technology.

So, if you are interested in implementation of innovating technology or intrigued by the hot discussion on LED, please, do read further.

1.3
Why LED is a topic?

I believe that far too often museums do not appreciate the effects of defined lighting design as much as they should. That is why I have chosen to write about Light. Light is what gives us sight and lighting design gives us a certain perception on what it is we see.

Lighting design is a pattern, a plot if you will, that is meant to manipulate our perception. Hence, lighting design is of great essence when creating a clear image and message during museum presentations. Well-honed lighting design can give immediate positive results in giving certain insight to museum artifacts on display, results that sometimes even trigger an emotional snare.

I choose to specifically write about LED and not just lighting design in general, because LED is the latest technology within lighting design. It has become a worldwide hype. LED is even said to be 'the light of the future'. It is a hot item on the international political agenda[2]. According to a new report by Pike Research, it is stated that the European Union is currently waiving certain incandescent bulbs. The United States will be following in 2012. This will leave fluorescent- and LED lighting as the leading lighting options[3]. It is therefore that I became quite curious and wanted to research the possibilities, benefits and setbacks of LED lighting meant for museum exhibition purposes. I started to wonder what and how LED could contribute to our collective perception of cultural heritage when used in museums.

Although manufactures state that the LED is adequate for museum purposes, many museums remain hesitant. According to many LED manufactures, such as Philips, LED technology has grown at such a rapid pace that LED lighting is now able to compete as well as complete halogen-, gas discharge- , fluorescent- and fiber lighting in museum settings taking environmental, aesthetical and financial benefits to account.

Museums have a great responsibility to current and future public to protect the quality of their collection by following high standards when it comes to lighting. It is therefore logical that they are hesitant. With all this popularity and contradistinction around LED, you start to wonder: If all manufactures say that LED is a qualified

[2] M.A. Myer and B.R. Kinzey, *Demonstration Assessment of Light- Emitting Diode (LED) Accent Lighting at the Field Museum in Chicago, IL* (USA, November 2010). This document was made possible by the following study participants: Pacific Northwest national Laboratory, U.S. Department of Energy, Field Museum of Natural History, Lighting Services, Inc. and Xicato. This document was prepared for the U.S. Department of Energy under contract. This is merely one example of many documents found on this matter. (most found on internet which are referred to later on)

[3] Amy Westervelt, explosive growth for led lights in next decade, report says Next-generation bulbs to capture nearly 50% of lighting market by 2020 (13 May 2011) http://solveclimate.com/news/20100513/explosive-growth-led-lights-next-decade-report-says (13 May 2011)

lighting source for museum standards, then why haven't more museums invested in LED? Can LEDs really live up to the museum standards and guidelines? And can museums finance it? And an even more intriguing question, to my opinion is, is it possible that LED lighting can contribute to a new collective perception of cultural heritage which is presented in museum exhibits in ways we never even thought possible?

According to Scott Geffert (LED visionary) LED has a lot of potential;

"There are lighting designers out there, with a vision on LED for museum lighting design". Once manufactures and museum staff start corresponding with these visionaries, LED has a chance of becoming a great advantage to museum presentations"[4].

1.4
Museum philosophy

Another reason for this specific research is based on my own idea on the correlation between a current collective museum philosophy and the innovating technology of LEDs. Museum philosophy has been changing in an interesting direction. In the past, museums proclaimed to present you the truth and nothing but the truth. As societies have become more diverse, museums have been forced to look more critical at their proclamations. Generally speaking, museums both progressive and conservative institutions, have learned to acknowledge the fact that when presenting their artifacts it is never completely objective even though the information gathered and presented is based on scientific research. Another realization museums have come across is that the aesthetic form in which the artifacts are presented influences the opinion on the topic. Lighting is part of this aesthetic form.

This has led museums to change their philosophy on information distribution. Also, generally speaking, museum staff has become more aware of what they are displaying and what effect it may have on its audiences. Nowadays museums choose to share different points of views and use a more open- source playful approach-philosophy. This new philosophy indicates a strong necessity to share information on a more international, virtual and intercultural level. People today want to find out the truth for themselves.

This new awareness calls for a new approach in lighting design within museums. If a museum has become more aware of the effects that their artifacts have on their audience then they should also have a greater understanding and appreciation of the power of lighting design using LEDs. LEDs have the capability to create a very subtle theatrical ambiance in ways no other lighting source can match. This theatrical subtleness has proven to make the museum audience more at ease and therefor gives them the opportunity to facilitate their curiosity towards the exhibit as a whole.

[4] Interview with Scott Geffert by Sjoukje Kerman in the testing facility; Led's Talk Light at UvAErfgoedLab on 19 February 2011.

1.5
Research

When considering investments in LED for museum purposes two questions came to mind. First of all to which extent LED lighting can be valuable to a collective museum experience. Secondly how LED might influence our collective perception of cultural heritage as a whole.

Goal:
To offer professionals in the field of cultural heritage, museums in particular, an understanding of the effects LED has to offer its artifacts and its audiences during museum exhibitions.

Research Question:
Is it true that LED lighting can be a valuable asset to an innovative and vivid collective museum experience?

1. What are LEDs?

2. What are the functions and controllable properties for artificial lighting in general and LED in particular?

3. How do LEDs compare to current leading lighting sources in museums?

4. How do lighting designers, LED manufactures and distributors, museum staff and exhibition designers look upon LED?

5. How do museums that use LED view their investments?

6. What can be recommended to museums on future LED implementation?

Methodology:
First it was essential to find out exactly what LEDs are. In an early stage I noticed that the technology of LEDs is still growing at such a rapid pace that most books I read, even those written in 2008, where out- dated. Therefore I decided to search The internet for reliable and current sources. I came across a discussion panel on LinkedIn[5] for professional lighting experts and found many different websites, articles and documents all written between 2010 and the present. These sources gave information on investing in LEDs as well as the effects of LED lighting in general. The information I found gave a broad understanding of the qualities and malfunctions of LED. I began to understand what LEDs actually are. I found what the technical and aesthetical setbacks and benefits are when using LEDs in general. But I soon realized that the information I found was not specific enough for museum purposes. For museums have very strict standards when lighting its fragile and unique artifacts.

5 http://www.linkedin.com/groupAnswers?searchQuestions=&fromEmail=&gid=3003087&trk=eml-anet_dig-h_gn-tpd-cn (29 May 2011)

When researching the effects of lighting design I found it is desirable to see the results first hand. I felt the need to experience the effects of LED lighting on museum artifacts myself. I also wanted to understand the backbone of the standards that museums use when presenting their artifacts to the public. Therefore I singlehandedly organized a testing facility. This testing facility was located in Amsterdam in the UvAErfgoedLab, using three different brands of LEDs and the museum's current halogen lighting source and six artifacts. I tested the LEDs based on its UV and IR radiation and CRI ratings[6]. It gave me a detailed understanding of the effects and complications of the lighting sources and design and gave insight in the guidelines that museums currently use.

At first I only had access to one brand of LEDs. I did not realize that the quality of LEDs differed so much per brand. I thought that my test was adequate. This changed when I invited a reknowned lighting designer
(Hans Wolff) for an interview in the testing facility. He said he was only interested in the interview if I had a certain brand, which I did not have. I immediately searched The internet to find if this specific brand was available in The Netherlands. Luckily there is one supplier and he was able to deliver three of his LEDs that same day. I called Hans Wolff back and told him his wishes had been met. The third brand of LEDs was also added to the test after an interview, this time with Taco DeBie
(exhibition designer).

During the tests at UvAErfgoedLab I interviewed a total of eight professionals. I interviewed three lighting designers. I wanted to understand which setbacks and benefits they have come across using LED in museums based on their expertise and experience. I found that they had all been working with other leading lighting sources for over twenty years and therefore where not well accustomed to working with LEDs. I felt the need to interview a young lighting designer but no one had time. Therefore I interviewed a visionary on LEDs for museum purposes, Scott Geffert, to see what one can possibly expect of LED lighting design in the future. We tested his own LEDs and he showed me how one can tune the color, color intensity and color temperature all within one system[7] to create a specific effect. I have made a short video of this interview that will be presented during my presentation in June.

After speaking to designers and a visionary I wanted to accumulate an understanding of the guidelines that museums use to protect their artifacts on display and interviewed Marysa Otte, (staff member of the Van Gogh museum on (preventive-) conservation and author of one of the books I read). Only once we experimented with the artifacts and lighting sources in the testing facility, did I really understand the museum standards for lighting design.

After gaining an understanding of museum standards I wanted to speak to LED manufactures. I wanted to find out to what extent current LEDs are actually put to use and to understand which setbacks and benefits they say LED holds. They also gave me information on the differences and similarities LED has compared to current leading lighting sources for museum exhibitions.

My last interview was with the artist that had contributed two of his paintings to the testing facility. One with mainly warm colors (particularly red) and one mainly with

[6] See the Glossary
[7] See the Glossary

cold colors (shades of blue).I wanted to have a clear understanding of how much influence lighting has on his art and how he would like his art to be lit. I was interested in finding out where he thought that his paintings where being highlighted and where he felt that his art was being manipulated too much. He shared his opinion when I lighted his paintings with LEDs.

When I heard I was able to organize a testing facility I also decided to organize a debate. To attract people to the debate I created my own website[8]. This debate was meant to share questions and discussions on LEDs for museum purposes, with a bigger group of professionals. I wanted to see them discuss LEDs on a professional level instead of just answering questions from a layman (me). I felt I could gather more knowledge than during an interview. It allowed me to accumulate an understanding of how each group of stakeholders stands towards LED implementation for museum exhibition purposes and how they communicated with one another. The target groups where: museum staff, lighting designers, exhibition designers, LED manufactures and artists. All of these target groups where represented except for the exhibition designers. I came up with the following three topics of debate:

- Current lighting sources in museums vs. LED
  What do you base your choice on?
- Museum Artifact vs. Museum audience
  How can one combine both needs?
- Artist vs. Lighting Designer
  A thin line between lighting an object and interfering with its content.

Through this debate I was able to analyse and accumulate an understanding of the current discussions that the stakeholders in the Netherlands have with one another. All three topics where presented by professionals. The debate created a safe atmosphere where all parties could openly speak of the problems and benefits of implementing and usage of LED for museum propose[9].

Once the debate and the testing facility where behind me I wanted to research the functions and controllable properties of lighting design in general using LED in particular for museum exhibitions. I read books on theatre lighting design and on architectural lighting design. For I could not find specific guidelines or theories on museum lighting design that could be suitable from a scenic lighting property. Once I had a broad understanding of lighting design in general I wanted to experience a museum exhibition that used LED as the only lighting source. I paid a visit to the Kinderboekenmuseum in The Hague to see their permanent exhibition ‘Papiria’. I also interviewed their staff member on preventive- conservation. I wanted to know if the museum is satisfied with the results due to the LED lighting design.

[8] http://www.wix.com/sjoukjekerman/cultuurbelichting
[9] Throughout this report photos that where taken during the debate are enclosed.

Intermezzo

Comic: What are LEDs?

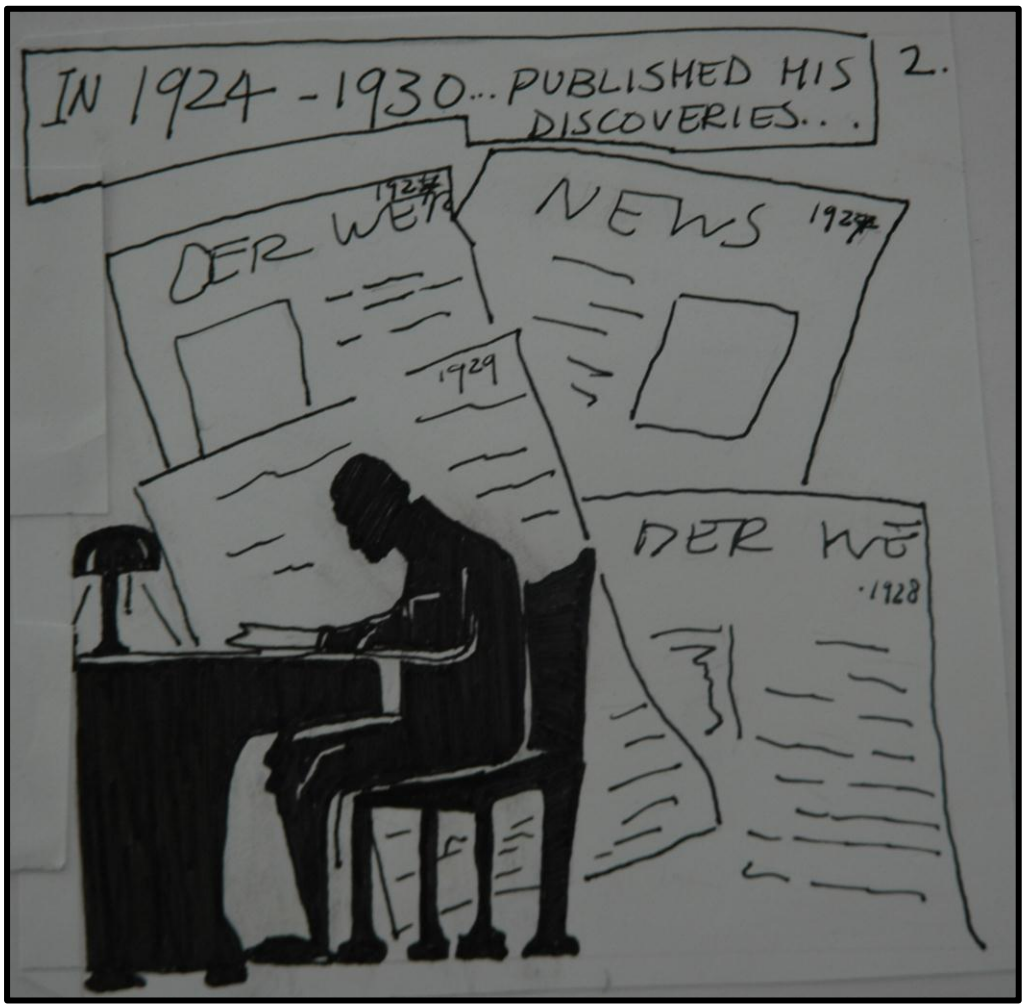
[10]

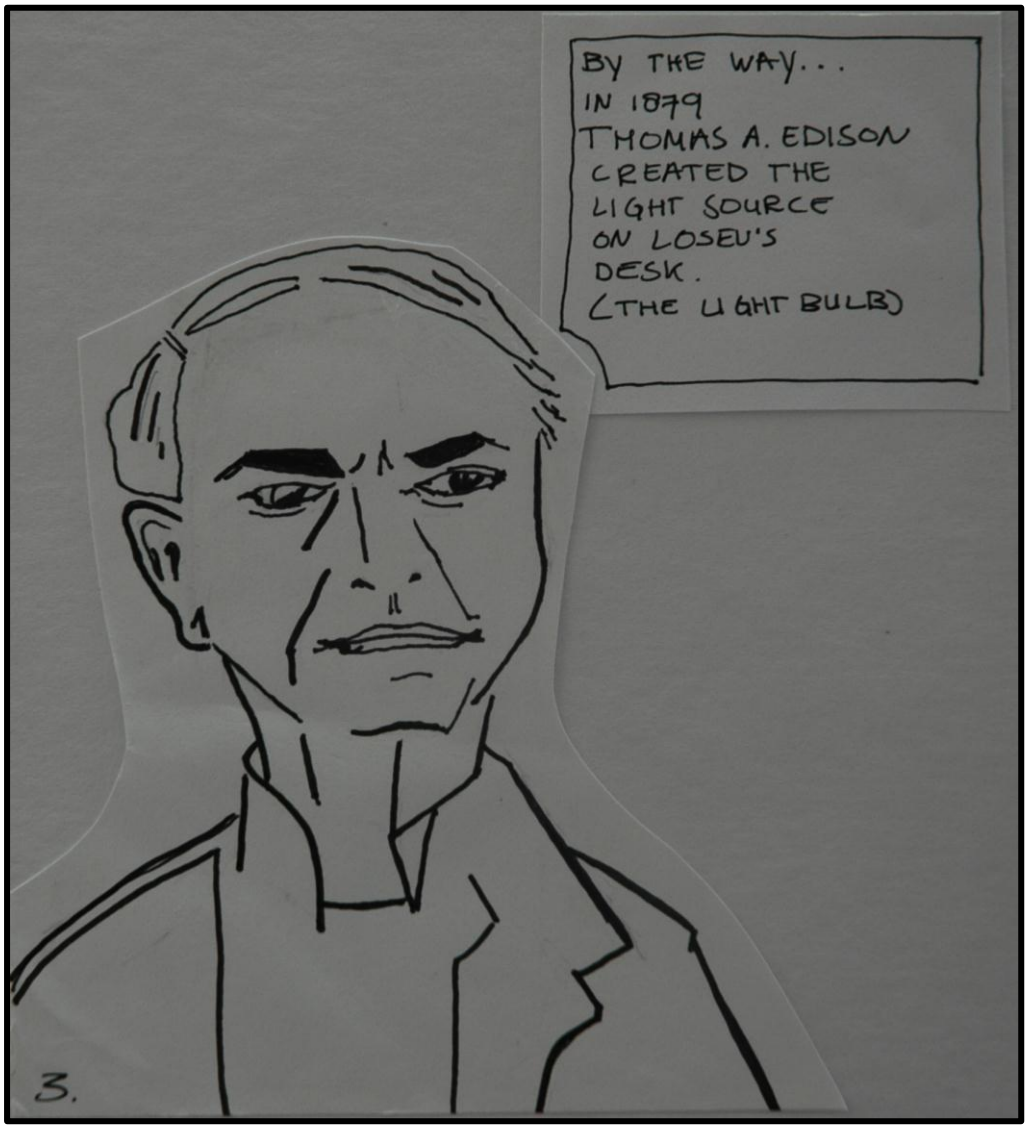
A brief history, development and a definition of LED.

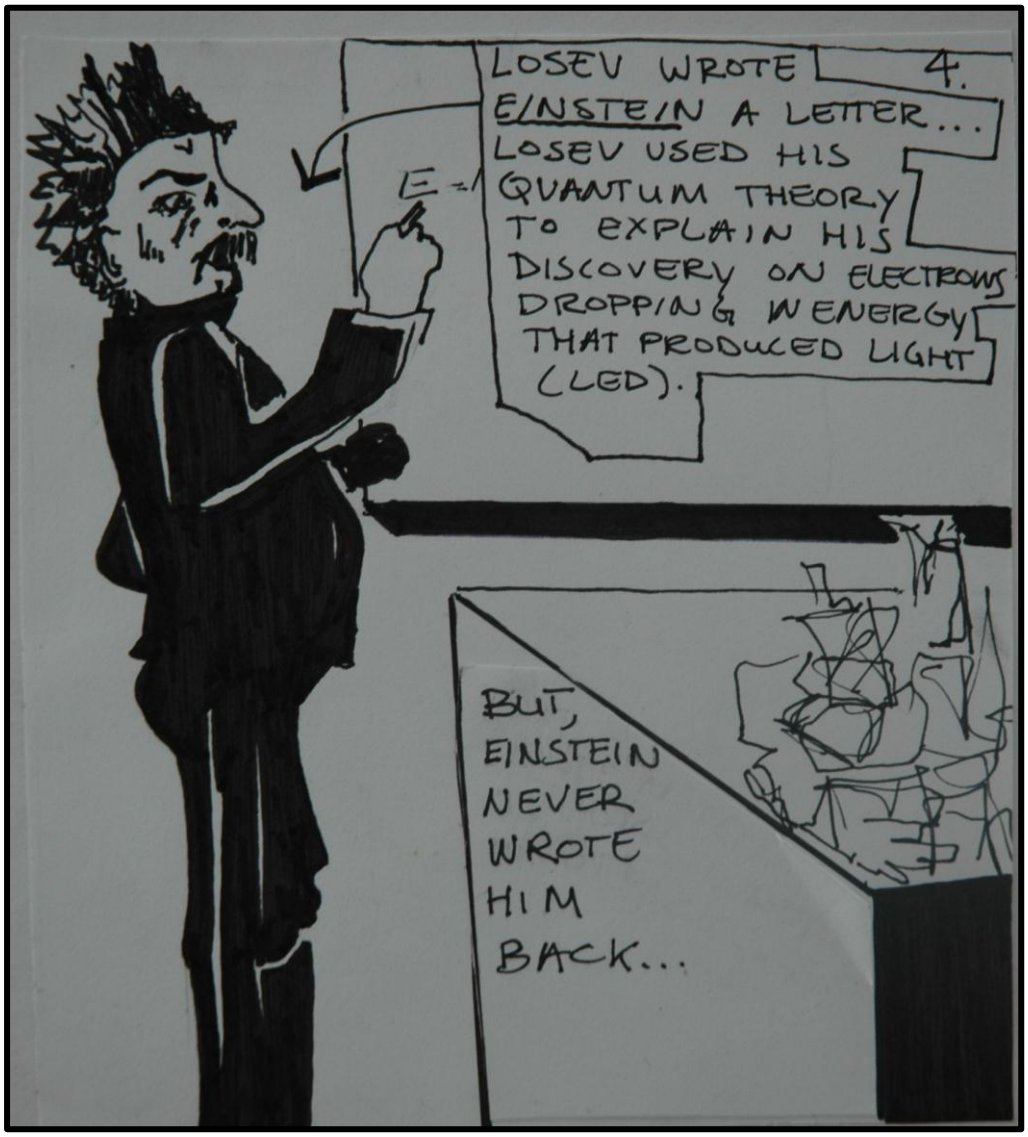
[10] This comic strip is based on information gathered through a couple of sources:

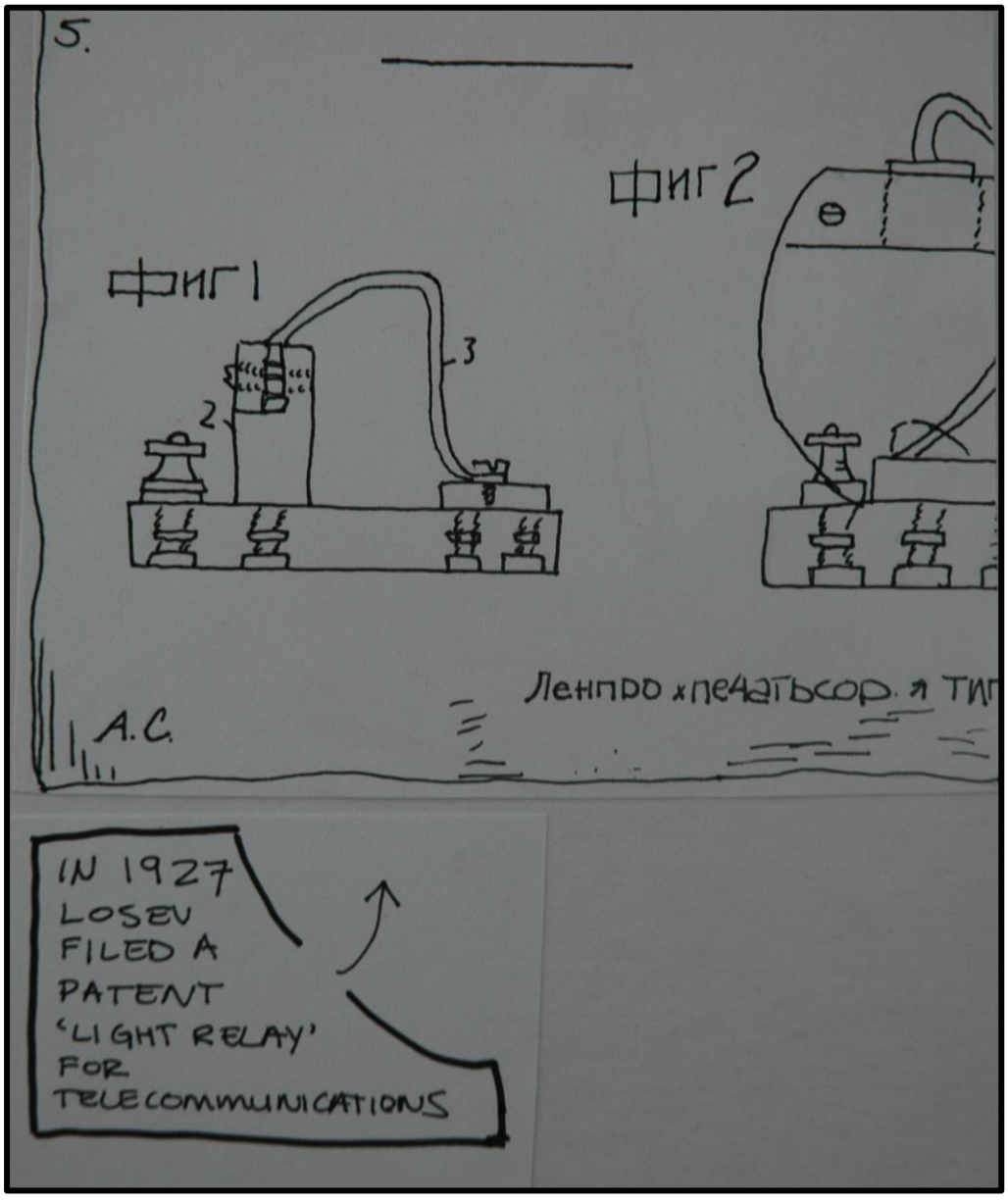
- Nikolay Zheludev, 'The life and times of the LED- A 100 year history', Nature Phontonics (April 2007)
- Joseph J. Carrand and Tony van Roon, Light Emitting Diode History (2010) www.sentex.ca/~mec1995/tutoral/leds/leds.html (April 4 2011)
- My-Led-Passion.com/Nick-Holonyak.html (April 2011)

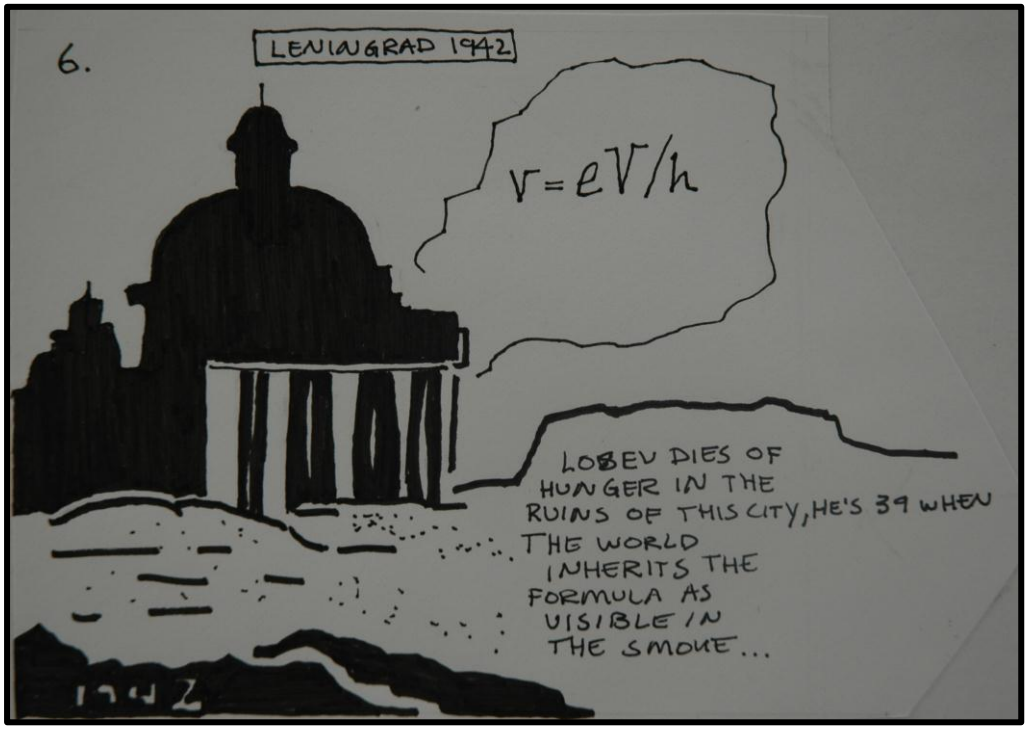

RUSSIAN
In 1923...
OLEG LOSEV
...INDEPENDENTLY CREATED THE FIRST LED.
1.

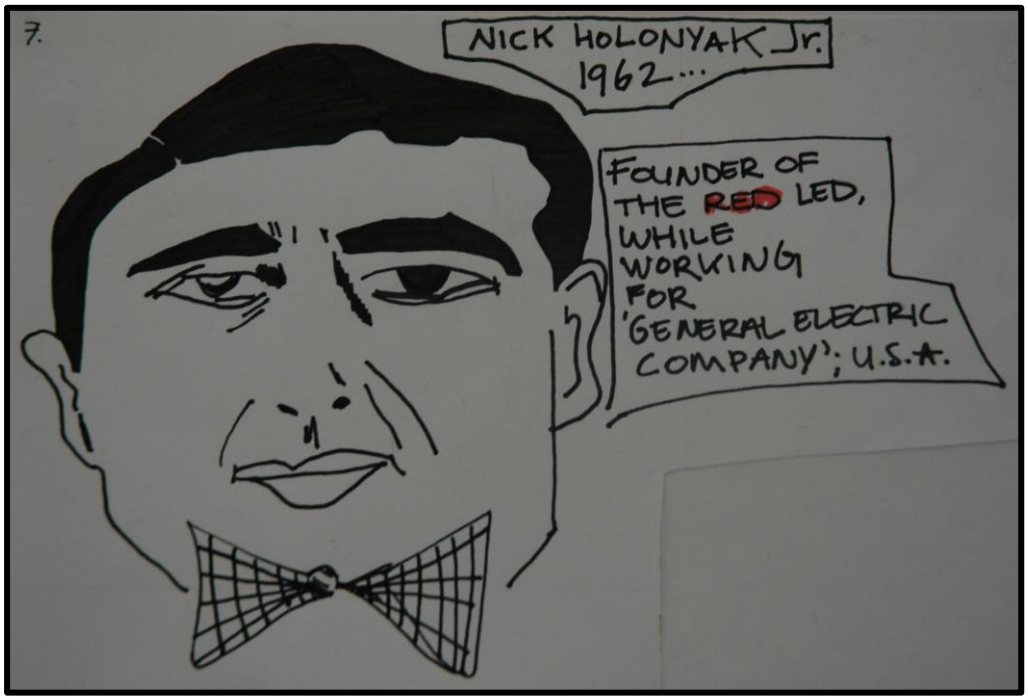

IN 1924 - 1930... PUBLISHED HIS DISCOVERIES...
2.
DER WELT
1929
NEWS
DER WE
1928

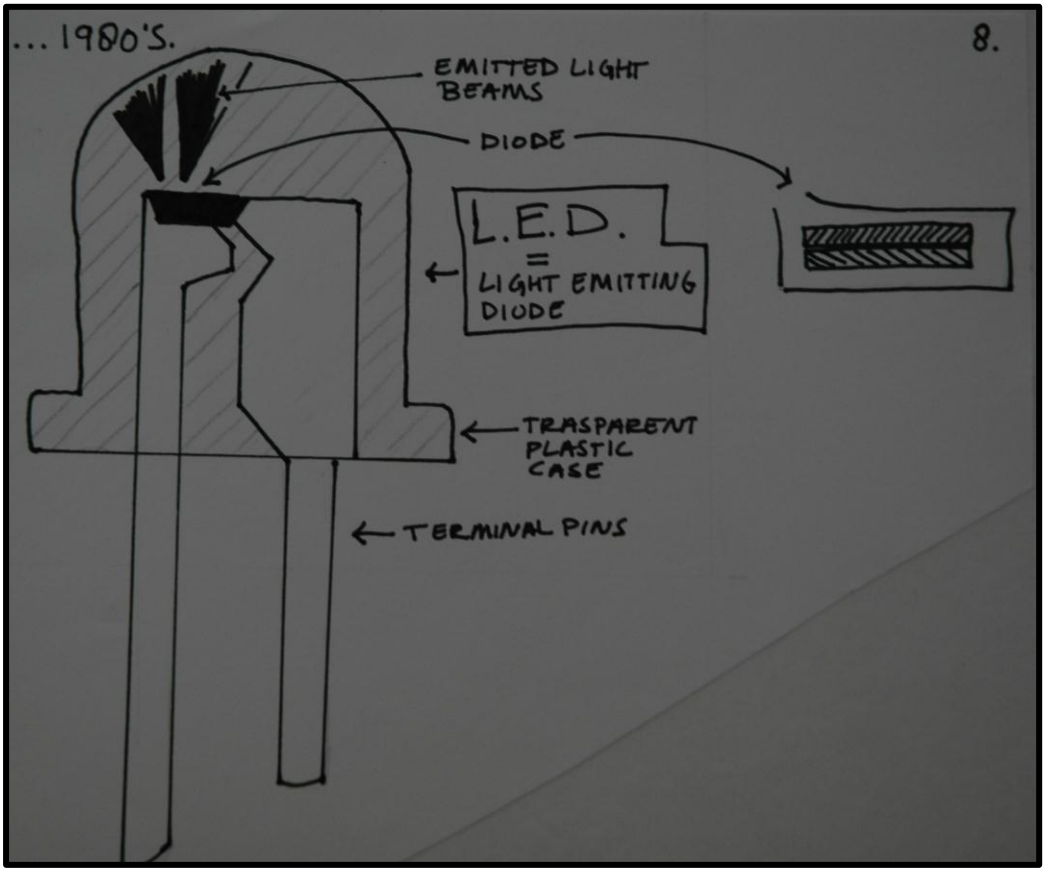

BY THE WAY...
IN 1879
THOMAS A. EDISON
CREATED THE
LIGHT SOURCE
ON LOSEU'S
DESK.
(THE LIGHT BULB)
3.

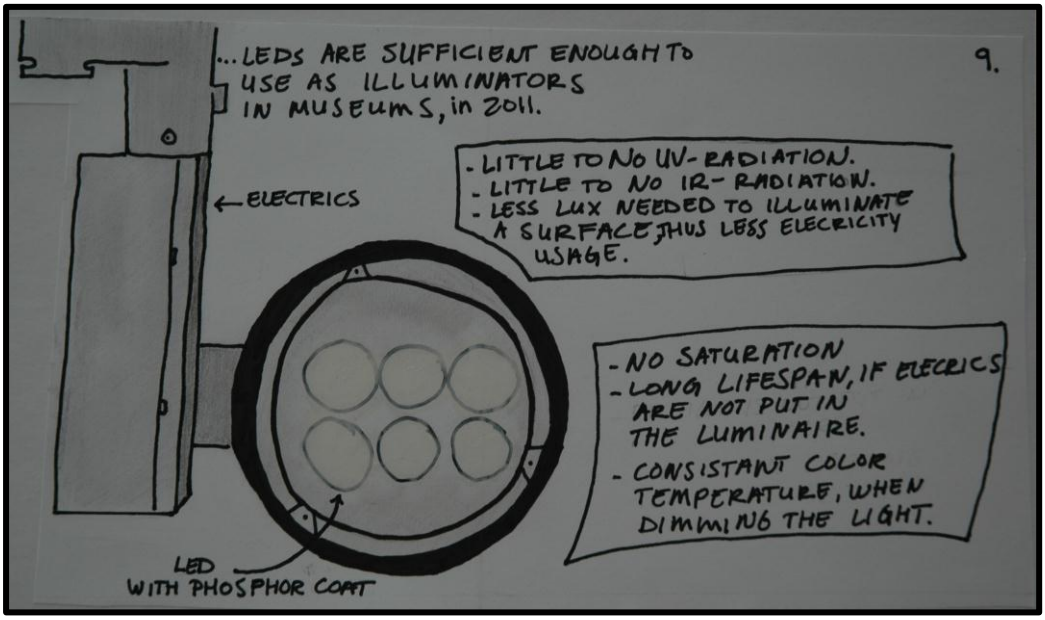

4.
LOSEV WROTE EINSTEIN A LETTER...
LOSEV USED HIS QUANTUM THEORY TO EXPLAIN HIS DISCOVERY ON ELECTRONS DROPPING W ENERGY THAT PRODUCED LIGHT (LED).
E=
BUT, EINSTEIN NEVER WROTE HIM BACK...


5.
фиг 2
фиг 1
3
2
Ленпро х печатьсор. я ТИ
A.C.
IN 1927
LOSEV
FILED A
PATENT
'LIGHT RELAY'
FOR
TELECOMMUNICATIONS


6.
LENINGRAD 1942
r=eV/h
LOBEV DIES OF HUNGER IN THE RUINS OF THIS CITY, HE'S 39 WHEN THE WORLD INHERITS THE FORMULA AS VISIBLE IN THE SMOKE...
1942


7.
NICK HOLONYAK Jr.
1962...
FOUNDER OF THE RED LED, WHILE WORKING FOR 'GENERAL ELECTRIC COMPANY'; U.S.A.


... 1980'S.
8.
EMITTED LIGHT BEAMS
DIODE
L.E.D.
=
LIGHT EMITTING DIODE
TRASPARENT PLASTIC CASE
TERMINAL PINS


...LEDS ARE SUFFICIENT ENOUGH TO USE AS ILLUMINATORS IN MUSEUMS, in 2011.
9.
ELECTRICS
- LITTLE TO NO UV-RADIATION.
- LITTLE TO NO IR-RADIATION.
- LESS LUX NEEDED TO ILLUMINATE A SURFACE, THUS LESS ELECRICITY USAGE.
- NO SATURATION
- LONG LIFESPAN, IF ELECRICS ARE NOT PUT IN THE LUMINAIRE.
- CONSISTANT COLOR TEMPERATURE, WHEN DIMMING THE LIGHT.
LED WITH PHOSPHOR COAT

Chapter 2

Functions of artificial lighting to fit museum standards

Without correct lighting one cannot see, cannot perceive and will not learn…[11]

[11] Just a thought I had.

Introduction

An estimated 80 to 85 percent of our daily impressions are based on visual sense[12]. Light makes this possible. It is therefore fair to state that light manipulates the perception of our surroundings. When creating such a design it is important to know what the functions and controllable properties for artificial lighting design are which museums can use to facilitate a specific museum experience.

This chapter is meant to give you an understanding of the power and fragility which lighting sources and lighting design effect your exhibit experience. Although there are different types of lighting design, there isn't a specific guideline-theory developed for museum lighting, specifically for LED usage. Therefore this chapter is based on two different types of lighting design;

- Architectural lighting design
- Theatre/ stage lighting design

In architectural lighting design one speaks of three lighting properties. Ambient, Accent and Scenic lighting[13],[14]. With these three aspects of lighting design one is able to tune the light to a specific goal. This chapter focuses on scenic lighting, for within the scenic lighting properties LED has much to offer.

Architectural Scenic lighting design has quite similar features compared to theatre lighting design. Using the basics of theater lighting standards, *Papiria*[15], an exhibit designed with LED, has been analyzed and described to illustrate the value of lighting design using LED.

The reason that this analysis is based on a theory of stage lighting design has to do with the fact that most lighting designers start their career within the walls of the theatre. They have worked within a black box to light a stage, actors and décor according to certain standards for decades. These standards work for the theatre, as well as to a certain extent, for museum exhibits.

Some museums have let loose of the idea that they can and therefore must create an objective exhibit. They have accumulated an awareness that there is never but one side to any story or artifact. This has lead these museums to facilitate a more theatrical approach in museums exhibitions. By triggering the audiences imagination museums such as het Kinderboekenmuseum in The Hague, believe that their audiences will search for the answer themselves.

---

[12] Lighting & Productivity, http://lightingdesignlab.com/articles/ltg_prod/ltg_productivity.htm (12 April 2011)

[13] See the glossary on page … for the meaning of these terms.

[14] Aksel Karcher e.d., *Light perspectives between culture and technology* (2009, Erco GmbH, Ludenschied)

[15] http://www.kinderboekenmuseum.nl/Tentoonstellingen/Papiria.aspx (24 may 2011)

A detailed description of the controllable properties that were implemented or neglected by Joost DeBeij (lighting designer) and Taco de Bie (exhibition designer) for the permanent exhibition 'Papiria' in the Kinderboekenmuseum in The Hague is stated in the following pages (2.1).

Having accumulated knowledge on the functions of lighting design for museum presentation purpose alone, is needless to say not enough. Due to the fragility and rarity of the artifacts on display, museums must stick to certain norms/ standards, and therefore it is even more complicated to make a museum lighting plot than it is a lighting plot for a play.

Therefore the *conflict* of museum standard requirements concerning preventive conservation versus the demands for effective presentation are outlined (2.2). Dealing with presentation and preventive conservation standards for museum artifacts , museum staff and the lighting and exhibition designers always balance on a thin line. Although museums have great awareness of their responsibility to protect their collections, it is unthinkable for contemporary museums to neglect the needs and health issues of its audience. Lighting design defines the quality of visibility of the artifacts and influences therefore the well- being of the audience.

To have an understanding of the possibilities lighting design offers *and* to have taken notice of the constraints of the museum standard requirements and that of the lighting designer, only then, can you choose which lighting source will best suit the needs of your collection and your audience.

The benefits and setbacks of LED are compared and analyzed with current leading lighting sources in museums in The Netherlands in the paragraph 2.3.

2.1
Lighting Functions and its controllable properties

- based on the exhibit Papiria

This subchapter describes a theory of theatre lighting design, adjusted to fulfill the needs of museums for the purpose of this study. To be able to give advice on when LED implementation is beneficial for museum purposes it is important to have some knowledge of the functions and controllable properties of lighting in general using LED in particular.

Adolphe Appia (Switzerland 1862- 1928), a visionary on nonillusionistic theatrical practice, proclaims that artistic unity is the fundamental goal of a theatrical production[16]. . It is possible that his theory can be applied to museum exhibits. Both museums and theatre create another world for you based on facts and fiction meant to enforce:

- Knowledge
- Emotional experience
- Inspiration

The controllable properties mentioned below, are all subject to *unity*. Lighting plots have a great responsibility to fulfill. It can and therefore must bring a museum exhibit to life by creating *unity* in the exhibition space as well as to the storyline

The beauty and fractiousness of exhibition lighting design, has a lot to do with a certain dependence on four aspects of the exhibit. Lighting designers must work with:

- the museum artifacts on display
- the three-dimensional moving audience
- the perpendicular décor designed by the exhibition designer
- the given circumstances such as the floor, walls and ceiling, possible daylight and emergency exits.

In a theatre one has different aspects to work with:

- the perpendicular décor and costumes.
- the three dimensional moving actors
- the stage

The greatest difference between stage theatre lighting and museum lighting design is the position and role of the audience. In theatrical lighting design one can forget about the audience while creating a plot. This means that a stage lighting designer can direct every second of his work with little to no unexpected interference from the audience. It also means that the positioning of the lighting sources are not dependent on the positioning of the audience. In a museum one must make sure that

[16] Oscar G. Brockett and Franklin J. Hildy, *History of the Theatre* (Allyn and Bacon, USA: 2003)413-417, 426

the positioning of the lighting sources does not create a glare, shade or blindness for the audience while they look at the artifacts on display.

Their colors, styles, mood, message and given circumstances (= amount of space, time of day, amount of people visiting, etc.) are all to be taken into consideration while creating a lighting plot. When the compositions of these aspects do not form a consistent image, a lighting designer stands for an almost impossible task.

According to J. Michael Gillette, one may divide stage lighting and thus for this study also exhibition lighting's controllable properties into eight categories[17]. Each category is of great importance. But it is yet once these properties are *combined and honed*, that a play or exhibit comes to life. The controllable properties of artificial lighting design are stated in the following paragraphs.

Photograph of Platvorm[18]

Walking down the winding stairs of the museum, I find myself in a neutrally lit spacious hallway. It has grey floors and white rounded walls with gaps in them. The walls have a stairs like functionality. You can climb these stairs and take books out of the gaps and just sit there and read. It feels as though I have walked into another world where books are sacred. So, to what extent, does lighting play on this effect?

Looking directly above there are holes in the ceiling. Parts of the ceiling are very high. Through these ceilings, daylight indirectly floods into the exhibition space. Looking at the lower ceiling a few ambient light sources are hanging down, just to give the audience enough Lux to read and get around. Inside the gaps, in the white

[17] J. Michael Gillette, *Designing with Light An Introduction To Stage Lighting* (The McGraw-Hill Companies: 2001)

[18] Bureau for exhibition design in Amsterdam, http://platvorm.nl/

rounded walls, you see warm colored, gold straw like accent lighting. It really draws your attention. This accent lighting creates the effect of the sacredness of these books. They are the only artifacts in this space that have accent lighting and that have this warm colored light.

Photograph of Platvorm

Color is one of the eight properties that Joost DeBeij miraculously put to use in every space throughout this exhibit. Each space had different colors that created a mood and theme to it. One room, for instance was dedicated to the topic of love. This room had deep warm red lighting. This matched the interior design which was as red as the lighting. It is typical for LED lighting to flatter and accentuate colors in a space by using the color of the light to match the color of its surroundings.[19]

Photograph of Platvorm

From this warm atmosphere you can walk into a room where adventure, mystic and spookiness are the theme. This room is filled with a dark shade of magenta on the ceilings and floor and has dark shades of orange and green on the rims of the floor and shelves. The colors that were selected affect my mood and create scope for the imagination without steering me to much as on what to focus on when walking around. By using such a broad scale of colors this exhibit gives me energy and boosts my interest to take time and look around. But it is not the colors alone that created this effect.

Diffusion is another important ingredient for establishing a well-honed lighting design. This is when light is equally divided in all directions upon a surface. DeBeij used this quality throughout the entire exhibit. Each artifact on display was visible without standing out of the crowd, so to say. It is comparable to a model for example for lipstick, who has a pimple on her chin. The pimple may be visible but the accent is on her entire face as not to put emphases on the deformation. By using the craft of diffusion all on display is in balance.

Direction of the light sources was also taken into a lot of consideration. The light sources where hung at certain angles to make sure that glare and being blinded by

[19] This information was accumulated during a test done in the testing facility at the UvAErfgoedLab.

the lighting never occurred. One knows that this is well done when you do not notice where a light source is coming from.

Photograph of Platvorm

Form is another property defined in J. Michael Gillette. The form of light can be manipulated by the armature the light is put in. In one of the spaces in the exhibit gobos[20] where implemented into the lighting sources to give the illusion of walking through a forest where the leaves had transformed into letters. Other than the use of gobos the form of light was not manipulated.

Motion is a fifth property known to stage lighting. Motion can be created by moving the luminaire (the fixture that holds a light) around but is rarely used in exhibition lighting. This has a lot to do with the fact that in a theatre the audience itself does not move from one place to another. In an exhibit the audience constantly is on the go. DeBeij was smart not to use this lighting property.

[20] See the glossary.

Photograph of Platvorm

Intensity is a sixth property. This property is determined by the amount of voltage and watt distributed through a lighting source from a electricity output. The intensity throughout the exhibit was quite consistent. I believe that amount of Lux per luminaire did not change during my visit.

Luminousness is another property of importance. Luminousness is the quality of light. The light sources and its chosen lamps are essential for quality lighting. DeBeij used warm and cold colored LED's simultaneously. Overlapping colors created a fuller look. And added depth to the storyline throughout the exhibit. The effect these lamps and light sources tend to have is that the light is clear, sharp and bright.

Photograph of Platvorm

Last but not least is the controllable property of **frequency**. This is determined by the rhythm of the colors or intensity of the light upon a surface. The lighting did not have a rhythmic style to it nor was the amount of light different throughout the exhibit. Frequency plays but a very small part in this exhibit. The effect of not using much frequency, is that the atmosphere was very calm and comfortable and very clear and vivid.

Photograph of Platvorm

These eight lighting functions have been divided into three categories to fulfill the needs of museums for the purpose of this study:

- Composition
- Style
- Functionality

Composition

Composition of the exhibition space, to my understanding, is the essence of lighting design. One works hard to create a unity of art forms presented in a space. Lighting functions defined by J. Michael Gillette which I include to the composition are **composition of the stage/ exhibition space** and ***setting a mood.*** Setting a mood is an emotional composition and the composition of the stage/ exhibition space is more of a visual composition. These two functions combined create a message.

The frequency, color, intensity and luminousness used for **setting a mood** and **composition of the exhibition space** where used to a great extent. Throughout the exhibit each space had a theme, a message. The effect is that the audience understands how to *read* this scene/ messages. It is clear what the exhibit and its storyline have to share. The composition of the stage/ exhibition space has a lot to do with the **coloring of the stage**. The reason this is attractive is simple. The color compositions of the interior design, the artifacts themselves in combination with the themes are very consistent and thus, did form unity. LED has a way of creating very vivid colors.

Style

Besides the coloring of the exhibition space it is vital to **establish a style** when creating a composition of the exhibition space. This is well honed. The brightness, direction, motion and the frequency of intensity where consistent throughout the entire exhibit. Although the colors changed dramatically in every space DeBeij kept one aspect the same in all properties. In each space one will find a few gaps in the walls filled with books. These books are lit with LED warm white lights.

Functionality

To establish a style and to be able to color and compose a unity in an exhibition space, one must carefully choose how to use the other four functions of exhibition lighting. These four functions I have collated under the term *Functionality*.

Selecting visibility is one of the four. This exhibition space is large and can be lit in many ways.

This function of selecting visibility goes hand in hand with another function; **focusing attention**. The attention to detail can easily be manipulated by light. I did not see a distinct example of this in the show. There were, to my knowledge, a few interesting possibilities put to use, such as the gaps in the walls with the books.

A third function united with this category of Functionality, is the **shaping space and form**. This function is created by all controllable properties used together. Everything was nicely visible. The three dimensional forms where revealed by the angle and color of the lights.

The last of the Functionality functions is; ***establishing given circumstances***. Much work has been put into creating a visual composition of creating drama and inviting the audience to take time to hang out.

2.2
A lighting designers experience with LED for *Papiria*[21]

Dealing with LEDs in a museum setting there are certain setbacks and benefits that each lighting designer will come across per lighting source. His approach is to create an aesthetic unity within the exhibit whereas the museum conservation staff is more focused on sustaining the quality of the artifacts on display. Each lighting designer uses his instruments (lighting sources and the given circumstances) differently. Joost DeBeij came across the following when he created a lighting plot for Papiria using only LED.

Technical Setbacks

For Papiria RGBW LEDs (red, green, blue and white colored light) were at hand. A major setback when working with this type of LED is that the consistency of these colors is not stable. One must emit each light source to create unity of the color of a space.The result is that when lighting a wall with one color using different luminaires a definite color difference was visible. Therefore Debeij had to adjust each luminaire separately to facilitate a consistent color range and had to implement a certain lens on each luminaire. This cost a lot of time than one would have if he had access to white LEDs.

Another serious setback was the fragility of the LED regarding the electricity malfunctions. In the building where Papiria is staged there are often little failures in the wires. The LEDs are very vulnerable to this, for they easily flicker once the LED is dimmed. With halogen lighting this would not have been an issue. To undermine this problem DeBeij had to program the lighting around the fragile moments in the electricity system by working around the dim curve. Although DeBeijs solution did indeed work, it cost him more time and energy than he is used to when working with halogen lighting.

Aesthetic setbacks

Although DeBeij specifically chose to work with RGBW LEDs over halogen lighting he has found this specific LED type not perfect. He has come across problems in the vitrines concerning the color authenticity and visibility of materials. He plans to work on getting another type of LED in these vitrines in the future.

Another setback DeBeij experienced is the fact that LEDs never saturate. This resulted in the fact that the people walking through the exhibit also changed color as they walked. If he had foreseen this issue he would have implemented white LEDs.

[21] The information in this subchapter has been accumulated through email correspondence with Joost DeBeij in May of 2011.

He says that it can also be a benefit, but using the light to change the color of the audience must be a choice. He would rather have not had this as a result.

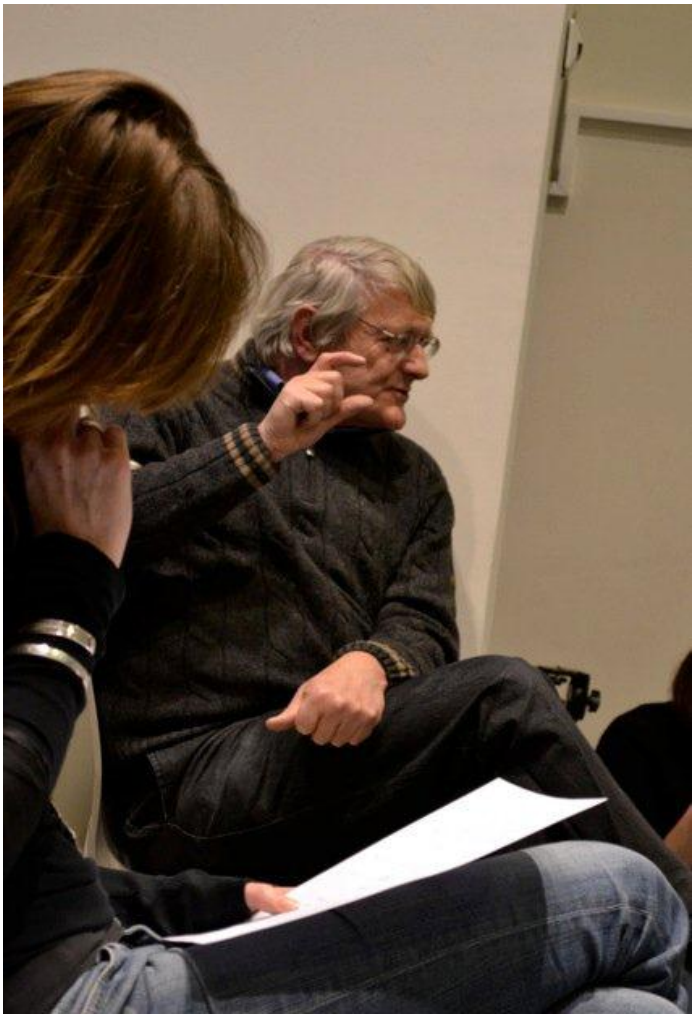
Benefits

According to DeBeij LEDs are beneficial to creating a theatrical, lively museum experience. Due to the fact that LEDs are non- saturating lights, that can create color without use of filters and that the lighting is sharper.

2.3
Museum Standards

In museums a lighting designer cannot only focus on the aesthetic well- being of the space and the artifacts on display. For he is dealing with very fragile often expensive and unique artifacts. The artifacts on display must be well preserved. A museum has three main responsibilities of which a lighting designer must take notice:

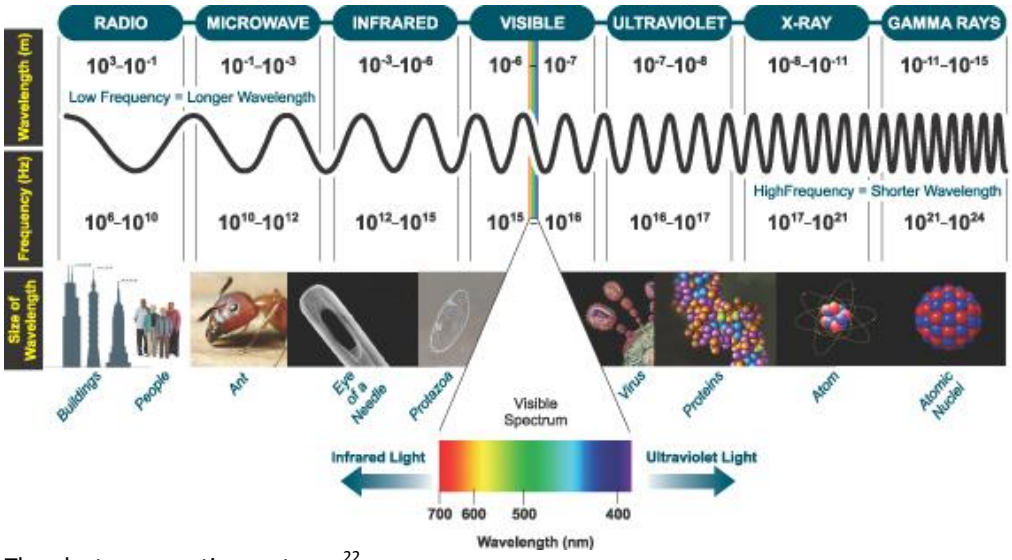
- Collections management
- (Preventive) Conservation
- Presentation



Pieter Keune (Lecturer at the Reinwardt Academy) describes museum guidelines for lighting design during the debate; Led's Talk Light, February 18, 2011.

Taking the above into consideration this chapter gives a description of the benefits and setbacks of LED when dealing with damage control (preventive conservation) standards for museum artifacts and museum audiences. One must stick to specific guidelines and standards in museum settings. This chapter explains the meaning of these standards and guidelines for museum lighting that where implemented in the 1960's. But first, one must know a bit more about what light is.

Light is part of the electromagnetic spectrum (see the image beneath) and is the only part visible to the human eye. It is also called the visible spectrum, and allows us to see our surroundings, see its depth, shape, color and material. On the outskirts of the visible spectrum we find infrared (IR) and ultraviolet (UV) radiation. Although we cannot see this radiation, we are able to see the effect that this radiation has on museum artifacts.



The electromagnetic spectrum.[22]

Three of these seven forms of radiation are said to have damageable effects on artifacts. These three are:

- UV (ultraviolet radiation)
- IR / heat (Infrared radiation)
- The visible spectrum / light intensity- lux

22

http://www.google.nl/imgres?imgurl=http://www.andor.com/image_lib/lores/INTRODUCTION/Introduction%2520(Light)/IntLight%25201%2520Small.jpg&imgrefurl=http://www.andor.com/learning/light/&usg=__guoHC72yxyVE4DrHqLp_IFPi1tI=&h=308&w=570&sz=148&hl=nl&start=16&zoom=1&tbnid=FuGLJE6n2EoKKM:&tbnh=79&tbnw=146&ei=h__QTfzyK5Ce-wbFrvXqCQ&prev=/search%3Fq%3Delectromagnetic%2Bspectrum%26hl%3Dnl%26sa%3DX%26rlz%3D1R2ACAW_nlNL378%26biw%3D1345%26bih%3D561%26tbm%3Disch%26prmd%3Divns0%2C374&itbs=1&iact=hc&vpx=341&vpy=158&dur=90&hovh=165&hovw=306&tx=171&ty=86&page=2&ndsp=18&ved=1t:429,r:2,s:16&biw=1083&bih=544

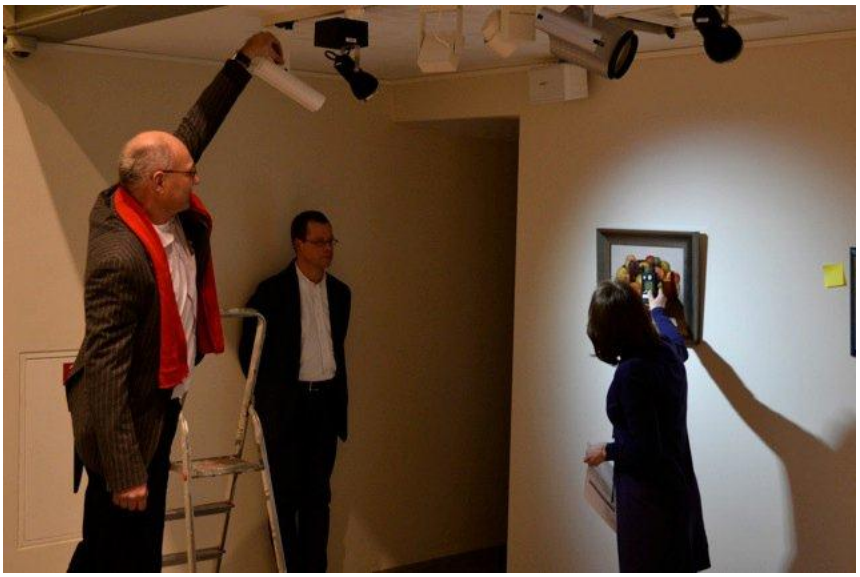
Once a certain amount of time and a certain amount of radiation hits the surface of an artifact, a chemical process is activated. A chemical reaction is a change in the consistency of the electrons and neutrons, etc. of matter, that is not reversible. An example: one lights a fire with wood, due to the IR radiation (heat), the amount of this radiation and the timespan of this radiation the wood slowly changes into ash. One can never reverse the ashes back into wood.

The intensity of the damage brought upon an artifact has to do with three important factors:

- The type of radiation (The type of radiation differs per lighting source)
- The amount of radiation
- The radiation timespan

To minimalize inescapable damage of museum artifacts due to artificial lighting , guidelines and standards have been developed. These guidelines and standards where initially made for The National Gallery in London back in 1961 by a man named Thomson. His work quickly became and still is the international norm for museum lighting[23]. The following subchapters describe the damage control protocol for museum artifacts using LED as the lighting source on hand.

Preventive conservation during exhibit hours



Rene Pieterman (LED specialist, against the wall) and Marysa Otte (conservation specialist) measuring the amount of Lux distributed on a painting during Led's Talk Light, February 18, 2011.

[23] Agnes Brokerhof e .d. , *Praktijkdocument VERLICHTING IN MUSEA EN EXPOSITIERUIMTEN (Amsterdam , 2008)*

Ultraviolet Radiation (UV)
UV radiation is the largest component to result in damage to museum artifacts. To reduce the amount of radiation museums use external UV- filters put on luminaires. These filters reduce the amount of UV with 60%. LED's do not need this filter. Therefore they are more efficient and other leading lighting sources in museums, for LED's have little to no UV radiation at all.

Infrared (IR)
This radiation transforms into heat. Since LED's do not have any IR radiation on the front side of the lighting source they are perfect for museum settings. LEDs still produce around 80% of their electricity into heat but leaves on the backside of the luminaire. Fluorescent light also has little heat but still more than the LED.[24] Halogen also has certain technical setbacks that LED does not have on account to IR radiation. Halogen lamps have a shorter lifespan, have huge heating issues and uses a higher voltage. This means that halogen lighting is a larger fire hazard than LED.

Visible radiation (light)
Visible light itself also creates damage to the surface of artifacts. It is measured in Lux. One must use guideline to define how many Lux hours is permitted upon an artifact on display. LED needs far less Lux to illuminate a surface in comparison to other leading lighting sources such as fluorescent and halogen.

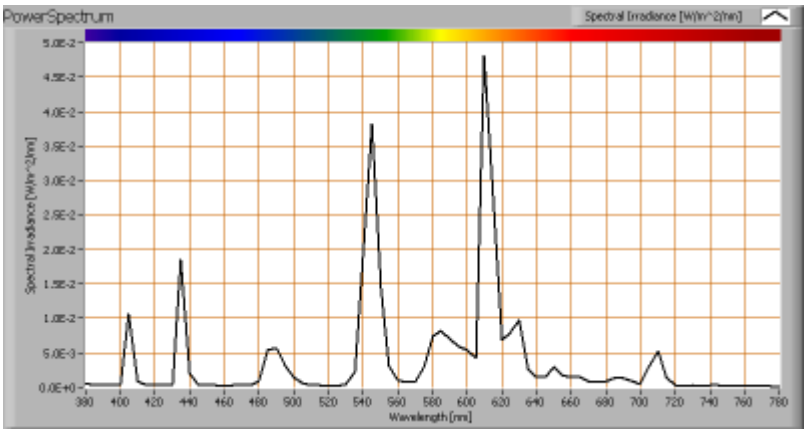
Presentation

There are other types of damage that are less eternal than the chemical reaction. It is that of an ethical and aesthetical matter. If your lighting source doesn't have a perfect CRI rating (this term is explained throughout the following paragraphs) you are tormenting with the quality of the colors and sometimes even the meaning of a piece of art and other artifacts on display.

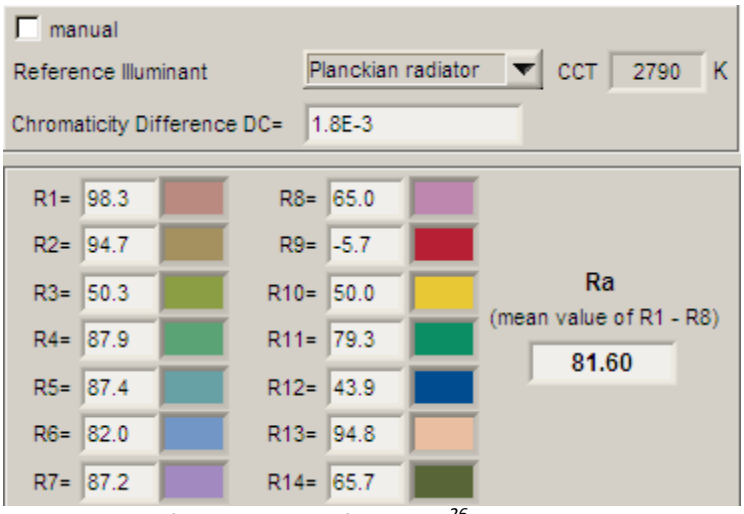
Each light source has a certain color that is visible to the human eye when one looks directly at the light or its surroundings. It is far more important though to realize that each light source also has a certain range of color authenticity (CRI- color render index) that is made visible on the artifact. As seen above in figure…the image, the visible spectrum offers us a scale of color. Not every type of light can give you all the colors in this spectrum. For instance; the sun allows us to see every color that the visible spectrum holds at all times. Its CRI rating is therefore 100%. This means that on a cloudy day or on a sunny day the color authenticity never shifts. Each color is in balance with the other colors.

In artificial lighting there lies a problem on this matter. Some lighting sources do not capture all the red or blue that the visible spectrum offers. Therefore you can be standing in front of a painting full of shades of red, and find it a bit dull. This can be a result due to the fact that the red in the painting is not well represented by the lighting source. This lighting source therefore does not have a CRI of 100%. You can see that there is very little to no red and lots of orange available in the image below.

[24] N. Dugen, 'Licht', *Syllabus bij basiscursus Preventieve Conservering,* Stichting LCM, Amsterdam (2002) H3, p. 36-49.



An example of an LED on its color spectrum capacity. [25]



An example of a CRI rating of an LED. [26]

Museums have a standard on CRI (color rendering index). A light source must have a CRI- rating of at least 80. The problem this standard creates is that there still can be colors completely missing from the visible spectrum , though its CRI rating is above the 80%. In the example above you can see that there is no red coming from this light source (-5.7). If a museum displays a red artifact using this specific light, the visitor will not see the color red to its full extent. This light is meant for shades of orange, greens and yellows. So, if you think that this light source is adequate for your exhibition due to the fact that the CRI has a 81.60% you are mistaken. Unless you only have orange, green, orange and yellow artifacts on display.

In 2010 T. Ashly McGrew, who was once Lead Preparator at J. Paul Getty Museum outlines the following point that we should take notice of:

[25] Marcel van der Steen (4 October 2011) http://www.olino.org/articles/2008/10/04/gogreen-dimbare-spaarlamp-6-20w-e27 (13- April 2011)
[26] Marcel van der Steen (4 October 2011) http://www.olino.org/articles/2008/10/04/gogreen-dimbare-spaarlamp-6-20w-e27 (13- April 2011)

'To expose them (= museum artifacts) to damage AND prevent an accurate sense of their visual characteristics seems to be the biggest crime of all.'[27]

He mentions an important aesthetic moral that should be acknowledged by museums and lighting designers.

There is an ethical issue when speaking of color authenticity. Our knowledge on certain symbolic values of colors known in the field of arts from the past and current, might be falsely interpreted today as well as in the future due to this malfunction of insufficient color rendering. This is something that must be taken in to great consideration when investing in lighting sources. Though the research done on paintings is usually done under very different lighting than in a museum setting the researcher might get his work done well, the audience will not be able to understand him ,his work and the work of the artist if the painting is not well lit.

At the moment important research is being done to create a standardized guideline for using LED for museum purposes. It is unfortunate, but the information on this research is not yet accessible to the public. During my presentation in June I will have this information ready. Once the information is gathered I will implement it in this report, for future readers.

[27]T. Ashly McGrew (25 April 2010) http://www.pacin.org/showthread.php?100-LED-as-a-light-source-for-sensitive-objects (13 April 2011)

2.4
LED compared to leading museum lighting sources

This chapter is meant to give some insight on a comparison between LED and leading lighting sources in museums today. This information is very basic and has been included to confirm other high tech research done throughout the world of LED.

Current leading lighting sources found in museums for exhibition purposes are halogen, gas discharge lamps, fluorescent lamps and fiber light. A comparison of the current leading lighting sources with LED is based on the following six aspects determined by participants during the debate Led's Talk Light[28]

1. Finance
   The short and long term costs of investment (purchase, maintenance, utility bill, RH-rating and lifespan)

2. Sustainability
   Development that meets the needs of the present without compromising the ability of future generations to meet their own needs[29].

3. Pre-conservation
   Damage control within museum exhibits.

4. Presentation/ Aesthetics
   The aesthetic value one associated with each lighting source.

5. Health
   The quality of each lighting source based on the damage it can do to the artifacts on display as well as to the audiences that view them.

6. New technology
   According to the balanced scorecard (BSC), a strategic performance management tool, new technology is an important aspect when searching for development within a company.

[28] http://en.wikipedia.org/wiki/Balanced_scorecard (23 May 2011)
[29] Bruntland Report for the World Commission on Environment and Development (1992) http://www.globalfootprints.org/page/id/0/5/ (23 May 2011)

Based on the six aspects above, two LED distributers and two lighting designers where able to compare all of these lighting sources with one another. The four experts have given each aspect a number on which they grade the lighting source to the specific aspect. Not every respondent had enough knowledge of each lighting source, and some had trouble with grading certain motives. Therefore you can see three different colors used in the column. Each color states how many respondents graded a specific motive and lighting source.

One may question validity of these results based on the fact that only four specialists have participated. The reason for doing this small research is merely meant to confirm data accumulated from earlier desk research. And luckily these four specialists confirmed the worldwide norm.

score is based on 4 respondents
score is based on 3 respondents
score is based on 2 respondents

Motivation	Halogen	Fluorescent	Gas discharge	Fiber light	LED
Financial Average	2,9	3,8	3,1	2,8	3,8
Sustainability	2,3	3,0	3,0	2,7	4,3
Pre- conservation	3,5	3,0	2,8	3,0	4,5
Presentation/Aesthetics	4,3	2,3	3,0	2,7	2,5
Health issues	4,0	2,8	2,8	3,3	3,5
Try new technology	2,5	2,3	3,0	2,0	5,0
Average score per source	3,2	2,9	2,9	2,8	3,9
Result (round figures)	**3**	**3**	**3**	**3**	**4**

Comparing five lighting sources for museum purposes in 2011 based on six motives.

1 = Poor
2 = Fair
3 = Good
4 = Very Good
5 = Excellent

The financial aspect has been divided into five categories.

1. Purchase
The cost of buying the luminaires.

2. Maintenance
The amount of man labor needed to keep a consistent quality of light. This is dependent on how and which lighting source has been implemented to the electric system at your museum. Please contact your electrician, lighting designer and lighting distributor for advise on sufficient implementation.

3. Utility costs
The electric bill.

4. RH rating
Museums guidelines advise that the relative humidity (heat and humidity) in a space where museum artifacts are on display must not fluctuate more than 3% over time. Lighting sources distribute a certain amount of heat that must be regulated.

5. Lifespan
Each lighting source is said to have a certain lifespan. The lifespan is dependent on the quality of the lighting source and the sufficiency of the implementation and connection with the electricity system of the museum. Please ask your electrician and your lighting distributor to explain what to do for the best results.

In the column below you can see the comparisons made by the lighting professionals:

Motivation	Halogen	Fluorescent	Gas discharge	Fiber light	LED
Purchase	3,3	3,8	2,0	1,7	1,8
Maintenance	2,3	4,3	3,3	2,3	5,0
Electrical bill	1,8	4,3	3,8	3,3	4,5
RH rating consistency	5,0	2,5	2,5	3,5	3,0
Lifespan	2,3	4,3	4,0	3,3	4,8
Financial Average	**2,9**	**3,8**	**3,1**	**2,8**	**3,8**

	score is based on 4 respondents
	score is based on 3 respondents
	score is based on 2 respondents

Based on the results in 2.4 one can make the following conclusions:

Overall, LEDs score the highest. From a Financial motive it is clear that LEDs are the most expensive lighting source to purchase. But LEDs use less electricity and need less maintenance than current leading lighting sources. Which makes them beneficial to long term financial planning. They are to this respect also the most suitable for maintaining a sustainable approach.

Concerning the preventive conservation issues on museum settings, LED also scores the highest. LEDs have minimal impact on damaging museum artifacts compared to current leading lighting sources in museum settings. This report does however score the lowest on aesthetical presentation. Through this does not agree with the results though tests in the testing facility in UvAErfgoedLab. The results in the image above have been filled out by leading lighting distributers and two lighting designers. Both have little experience with lighting design and therefore, based on this research are not sufficient.

However, through tests at the facility LEDs have proven to have potential to raise an emotional museum experience . LEDs offer a huge scale of colors without using any filters, which gives a museum the possibility to tune the exact lighting design that is desired. Therefore LEDs have the potential to create more scope for the imagination, which often triggers curiosity and therefore may indirectly inspire its audiences to accumulate more knowledge.

Regarding the health issues LED has scored lower than halogen lighting. This is still being questioned by scientists. Although halogen distributes light that allows us to feel comfortable, LEDs need far less lux to make a surface visible. This will be explained on a much more detailed level in 3.4.

Applying new technology in museums has been added as motive, because the museum is often said to be reflection of our current society. Therefore it can be important for museums to invest in the leading technologies to sustain this social role.

LED implementation is not always the right choice to make. LEDs are less reliable than other lighting sources due to the fact that LEDs have a high voltage sensitivity. And it is also important to state that not ever lighting designer knows how to or wants to work with LEDs.

By simply replacing a LED into a fitting where a different lighting source has been taken out will not live up to the quality that LEDs are said to have. This new lighting source must be seen and treated as a completely new lighting source to be able to make use of its actual lighting qualities.

Chapter 3

Led's invest!

''Dutch society invests more money, time, energy, and creativity in lighting their *cheese* and *meats* (with LED) than they do their *cultural heritage*'', states Scott Geffert during our interview.

Introduction

Tom Dalton, Vice President sales and marketing – Nuventix, USA, left this message on a LinkedIn website called: Innovation in Light:

'There are a lot of reasons why companies are moving to LED, big time: maintenance cost alone (…)add to that energy savings, lack of hazardous waste chemicals (as are found in CFL) and in many countries they're simply pulling certain bulbs off the market (primarily incandescent). Finally, there are a number of customers that simply want quality light (and when people went from incandescent to CFL they certainly sacrificed that).'[30]

Since the beginning of 2011 more and more museums are slowly investing in LEDs for exhibition purposes. For the past four- five years museums where far more hesitant. Due to new technology and the cumulating awareness of LEDs benefits on environmental and health issues LEDs are being used in museums. What led these museums to make such a sudden change?

The development of LED implementation based on the information in chapter 2 will know be described at a more detailed level in this chapter.

30

http://www.linkedin.com/groupItem?view=&srchtype=discussedNews&gid=3003087&item=46109989&type=member&trk=eml-anet_dig-b_pd-pmt-cn (29 April 2011)

3.1
Technology and the tradition of change

We tend to be blinded by three powerful factors when comparing the new to the old. One: we judge based on a collective perception of the current norm. Two: we have learned to become attracted to this norm which we like to call 'sense of taste' and Three: we tend to observe things around us based on a pattern of expectations. We are blinded by our deep connection with the present and therefore it is hard to see future technology.

In today's world of lighting technology, the LED has come a long way. From being fabricated for the usage of computers and telecommunications back in the 1980's to becoming one of the leading and most promising lighting sources for stage lighting, traffic lighting and even lighting in our own homes. The perception of LEDs has also had a history of resistance by the general public. We found and some of us still do find LED to be bleak and unpleasant. This has as much to do with the three factors mentioned in the past paragraph as with the pace of development of this lighting source and the way people talk about them.

LEDs made in 2010 are not comparable to LEDs that are made today. Technology has taken away complaints of the high blue rendering which created the bleak perception by adding phosphor coating to the LED and the costs of the lights are slowly going down and becoming more affordable. Knowing this now, and remembering the fact that LED has a very low level of UV and IR radiation and almost no heat that is transmitted through the front of the light, it is quite peculiar that museums have not all made the step from halogen lighting to the ever so clever LED.

According to Scott Geffert, former director at Center for Digital Imaging, Inc., consultant for the Rijksmuseum and the Van Gogh Museum and other museums, museums need to focus more on the cultural and aesthetic innovation in museum lighting that LED has to offer.' LED technology offers the world a new, fresh look upon museum lighting which will evidently lead to a new collective museum experience and perception of cultural heritage. ''The world invests more money, time, energy, and creativity in lighting their cheese and meats (with LED) than they do with their cultural heritage. Museums need to take responsibility on illuminating its cultural treasures to the best of its technical possibilities '', Geffert says during an interview. [31]

Lighting designer Joost de Beij, owner of Licht- Joost de Beij, is not as impressed by L.E.D.'s as Geffert is. Though he frequently uses L.E.D. lighting in his current designs, he states that the development of LED is still very turbulent and advises museums to hold back their purchases until current lighting no longer meets the norm. He also mentions that LEDs have limitations to halogen lamps that he would rather not do without. '' With halogen lighting I can create a warm atmosphere by dimming the light. When I dim an LED the light intensity changes but the color temperature (the warmth of a color) does not. In the end De Beij does not necessarily see LED as a step forward, but more as a mere step to the side. [32]

[31] Interview with Scott Geffert in UvAErfgoedLab, test facility: Led's Talk Light (19-02-11)
[32] Interview with Joost de Beij in UvAErfgoedLab, test facility: Led's Talk Light (10-02-11)

The technology of LED can be compared to that of the digitalization of photography. It took professional photographers over thirty years to understand this new mechanism and to appreciate it as well. Nowadays you cannot imagine going back to the analog photography. Digital photography has not only offered the world new ways to illustrate our surroundings, but it has also created unthinkable possibilities in video as well. Therefore it is so, only by investing and working with LED will we discover its real potential.

3.2
Greening your museum concerning preventive conservation and aesthetic presentation

One kilowatt-hour of electricity will cause 1.34 pounds (610 g) of CO_2 emission.[108] Assuming the average light bulb is on for 10 hours a day, one 40-watt incandescent bulb will cause 196 pounds (89 kg) of CO_2 emission per year. The 13-watt LED equivalent will only cause 63 pounds (29 kg) of CO_2 over the same time span. A building's carbon footprint from lighting can be reduced by 68% by exchanging all incandescent bulbs for new LEDs in warm climates. In cold climates, the energy saving may be lower, since more heating is needed to compensate for the lower temperature.'[33]

There lies a collective awareness on the urgency in getting involved with and influencing current environmental issues and climate change in today's society. This phenomenon is known by the general public as: Greening. It is important, according to collective standards in western society, for museums to participate in this occurrence any way possible within the walls of their surroundings. To be able to sustain the quality and quantity of our cultural heritage, museums must take matters into their own hands. Visitors (and sponsors) will start demanding it from them[34]. But the real reason museums should start Greening their museums has less to do with a demand from the outside world and far more to do with two essential aspects: an ethical and a financial essence of sufficient and sustainable practice.

Ethically speaking one can state that it is simply the correct thing to do, now and for our future. Musicologists understand the importance of preserving heritage for future generations as well as displaying it for contemporary audiences in a way that they can connect with their own heritage and that of others. They need to encourage sustainable actions in museums.

By Greening your museum, mankind will benefit. The longer tangible and intangible artifacts are preserved the more contemporary and future civilizations can learn from

[33] http://en.wikipedia.org/wiki/Light-emitting_diode (5 May 2011)

[34] Sarah S. Brophy and Elisebeth Wylie, *The Green Museum a primer on environmental practice* (Plymouth: 2008) xiii. (http://www.amazon.com/Green-Museum-Primer-Environmental-Practice/dp/0759111650#reader_0759111650)

themselves. The benefits of investing in LED lighting based on the matter of ethical reason have been explored during this research. In past pages it is stated that LED is known to have little or no UV and IR radiation. It is a fact that on the front side of the light, little heat is produced.

Please take notice though that museum artifacts do not really benefit from these factors. By dimming the light and therefore lowering the amount of Lux, all artifacts can be safely displayed. It is the visitor who benefits. By lighting an exhibit with LED, one accumulates more visibility and far less damage to the artifacts as well as to utility bills and our environment.

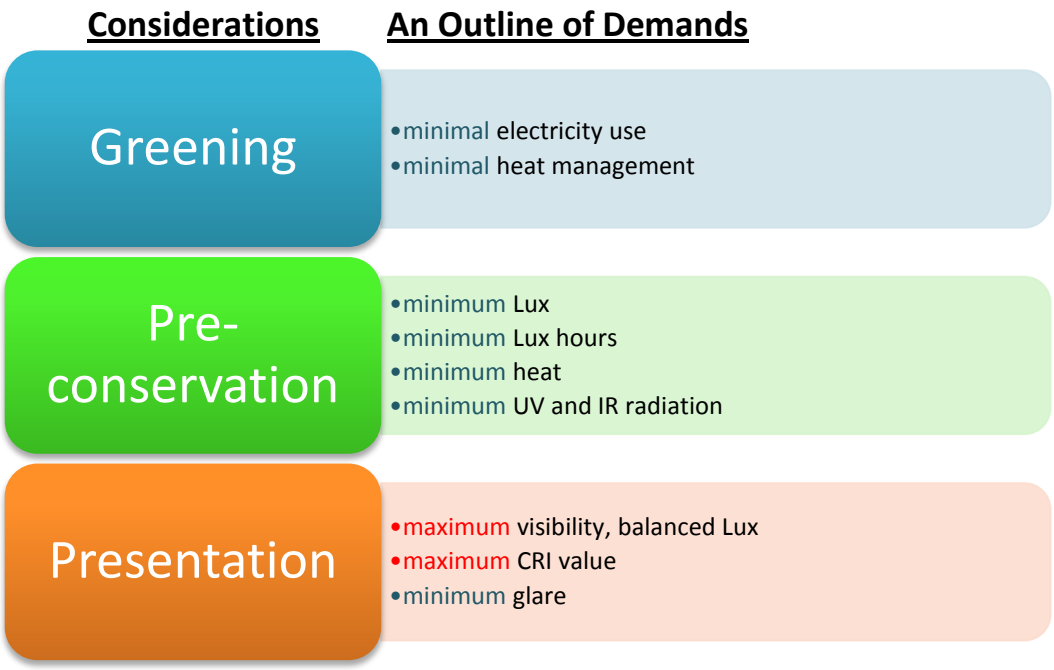
So, creating a beneficial situation in your museum by investing in LEDs sounds like a good plan. But do realize the pros and cons on possible investments. LED's can facilitate this need to Green your museum. But not everyone is sure about this. It is, of course never a black and white situation.

In 2010 Dale Kronkright, Head of Conservation at the Georgia O'Keeffe Museum , USA, wrote in a letter:

(…)Because so much is piled on to narrow bands in LEDs, the possibility of hole burning is very possible and trying to be "green" with so little knowledge is Russian Roulette and the LED green committee is playing with fire. At this time I don't think LEDs are ready for prime time both from the point of view of color rendering and conservation. Clearly two LEDs with a bridging phosphor is better than all LEDs but some manufacturers have driver problems, green is mismatched for optimal color rendering, and only one manufacturer hits the Energy Star specification. I know all this because I just came back from NIST which is a hotbed of research on LED lighting and that's most of what all the current research is about.(…) To expose them to damage AND prevent an accurate sense of their visual characteristics seems to be the biggest crime of all.- [35]

[35] D. Kronkright (25 April 2010) http://www.pacin.org/showthread.php?100-LED-as-a-light-source-for-sensitive-objects (13 April 2011)

It is important to realize that this letter was written in 2010. LED technology has grown a lot since then. Dale Kronkright does, even though this text is over a year old, make an interesting observation. By greening your museum you may be hurting your collection. It is therefore essentially important to recognize the specific needs for your museums artifacts and visitors and to find a LED type that will suit your specific artifacts keeping the following in mind;



An Outline of Demands concerning: Greening, Preventive conservation and presentation for museum exhibitions[36].

Harold Brunt, Optomechanical Designer, Corporate Officer at LumenFlow Corp, USA, states in April of 2011 the following message on the LinkedIn website; Innovation in Light:

(…)I tend to be cautious of anyone trying to sell me new technology in a fast growing market. Early adopters often get the burden of being unwitting beta-testers. I have also been exposed to plenty of people that promote LED because it is "green" even though they do not live a green lifestyle as though saying so makes a product great. Even with all of the negatives of being involved with a growing industry I firmly believe that LED bulbs will dominate the market in the near future both commercially and domestically. [37]

[36] This image is made by Sjoukje Kerman.

[37] http://www.linkedin.com/groupItem?view=&srchtype=discussedNews&gid=3003087&item=46109989&type=member&trk=eml-anet_dig-b_pd-pmt-cn (29 April 2011)

3.3
Financial Motives

And then there are the financial benefits to investing in LED for your museum. Utility costs are of course very concrete. They turn up on your doorstep every month. The amount of money that a museum spends on electricity and maintenance concerning the lighting, depending on the amount of lamps and the dimension of space, can grow sky high. The Hermitage Amsterdam is well aware of these enormous costs. They, on the other hand, are also very aware of the essence and effects of lighting in the museum. This museum had attended the debate: Led's Talk Light, because of these costs. During the debate they learned what LED has to offer them. Though the purchase of LED's is quite expensive the investment based on money, sustainability and man-hours is worth it.

(Front Left)Presence of Hermitage staff at Led's Talk Light, February 18, 2011

It is up to the museum to concentrate on the future well- being of their museum's building, its museum artifacts and that of their visitors as well as their employees. By investing in LED each museum is contributing to the world on two different levels: to the artifacts and to todays and tomorrows visitors. Of course there are threshold's concerning this large scale investment. Museums will not only have to invest money but must invest many time -consuming hours working together with lighting designers whom understand LED's and Museums will also have to stay open to new exhibition possibilities that come along with LED's. In Chapter four an overview is presented of all costs related to investments in LED.

3.4
A healthy museum experience

What, you may ask does your health have to do with lighting design? The greater number of visitors each day in a museum, are women above 55 years of age[38]. Can these visitors see well enough in minimally lit spaces in the museum? Do they feel comfortable in a museum setting?

The elderly, visual impaired and people whom are tired or ill need more time to adjust to a change in the intensity of light. It has to do with the brain that stands in contact with your eyes. According to Thomas Schielke at ERCO lighting, a healthy young person needs but one minute to fully adjust from a dark room to a room with full brightness. If you are not within this category one will need far more time to adjust to the lighting. This means that for a few minutes you are not well orientated through temporary blindness.

But in a standard museum setting, one will more often walk from a highly lit hallway into a dark room to see artifacts on display. A healthy person needs six minutes to adjust to the dark. And the lux must then also be above 0.4 lux to actually see color after these six minutes. It is interesting for museums to realize that something can be done to minimize this problem. One can simply create a more gradual transition between the lux value per space. For starters one can add more lighting in the darker spaces (raise the amount of lux. Secondly one can simply make the brighter surroundings darker. LEDs are well known for their straight beams of light. This can create a very effective spotlight effect. Because of this quality museums can play with the natural game of light and dark. By just slightly lighting that what is of importance a lighting design stimulates the interest a person will have towards the artifact set in the lime- light. People feel comfortable in simulations of nature. And in real life nature we constantly are effected by natures game of light and dark. Each moment of every day and night has a different light intensity. When this phenomenon is simulated in a museum space your audiences will feel at ease, and therefore might even stick around longer.

According to Rogier van der Heide it is the responsibility of institutions to make sure their collections on display are visible for all visitors[39]. But visibility alone is not enough. The intensity (lux), color and temperature of a light source does affect your perception and therefor has effect on your state of mind and body. Philips has come up with a lighting system based on this idea called SchoolVision. Every classroom has access to different lighting settings. One for a calm class setting, one for focusing and test taking. The lighting source is LED, because it needs but little electricity. Research has proved that the scholastic focus has grown rapidly since this lighting system has been implemented. Being that museums have a goal to educate their audiences, such

[38] http://www.zeelandmuseumland.nl/zeeuwse%20museumpeiling%202009%20-%20algemeen%20rapport.pdf/ p. 20 (29 May 2011)

[39] TED,http://www.ted.com/talks/rogier_van_der_heide_why_light_needs_darkness.html (2 April 2011)

as school groups, it is likely that a system such as this one can stimulate the museum experience in a positive way. [40]

When the interest of a museum visitor decreases during an exhibit viewing, he is said to have; 'museum fatigue'. This phenomenon is based on research that has been done since the early 1920's. Gareth Davey summarised this research and has come to a conclusion that museum fatigue is a consequence of the following four points:

1. The traditional view of museum fatigue is that visitor interest decreases as visits progress. For example, it has been shown that interest reaches a high plateau for the first 30 minutes of a visit, and decreases thereafter.

2. A second pattern, whereby visitor interest decreases within smaller areas (such as a succession of displays), has also been reported.

3. The behavioral changes that categorize fatigued visitors include cruising through galleries, relatively rapid rates of viewing without rest periods, and increased selectivity towards exhibits.

4. Patterns of fatigue are generally constant and predictable within an institution and, further, the concept generalises across different museums. [41]

Not once has lighting been taken into consideration on terms of the effects that it might have on the result of museum fatigue. Anita Rui Olds states in her article 'Sending them home alive', that lighting does play an important part in living up the museum experience. And as liveliness is the opposite of fatigue, Olds clearly proves that by combining daylight with artificial lighting design one is able to create more energy amongst the people in a space[42]. Just think of the controllable properties and lighting design functions mentioned in chapter 2. Lighting design using LEDs provides a vivid experience that is best proved when seen by yourself.

[40] http://www.lighting.philips.nl/lightcommunity/trends/dynamic_lighting/dl_for_school.wpd (3 May 2011)

[41] Gareth Davey, *What is museum fatigue?,* Visitor Studies Today (volume 8 issue 3: 2005)17-20 (http://informalscience.org/researches/VSA-a0a5y5-a_5730.pdf)

[42] Anita Rui Olds, '*Sending them home alive'*, e.d. Eilean Hooper- Greenhill, The Educational Role of the Museum (Cornwall,2004) 332- 335

Chapter 4

Results And Recommendations

4.1
Reviewing results

This chapter is meant to give insight in the findings accumulated during the research done for this study. The main goal for this study is to offer professionals in the field of cultural heritage, museums in particular, an understanding of what LED can offer museum artifacts and its audiences during museum exhibitions.

The main question is if it is true that LED lighting can be a valuable asset when facilitating an innovative and vivid collective museum experience. The following information, has been collected on LEDs for museum exhibition purposes.

This paragraph is divided into the six motivations for LED investments stated in chapter 2.3 and furthermore described in chapter 3. I must state that each motivation has positive and negative aspects. When deciding on investing in LEDs a museum can choose what is of the highest value to them. This list gives insight in the data accumulated during this specific study.

While researching LEDs I have tried to answer six questions:

1. What are LEDs?
2. What are the functions and controllable properties for artificial lighting in general and LED in particular?
3. How do LEDs compare to current leading lighting sources in museums?
4. How do lighting designers, LED manufactures and distributors, museum staff and exhibition designers look upon LED?
5. How do museums that use LED view their investments?
6. What can be recommended to museums on future LED implementation?

I believe question 3 and 6 have not been answered their full extent. While comparing the lighting sources (question 3) I came across so many acceptations to the standard results that I was not able to comprehend them all. This chapter is quite technical and was above my capacity to digest. I therefore advise you to speak to your lighting distributor and lighting designer before making any decisions on LED investments.

Question 6 has only been answered by just one museum. Therefore this result is not representative for LED experiences from a museums point of view. In my recommendations you will read my proposal on this issue. The Kinderboekenmuseum invested in LED based on a financial motive, and is very satisfied with the results.

Finance

Positive

- LEDs have a very long lifespan and therefore have low maintenance costs. If of course the electrics are not implemented inside the luminaire.

- LEDs use less electricity than other leading light sources and therefore the utility bills will be lower when using this lighting source.

- LEDs have little to no UV radiation, therefore a museum does not have to invest in external color filters.

- LEDs have little to no IR- Radiation so climate control is more stable.

Negative

- LEDs are more expensive to purchase than other leading lighting sources used for museum exhibitions.

Sustainability

Positive

- LEDs need very little lux to light a surface in comparison to the leading lighting sources studied throughout this thesis (2.3). Therefore LEDs use less electricity and have less negative effects on the environment.

Preventive conservation

Positive

- Due to the fact that LEDs have little to no UV and IR radiation they are well suited for lighting museum artifacts on display.

- LEDs need less lux to light a surface than other lighting sources, therefore an artifact can be displayed longer before damaging the artifact too much.

Presentation/ Aesthetics

Positive

- LEDs have a huge range of color possibilities without using external color filters. Therefore LED lighting is a competent tool when creating dramatic effects in museum exhibits due to the large range of colors and little to no saturation from the lighting source.

- LEDs also make it possible to create a clear contrast between light and dark. This can create a dramatic effect if desired.

- LEDs do not change its color temperature when they are dimmed. So the intensity can be minimalized without losing the desirable color temperature.

- LED lighting does not saturate.

Negative

- LEDs are known to flicker when they are fully dimmed. Therefore they are not always reliable if the electricity system is not consistent.

- The quality per LED can vary, therefore a lighting designer must often take extra time to emit each luminaire separately to create unity in color throughout an exhibit.

Health Issues

Positive:

- LEDs create sharp beams of light. Therefore this lighting source creates a strong contrast in light and dark. This allows a lighting designer to use light only when it is really desired. The contrast in light and dark suites the natural lighting our bodies and mind are accustomed to.

- LEDs have a vivid appearance and therefore can contribute to a more lively museum experience that might decrease feelings of ‘museum fatigue’.

New Technology

Ultimately, the use of LEDs will not depend on the opinions of lighting professionals. It’s usage lies in the hands of the willingness of museum professionals to invest money, to gain a larger understanding of LED as a tool and to accumulate a greater amount of courage for the innovation of the museum experience of the future.

4.2
Conclusion

So, is it true that LED lighting can be a valuable asset when facilitating an innovative and vivid collective museum experience?

On one hand: Yes
LEDs have minimal impact on damaging museum artifacts compared to current leading lighting sources in museum settings.

LEDs have the potential to raise an emotional museum experience and therefore create more scope for the imagination, which often triggers curiosity and therefore may indirectly inspire its audiences to accumulate more knowledge.

LEDs use less electricity and need less maintenance than current leading lighting sources. Which makes them beneficial to long term financial planning. And LEDs offer a huge scale of colors without using any filters, which gives a museum the possibility to hone the exact lighting design that is desired.

On the other hand: No
Research has made clear that LEDs have a high voltage sensitivity. They tend to flicker when they are fully dimmed. This can have a disturbing effect throughout a museum visit. It is also clear that not every lighting designer knows how to or wants to work with LEDs.

The choice to either do or don't invest in LEDs for your museum settings lies to what extent each motive and result that has is most stated most important. To provide more information please read the recommendations stated in the following paragraph.

When to definitely use LED:

- For black and white artifacts due to the fact that the CRI ratings of LED are still not at a stable 100% accuracy. This was highly discussed during the debate. During the debate it must be said that Wouter Verhoeven, as seen in the picture below, does say to have high CRI ratings for his LEDs. But still, most LEDs are not consistent enough to change the norm. Verhoeven's LEDs are more the acceptation than the rule.

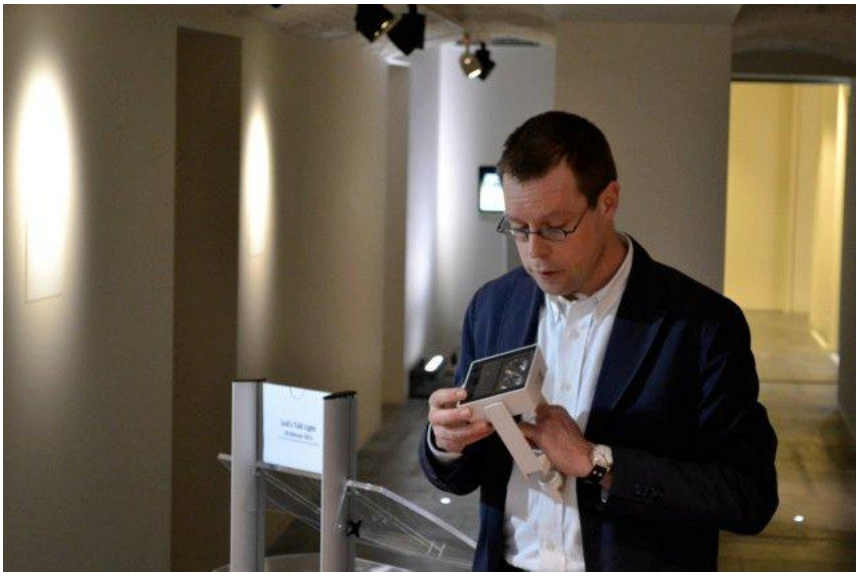
Wouter Verhoeven, centre, (designer/developer of LEDs) explains how his LEDs do have a reliable and very high CRI rating, during; Led's Talk Light on February 18 2011.

- For scenic purposes in a space due to the huge amount of colors that LED has to offer without the use of any color filters as do other lighting sources.

- For spaces in a museum where maintenance is difficult due to the fact that LED has an enormous lifespan (estimates 35,000 to 50,000 hours of useful life).

Sjoukje Kerman fixing the LEDs on display on a ladder during Led's Talk Light.

- For small artifacts in a case, because of the sharp beam of light LED produces and because LEDs have but very little UV, IR and heat radiation coming from the front of the light. And due to the fact that LEDs are very small, and easy to fit into a case. But The heat from the back of the light needs to be able to leave the case. So this only works well if cool air can enter the case to regulate the temperature.



Rene Pieterman (LED specialist) explains radiation levels of LEDs, during the debate Led's Talk Light, February 18, 2011.

- For saving money on the utility bill. LEDs produce more light per watt than for example than incandescent light. The efficiency of LEDs in not affected by size and shape as do fluorescent lighting.

The innovating aspect is not mentioned in the above. Innovation means an introduction of a new idea, method or devise. So basically by just using LEDs (a new devise) already states that it is innovative. But what does LED offer that affects the museum experience in ways not possible with current leading lighting sources?

Based on this research the answer is not very special until you experience it in real life. LEDs create a very clear, fresh and healthier museum experience than current leading lighting sources. When implemented correctly LEDs have the potential to subconsciously allow people to stay in a space longer and to experience their visit with more liveliness. This is due to the fact that LEDs have the same capability as the Sun to consistently change the color temperature without tormenting with the color of the light. I believe that the people whom attended the debate will back this up.

The debate came to an end, after 1,5 hours of questioning, arguing and agreeing on the benefits and setbacks of LED while paying close attention to museum standards on preventive conservation and aesthetic presentation issues.

4.3 Recommendations

- This thesis should *not* be used as a checklist when deciding to invest in LED. This thesis should be used as a source to read up on the issues that are paired with LED implementation used specifically for museum exhibit lighting design.

- The question included in this research: How do museums that use LED view their investments? I have only been able to contact the Kinderboeken Museum in the Hague on this issue. They are very content. But one answer is not representable. Therefore I would recommend further research to be done on the effects LED investments have on a long term basis for all museums in The Netherlands that have made such an investment.

- It would also be very interesting and useful to interview the audience that is visiting Papiria on how they feel/ felt during the exhibit and what they have accumulated on information throughout their visit. This might give more insight on the effects that the LED lighting design has on museum audiences. In the testing facility a small observation was done on the audience. But this is not representative, for the lighting design was not refined well enough.

- Before deciding to invest in LEDs for museum exhibition purposes, museum management should recollect which motivations are valued by the mission statement of their museum.

- Before investing in LEDs museum management should speak to lighting designers as well as LED distributors to fulfill the museums specific needs.

- It is important to handle LED as a new lighting tool. LED has different needs and capabilities than other lighting sources. *Do not* replace your current lighting by simply screwing in the LED where the old one has been taken out. For if you do you are missing out on the beauty that this specific lighting tool offers.

- Please ask for a screening of the chosen LED before investing in it. You do not want to end up with, for instance insufficient CRI ratings. For your screening you should contact: **OLINO.org**

Glossary

A

Accent Lighting
A form of lighting used to highlight objects and focal points.

Ambient Lighting
A constant illumination in a space placed from all directions, that generally has no visible source. This type of lighting is in contrast to accent lighting.

B

Brilliance
This is created by the reflection of a light source onto a reflective surface or off of transparent materials. Synonym= shine.

C

Color Rendering
A percentage of visible colors from the color spectrum that is visible due to a light source.

Color Rendering Index (CRI)
A mathematical system to indicate how colors will appear under different light sources and compares how a light source brings out the same colors that are lighted by a reference source of the same Color Temperature. When there is no difference, the source in question is given a CRI of 100 by definition.

Color Temperature
The color temperature is measured in Kelvin. Low color temperature is the warmer, more yellow to red light while high color temperature is the colder, more blue light. The color temperature of the sun, for instance, changes constantly due to weather conditions and the position of the sun and the direction you are facing.

D

Diffuse Light
Light equally divided in all directions upon a surface. It is affected by the distance and angle between the surface and the light, but is unaffected by the viewer's position or view angle.

E

Electromagnetic spectrum
The range of all possible frequencies of electromagnetic radiation.

G

Gobo
A plate made of glass or metal with a certain pattern in it that is projected in a space. The gobo is put into the luminaire to create a desired form.

Greening
The process of transforming artifacts such as a space, a lifestyle or a brand image into a more environmentally friendly version.

I

Illuminance
The amount of light measured in lux with a photometer.

L

Lumen (Im)
A measure of the power of light perceived by the human eye.

Luminance
The measurement of brightness with which the eye perceives an illuminated surface.

Lux
A measurement of light intensity that is reflected on a surface.

Light Emitted Diode (LED)
LEDs distribute light by conducting electric current in only one direction.

V

Visible spectrum
The portion of the electromagnetic spectrum that is visible to the human eye.

Bibliography

Literature. Documents.

- Agnes Brokerhof e.d., *Praktijkdocument VERLICHTING IN MUSEA EN EXPOSITIERUIMTEN (Amsterdam , 2008)*1-147
- M.A. Myer and B.R. Kinzey, *Demonstration Assessment of Light- Emitting Diode (LED) Accent Lighting at the Field Museum in Chicago, IL* (USA, November 2010)
- N. Dugen, 'Licht', *Syllabus bij basiscursus Preventieve Conservering,* Stichting LCM, Amsterdam (2002) H3, p. 36-49
- Richard C. Beacham, *Adolphe Appia: artisit and visionary of the modern theatre*

  (Australia 1994)
- Aksel Karcher, *Light perspectives, between culture and technology* (Ludenschied

  2009) 11- 247
- Hendriks, *Kunstlicht als instrument binnen tentoonstellingsvormgeving,* (Amsterdam 2005)
- Oscar G. Brockett and Franklin J. Hildy, *History of the Theatre* (Allyn and Bacon, USA: 2003)413-417, 426
- J. Michael Gillette, *Designing with Light An Introduction To Stage Lighting* (The McGraw-Hill Companies: 2001)
- Anita Rui Olds, '*Sending them home alive'*, e.d. Eilean Hooper- Greenhill, The Educational Role of the Museum (Cornwall,2004) 332- 335

URL's

- Amy Westervelt, *Explosive growth for led lights in next decade, report says Next-generation bulbs to capture nearly 50% of lighting market by 2020* (13 May 2011)

http://solveclimate.com/news/20100513/explosive-growth-led-lights-next-decade-report-says (13 May 2011)

- http://www.linkedin.com/groupAnswers?searchQuestions=&fromEmail=&gid=3003087&trk=eml-anet_dig-h_gn-tpd-cn (29 May 2011)
- http://www.wix.com/sjoukjekerman/cultuurbelichting (Febraury 2011)
- Nikolay Zheludev, *The life and times of the LED- A 100 year history,* Nature Phontonics (April 2007)
- Joseph J. Carrand and Tony van Roon, Light Emitting Diode History (2010) www.sentex.ca/~mec1995/tutoral/leds/leds.html (April 4 2011)
- My-Led-Passion.com/Nick-Holonyak.html (April 2011)
- Lighting & Productivity,http://lightingdesignlab.com/articles/ltg_prod/ltg_productivity.htm (12 April 2011)
- http://www.kinderboekenmuseum.nl/Tentoonstellingen/Papiria.aspx (24 may 2011)
- Bureau for exhibition design in Amsterdam, http://platvorm.nl/
- [1]T. Ashly McGrew (25 April 2010) http://www.pacin.org/showthread.php?100-LED-as-a-light-source-for-sensitive-objects (13 April 2011)
- http://en.wikipedia.org/wiki/Balanced_scorecard (23 May 2011)
- Bruntland Report for the World Commission on Environment and Development (1992) http://www.globalfootprints.org/page/id/0/5/ (23 May 2011)
- http://www.linkedin.com/groupItem?view=&srchtype=discussedNews&gid=3003087&item=46109989&type=member&trk=eml-anet_dig-b_pd-pmt-cn (29 April 2011)
- http://en.wikipedia.org/wiki/Light-emitting_diode (5 May 2011)
- Sarah S. Brophy and Elisebeth Wylie, *The Green Museum a primer on environmental practice* (Plymouth: 2008) xiii. (http://www.amazon.com/Green-Museum-Primer-Environmental-Practice/dp/0759111650#reader_0759111650)
- D. Kronkright (25 April 2010) http://www.pacin.org/showthread.php?100-LED-as-a-light-source-for-sensitive-objects (13 April 2011)
- http://www.linkedin.com/groupItem?view=&srchtype=discussedNews&gid=3003087&item=46109989&type=member&trk=eml-anet_dig-b_pd-pmt-cn (29 April 2011)
- http://www.zeelandmuseumland.nl/zeeuwse%20museumpeiling%202009%20-%20algemeen%20rapport.pdf/ p. 20 (29 May 2011)

- TED,http://www.ted.com/talks/rogier_van_der_heide_why_light_needs_darkness.html (2 April 2011)
- http://www.lighting.philips.nl/lightcommunity/trends/dynamic_lighting/dl_for_school.wpd (3 May 2011)

- Gareth Davey, *What is museum fatigue?,* Visitor Studies Today (volume 8 issue 3: 2005)17- 20 (http://informalscience.org/researches/VSA-a0a5y5-a_5730.pdf)

- W. E. Johns, 'Notes on LEDs'(versie 2003), http://www.gizmology.net/LEDs.htm, (8 February 2011).

- S.Geffert, 'The Next Chapter in Photographic Lighting' (versie September 2010),http://www.luminouslandscape.com/techniques/the_next_chapter_in_photographic_lighting.shtml, (11 February 2011)

Interviews

Lichting designers

Joost de Beij
Boschstraat 79
5301AC Zaltbommel
T 0418-515287
F 0418-515289
E info@licht-joostdebeij.nl
W www.licht-joostdebeij.nl

Henk van der Geest
Keizersgracht 264
1016 EV Amsterdam
T 020 6253136
F 020 4280138
M 06 29005837
E henk@henkvandergeest.nl
W www.henkvandergeest.nl

Hans Wolff (& Partners BV)
Herengracht 109
1015 BE Amsterdam
T 020 - 3304718
F 020 - 3304719
E wolff@xs4all.nl

Exhibition designer

Taco de Bie
Eigenaar en ruimtelijk ontwerper Platvorm
Silodam 182

1013 AS Amsterdam
T 020 530 4182
F 020 624 44 04
E taco@platvorm.nl
W www.platvorm.nl/uitgelicht.html

Visionary

Scott Geffert

Artist

Jack van Elewout
T 076 5418740

Head collections management

Marysa Otte
E Otte@vangoghmuseum.nl

LED Distributors

ERCO
Gooimeer 13
1411 DE Naarden
E info@ERCO.nl

Proliad
Wouter Verhoeven
Drift 96
3941 DD Doorn
E info@proliad.com

Images

- IDEA
http://www.google.nl/imgres?imgurl=http://photos2.pix.ie/10/F2/10F2973EBEB442C3B026617B29E91162.jpg&imgrefurl=http://pix.ie/trusttommy/807381&usg=__k456Pl2unqkvGGwJtisVIxFHG-s=&h=400&w=400&sz=22&hl=nl&start=0&zoom=1&tbnid=UKYIg9_iatTsEM:&tbnh=129&tbnw=134&ei=aDviTc-ZLsOfOuOUhfcG&prev=/search%3Fq%3Dlight%2Bbulb%2Bidea%26um%3D1%26hl%3Dnl%26sa%3DN%26rlz%3D1W1ACAW_nlNL378%26biw%3D1345%26bih%3D561%26tbm%3Disch&um=1&itbs=1&iact=rc&dur=110&page=1&ndsp=26&ved=1t:429,r:0,s:0&tx=71&ty=65 (14 May 2011)

- The Electromagnetic Spectrum
  http://www.google.nl/imgres?imgurl=http://www.andor.com/image_lib/lores/INTRODUCTION/Introduction%2520(Light)/IntLight%25201%2520Small.jpg&imgrefurl=http://www.andor.com/learning/light/&usg=__guoHC72yxyVE4DrHqLp_IFPi1tI=&h=308&w=570&sz=148&hl=nl&start=16&zoom=1&tbnid=FuGLJE6n2EoKKM:&tbnh=79&tbnw=146&ei=h__QTfzyK5Ce-wbFrvXqCQ&prev=/search%3Fq%3Delectromagnetic%2Bspectrum%26hl%3Dnl%26sa%3DX%26rlz%3D1R2ACAW_nlNL378%26biw%3D1345%26bih%3D561%26tbm%3Disch%26prmd%3Divns0%2C374&itbs=1&iact=hc&vpx=341&vpy=158&dur=90&hovh=165&hovw=306&tx=171&ty=86&page=2&ndsp=18&ved=1t:429,r:2,s:16&biw=1083&bih=544 (26 April 2011)

- An example of an LED on its color spectrum capacity.
  Marcel van der Steen (4 October 2011)
  http://www.olino.org/articles/2008/10/04/gogreen-dimbare-spaarlamp-6-20w-e27
  (13- April 2011)

- An example of a CRI rating of an LED.
  Marcel van der Steen (4 October 2011)
  http://www.olino.org/articles/2008/10/04/gogreen-dimbare-spaarlamp-6-20w-e27
  (13- April 20

Appendix 1:

The Testing Facility

7 February – 20 February 2011

Story line

1. Inleiding
2. De functie van licht
3.Uitvindingen leiden tot verandering van perceptie en later tot smaakverschuiving
4. Uw experiment

1. Inleidende tekst

Welkom bij Led's Talk Light

U staat hier in mijn laboratorium waar onderzoek gedaan wordt naar LED-verlichting. Tegenwoordig wordt LED gebruikt in mobiele telefoons, televisieschermen, fietslampen, verkeerslichten en zelfs - als u zou willen - in uw eigen woonkamer. LED-verlichting wordt vaak gebruikt omdat het licht in één richting schijnt en weinig energie verbruikt.

Omdat LED- verlichting ook wel 'het licht van de toekomst' wordt genoemd, is het reëel dat dit ook in musea gebruikt zal worden. Dit gebeurt deels al. LED- verlichting kent vele voordelen bij het presenteren van museale objecten, omdat het slechts tot minimale beschadigingen leidt. Maar, is LED- verlichting wel geschikt voor het belichten van museale objecten? Kan LED- verlichting op tegen de huidige perceptie, de smaak en het verwachtingspatroon van u, de bezoeker?

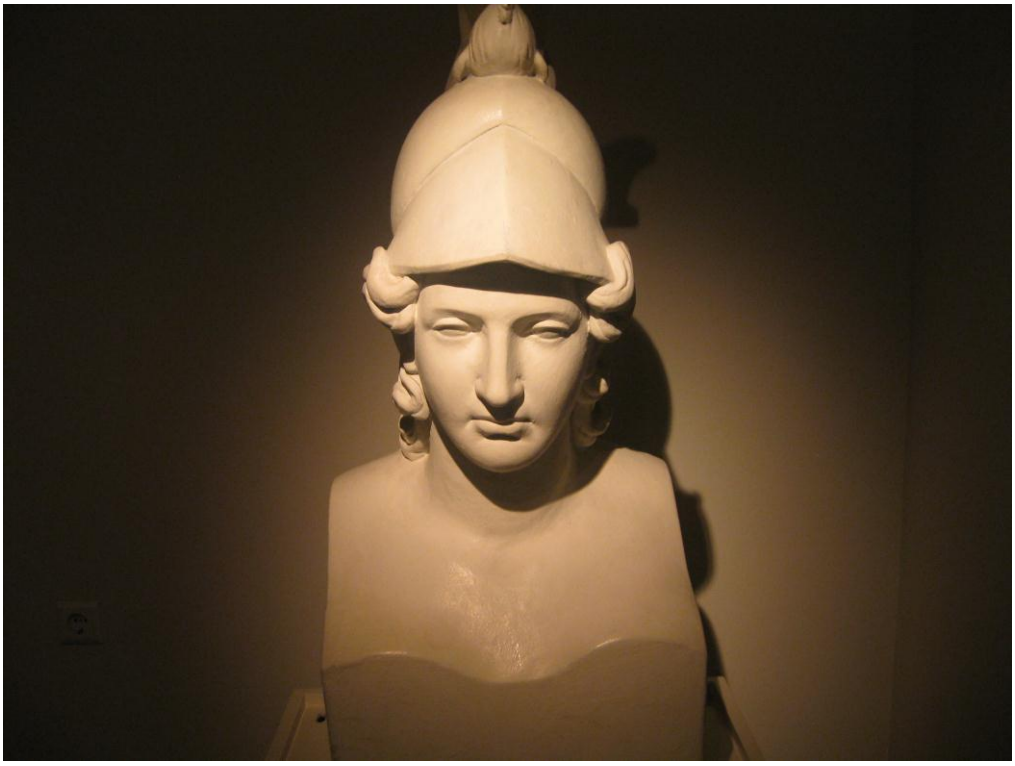
- Uw kennis, vragen en scepsis zijn zeer welkom.

2.

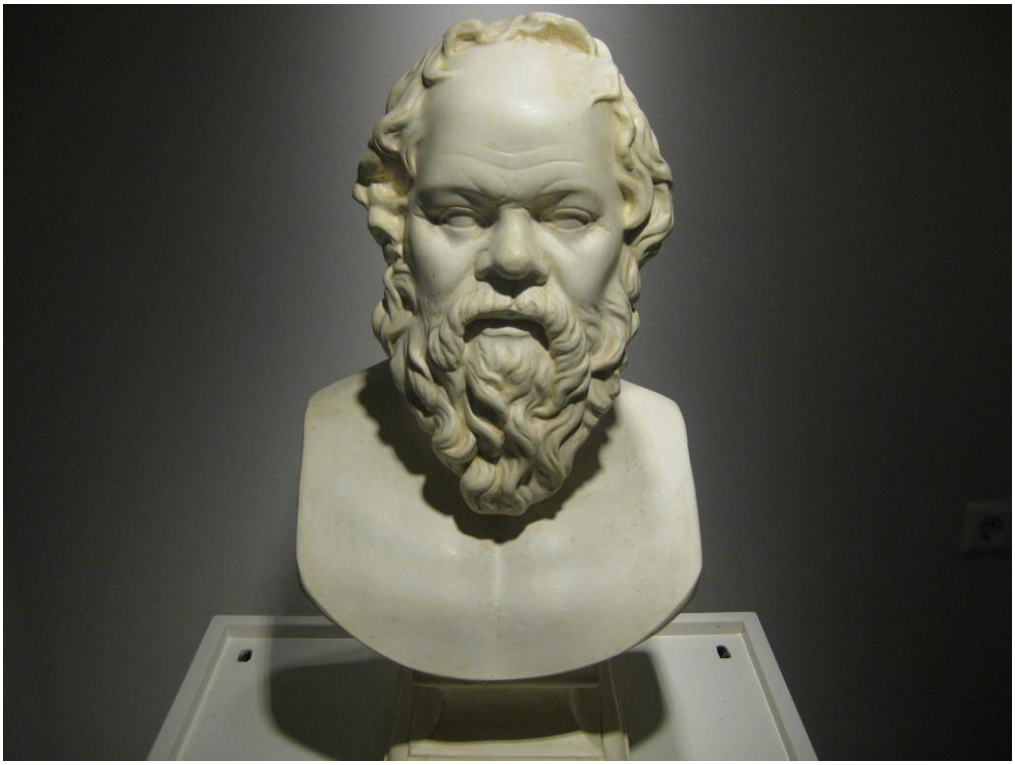
Welkom in zaal 1: de kamer met de beelden

Het is hier wat krap, dus pas op waar u loopt. Uw ziet hier twee beelden staan. Beiden zijn van steen en komen uit dezelfde periode. Maar door de keuze van het licht, vertellen beide beelden een ander verhaal.

Welke informatie maakt u op uit deze beelden?
Wat voor sfeer is er gecreëerd? En waarmee, denkt u?



Halogen. Foto gemaakt door Theo Krol.



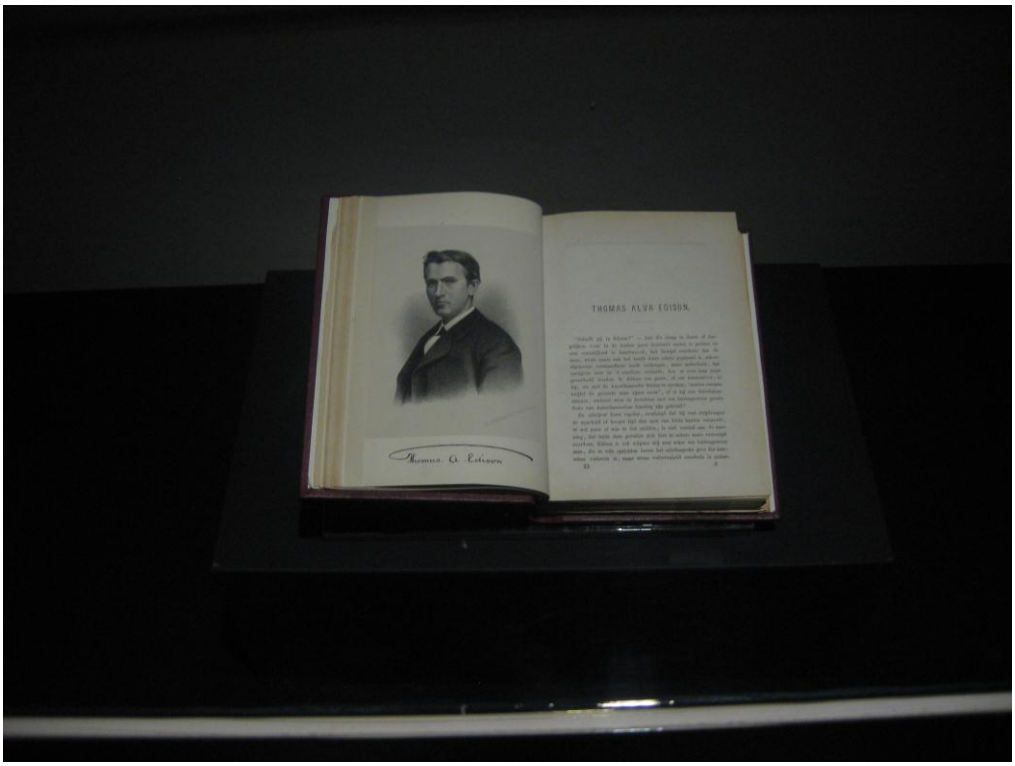
LED. Foto gemaakt door Theo Krol. Stenen beeld van Socrates.

3.

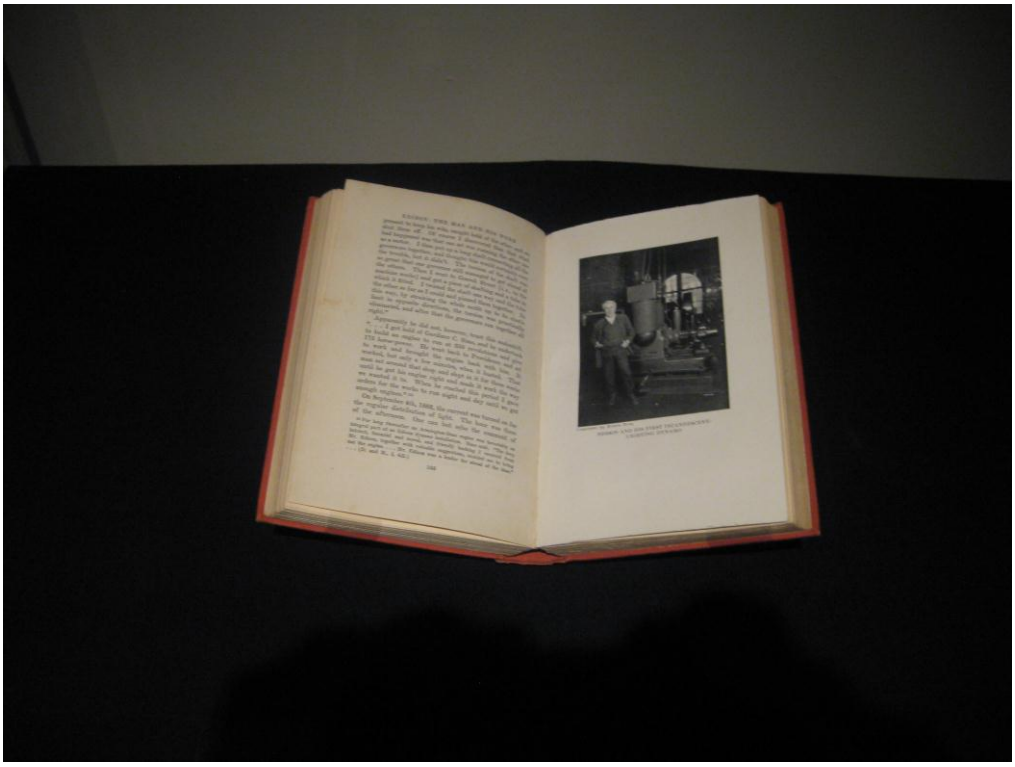
Welkom in zaal 2: de kamer met de boeken.

Lange tijd werd er gaslicht gebruikt voor bijvoorbeeld straattheater en museumverlichting. De sfeer in het dagelijks leven werd mede bepaald door de sfeer die gaslicht met zich meedroeg. Daarna verscheen de gloeilamp. Dit zorgde voor veel opstand in de musea. Men vond o.a. dat de kleuren van kunstwerken niet tot hun recht kwamen met deze elektrische lichtbron. Het tegendeel was eigenlijk waar. Het probleem zat 'm niet in de achteruitgang van de kleurenkwaliteit maar in een verandering in perceptie. Dit kwam niet overeen met hun verwachtingspatroon, smaak en wens. Uiteindelijk is men gewend geraakt aan de gloeilamp. En nu gaan we wennen aan LED-verlichting.

Kijk eens naar deze twee boeken. Kunt u ze allebei lezen? Welke opstelling vindt u mooier, waarom?



LED. Foto gemaakt door Theo Krol.



Halogen. Foto gemaakt door Theo Krol.

4.

Licht beïnvloedt uw perceptie. LED- verlichting kan uw huidige perceptie veranderen. Is uw perceptie een subjectieve wens om alles waar te nemen zoals u het gewend bent te doen? Of kunt u uw oude gedachtes over licht loslaten en openstaan voor iets nieuws?
Als u er klaar voor bent om met een frisse blik te experimenteren met natuurlijk licht en LED, kunt u mij aanspreken.

In de vorige kamer las u dat er altijd voor en tegenstanders zijn bij veranderingen. Bent u nog overtuigd van uw eigen standpunt?

Foto gemaakt door Theo Krol. Schilderij van Jack van Elewout.

Foto gemaakt door Theo Krol. Schilderij van Jack van Elewout.

Appendix 2:

Complete Results of 2.3

Motivation	Halogen	Fluorescent lamps	Gas discharge lamps	Fiber light	LED
Financial	2,6	4,8	3,6	3,2	4
...purchase	4	5	2	2	2
…maintenance	2	5	4	2	5
…electrical bill	1	5	4	4	4
…RH rating consistency	5	4	4	4	4
…lifespan	1	5	4	4	5
Sustainability	2	2	2	2	3
Pre- conservation	2	3	2	2	4
Aesthetics	5	2	3	3	2
Health	5	3	3	3	3
Try new technology	1	2	3	1	5
	28	36	31	27	37
1 = Poor	2,8	3,6	3,1	2,7	3,7
2 = Fair	2,9	2,8	2,8	2,4	3,5

3 = Good
4 = Very good
5 = Excellent

#1

Motivation	Halogen	Fluorescent lamps	Gas discharge lamps	Fiber light	LED
Financial	3,4	4,2	3	2,4	3,4
...purchase	3	5	1	1	1
...maintenance	3	5	3	2	5
...electrical bill	2	5	5	3	5
...RH rating consistency	5	1	1	3	2
...lifespan	4	5	5	3	4
Sustainability	3	3	3	3	5
Pre- conservation	4	1	1	4	4
Presentation/Aesthetics	5	2	3	2	
Health issues	3	2	2	4	5
Try new technology	2	1	2	2	5
	34	30	26	27	36
average	3,4	3	2,6	2,7	4
	3,4	2,2	2,3	2,9	4,5
OUT	3	2	2	3	4

#2

Motivation	Halogen	Fluorescent lamps	Gas discharge lamps	Fiber light	LED
Financial	2,25	3,75	3,25	0	4,25
...purchase	3	3	3		2
...maintenance	2	4	3		5
...electrical bill	2	4	3		5
...RH rating consistency					
...lifespan	2	4	4		5
Sustainability	2	4	4		5
Pre- conservation	5	5	5		5
Presentation/Aesthetics					
Health issues	5	3	3		3
Try new technology	5	4	4		5
	26	31	29	0	35
average	3,25	3,875	3,625	0	4,375
	3,9	4,0	3,9	0,0	4,5

#3

Motivation	Halogen	Fluorescent lamps	Gas discharge lamps	Fiber light	LED
Financial	2,25	2,75	2,75	2,75	4
...purchase	3	2	2	2	2
...maintenance	2	3	3	3	5
...electrical bill	2	3	3	3	4
...RH rating consistency					
...lifespan	2	3	3	3	5
Sustainability	2	3	3	3	4
Pre- conservation	3	3	3	3	5
Presentation/Aesthetics	3	3	3	3	3
Health issues	3	3	3	3	3
Try new technology	2	2	3	3	5
	22	25	26	26	36
average	2,4	2,8	2,9	2,9	4,0
	2,5	2,8	3,0	3,0	4,0

#4

Motivation	Halogen	Fluorescent lamps	Gas discharge lamps	Fiber light	LED
Financial Average	2,9	3,8	3,1	2,8	3,8
...purchase	3,3	3,8	2,0	1,7	1,8
...maintenance	2,3	4,3	3,3	2,3	5,0
...electrical bill	1,8	4,3	3,8	3,3	4,5
...RH rating consistency	5,0	2,5	2,5	3,5	3,0
...lifespan	2,3	4,3	4,0	3,3	4,8
Sustainability	2,3	3,0	3,0	2,7	4,3
Pre- conservation	3,5	3,0	2,8	3,0	4,5
Presentation/Aesthetics	4,3	2,3	3,0	2,7	2,5
Health issues	4,0	2,8	2,8	3,3	3,5
Try new technology	2,5	2,3	3,0	2,0	5,0
total	31,1	32,3	30,0	27,8	38,8
average	3,1	3,2	3,0	2,8	3,9
average	3,2	2,9	2,9	2,8	3,9
OUTCOME	3	3	3	3	4

calculations

Motivation	Halogen	Fluorescent	Gas discharge	Fiber light	LED
Financial Average	2,9	3,8	3,1	2,8	3,8
Sustainability	2,3	3,0	3,0	2,7	4,3
Pre- conservation	3,5	3,0	2,8	3,0	4,5
Presentation/Aesthetics	4,3	2,3	3,0	2,7	2,5
Health issues	4,0	2,8	2,8	3,3	3,5
Try new technology	2,5	2,3	3,0	2,0	5,0
Average score per source	3,2	2,9	2,9	2,8	3,9
Result (round figures)	**3**	**3**	**3**	**3**	**4**

score is based on 4 respondents

score is based on 3 respondents

score is based on 2 respondents

Motivation	Halogen	Fluorescent	Gas discharge	Fiber light	LED
Purchase	3,3	3,8	2,0	1,7	1,8
Maintenance	2,3	4,3	3,3	2,3	5,0
Electrical bill	1,8	4,3	3,8	3,3	4,5
RH rating consistency	5,0	2,5	2,5	3,5	3,0
Lifespan	2,3	4,3	4,0	3,3	4,8
Financial Average	**2,9**	**3,8**	**3,1**	**2,8**	**3,8**

score is based on 4 respondents

score is based on 3 respondents

score is based on 2 respondents