Free dissemination

(ContractTREN/07/D3/390-2006/S07.72702)
Preparatory Studies for Eco-design Requirements of EuPs

Lot 19: Domestic lighting – Part 2 Directional lamps and household luminaires

Final Task Report

Task 3: Consumer behaviour and local infrastructure

Study for European Commission DGTREN unit D3, contact: Andras Toth

Contractor:

Project performed in cooperation with:

Contact Vito: Paul Van Tichelen, info@eup4light.net

2007/ETE/R/

VITO

August 2009

Project team

Vito:
Paul Van Tichelen
Bart Jansen
An Vercalsteren
Bio Intelligence Service:
Shailendra Mudgal
Alexander Thornton
Benoît Tinetti
Energy Piano:
Casper Kofod
Kreios:
Lieven Vanhooydonck
Laborelec (reflector lamp tests):
Jean-Michel Deswert

Important disclaimer:
The authors accept no liability for any material or immaterial direct or indirect damage resulting from the use of this report or its content.
Important note:
This report contains the updated draft results of research by the authors and is not to be perceived as the opinion of the European Commission.
This is an updated draft document intended for stakeholder communication.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

0 PREFACE

VITO and its partners are performing the preparatory study for the new upcoming eco-design directive for Energy Using Products (EuP) related to domestic lighting, on behalf of the European Commission (more info http://ec.europa.eu/enterprise/eco_design/index_en.htm).

The environmental impacts of Energy-using Products such as domestic lighting take various forms, including: energy consumption and the related negative contribution to climate change, consumption of materials and natural resources, waste generation and release of hazardous substances. Eco-design, which means the integration of environmental considerations at the design phase, is arguably the best way to improve the environmental performance of products.

The creation of a coherent framework for environmental product policy avoids the adoption of uncoordinated measures that could lead to an overall negative result; for example eliminating a toxic substance from a product, such as mercury from lamps, might lead to increased energy consumption, which could in total have a negative impact on the environment. A Community framework also ensures that divergent national or regional measures, which could hinder the free movement of products and reduce the competitiveness of businesses, are not taken. It is not the intention to decrease the quality of domestic lighting.

The objective of this interim draft document is to present preliminary data for discussion with stakeholders related to the EuP preparatory study for the lot 19.
You can follow the progress of our study and find general information related to lot 19 on the project website when you register as stakeholder: http://www.eup4light.net
Please, also consult the website for timing and organisation of the tasks.

Important remark:
It must be clearly stated that this part 2 of the study relies on the draft regulation resulting from part 1 of the study on non-directional light sources. Specific items on non directional lamps that were discussed in part 1 will not be repeated in this part 2. Items that are related to all light sources can be repeated, only to improve the readability, not for new discussion.

1 PRODUCT DEFINITION

For more info see website www.eup4light.net.

2 ECONOMIC AND MARKET ANALYSIS

For more info see website www.eup4light.net.

3 CONSUMER BEHAVIOUR AND LOCAL INFRASTRUCTURE

Consumer behaviour can -in part- be influenced by product-design but overall it is a very relevant input for the assessment of the environmental impact and the Life Cycle Cost of a product. The scope of this chapter is to identify barriers and restrictions to possible eco-design measures, due to social, cultural or infra-structural factors. A second aim is to quantify relevant user-parameters that influence the environmental impact during product-life and that are different from the Standard test conditions as described in section 1.2.

3.1 Definition of the Consumer and context

For domestic lighting it is important to discriminate between the two types of customers who purchase lamps and luminaires:

1. The person responsible for the putting into service of a new house/flat or renovation of parts of the home, e.g. interior designers, property developers, kitchen and bathroom designers and installers, hereafter called the *'service providers'*. Please note also that more and more appliances are including lighting, e.g. extractor fans in the kitchen in which case a service provider is also involved. Interior designers and/or lighting architects are thus having a growing influence and some decisions are taken in the same as in some parts of the tertiary sector.
2. The consumer who lives in the home and makes use of the lighting equipment, hereafter called the *' user'*.

In the domestic lighting market the 'service provider' and 'user' can be the same, especially when Do-It-Yourself (DIY) equipment is bought and put into service by the user as a DIY consumer.

Nevertheless, the ’service providers’ is often not the user. They have a growing influence on energy used in the domestic homes because with growing welfare, many people install new kitchens, bathrooms, corridor, adding a veranda etc. In this process, the designers, home decorators, installers or qualified electrician have a large influence by including lighting solutions that are typically outdoors, installations in the ceiling, and sometimes even more. Some of those furniture and appliance manufacturers include lighting in their products, and this market is dominated by a multitude of down lighting by reflector lamps actually mainly of the halogen type. The lighting is an integral subcomponent of the design and installation process where the customer buys “the whole package” including lighting. In this case both service providers and the consumers take decisions that affect the quality, cost and efficiency of lighting in the home. In case service providers tender and win jobs on having low costs while not having to pay any future operating costs there is a ‘split incentive’: there is no incentive for service providers to purchase high efficiency lighting because it usually has a higher first cost and may mean they aren’t awarded the contract.

It should be noted that the lamps and luminaries within the scope of this study are also used in lighting for the tertiary sector (e.g. Horeca sector, shops). In this sector, service providers are typically involved and often also lighting designers performing calculations. The process is similar to what is described in the preparatory study concerning office lighting (Lot 8). Please see this study[1] for description of this service approach – in contrary to domestic circumstances photometric data for 'architectural lighting luminaires' for offices is available for the service provider and lighting designer. In general, the tertiary sector is more conscious of full life-cycle costs and thus manufacturers tend to enter that market first with higher first-cost products with lower overall operating costs. The products then migrate to the domestic sector, as manufacturers perfect their designs and technology and lower the production costs.

3.2 Real Life Efficiency and quantification of relevant parameters

3.2.1 Background info on lighting design criteria

The concept of energy-efficient lighting is meaningless unless the lighting system provides the conditions necessary to perform the task. The goal in designing a lighting system is to provide a suitable visual environment that provides "right light at the right time at the right place".

The main objectives for installing electric lighting systems are:

- Facilitating the performance of visual tasks
- Promoting safety and security
- Attractively revealing the environment – create atmosphere
- Participating in the interior design of the household by attractive design of lamp or luminaire.

The priority of the above objectives in the design process depends on the specific situation and the preference of the user. Moreover, if the object is three-dimensional or coloured, the direction of the incident light or its colour rendering properties becomes important determinants of visibility.

In the domestic sector all the design is up to the consumer in contrast to the commercial sector using lighting codes and standards for satisfactory visual performance.

Considering usefulness and effectiveness of DLS, it is essential to choose the correct beam angle and field angle for cover of a kitchen work surface or highlight a painting on their wall.

[1] VITO EuP Lot 8, Office Lighting, Final Report, April 2007.

3.2.2 Lumen losses within luminaries

For *luminaires with DLS lamps* nearly all luminaires found on the market do not obstruct the functional lumen output from the lamp as defined in Task 1 (functional unit) (see Figure 3.1). Hence for these luminaires there is simply no improvement potential related to lumen losses. Please note that this might to some extent explain the popularity of those DLS lamps (see chapter 2). The LOR (Light Output Ratio) of those luminaires is 1.

Figure 3.1 DLS luminaires have most often LOR=1

For luminaires with NDLS lamps there is a broad spread on lumen losses within luminaires (LOR) (see Figure 3.2). The LOR for these luminaires can vary from below <0.1 up till 1 (bare lamp holder).

Figure 3.2 Domestic luminaire for NDLS: left with LOR <0.1, middle[2] LOR > 0.5, right >0.99

Notes on luminaire LOR (Light Output Ratio):

- Both the visual appearance and the lumen losses within luminaires are optimal when the luminaire is designed for the lamp type used in the luminaire. It is therefore important that luminaire manufacturers bring luminaires on the market that are dedicated to the lamp type so the customer is aware of combining luminaire and lamp in the best way. Hence LOR can vary in real life if another lamp type or shape is used in the luminaire.
- The right energy efficient luminaire will balance: maximum light output ratio, glare control, light distribution and amount of decorative ornaments that absorb light.
- It should be noted that the LOR improvement potential for functional luminaires that are used in the tertiary lighting sector were assessed in preparatory studies on office and street lighting (lot 8 and 9). All those luminaires have an optical system to control the light distribution. This information and approach will not be repeated in this study.
- Lumen losses can be compensated with a coating material combination with high reflectivity itself and a specified coating design for the reflector. Typical efficiency of the reflector (DLS) within the light field varies between 60% and 80%, depends on the reflector type, coating and light source.[3]
- In case of LED luminaires with integrated lamps, only LER can be used (see chapter 1 for definition of LER).
- The main parts (e.g. lamp cap) that influence LOR and light distribution are often sold separately (see Figure 3.3).

[2] Lesslamp by Jordi Canudas (b. 1975 Barcelona, Spain): The Less Lamp is a sealed lamp shade that needs to be broken in order to release the light trapped within. The shell is cracked using a specially designed hammer. The user decides the appearance and position of the hole depending on how much light is required and where it is to be directed.

[3] Information provided by Auer Lighting.

Figure 3.3 Domestic NDLS luminaire (LOR=1) that optionally can be equipped with a lampshade (LOR<1). The lampshade prevents glare and influences light distribution.

3.2.3 Illumination losses in the task area by lack of lighting design

For performing a visual task, maintaining a minimum illumination level in the task area is essential, moreover glare should be prevented and the uniformity should be kept within acceptable limits. This is the typical approach for a professional lighting design within the tertiary sector as explained in the preparatory study on office lighting (lot 8). Domestic lighting is typically not related to measurable lighting levels, so it is primarily up to the consumer's requirements of functionality and creating atmosphere. Luminaire efficiency has thus no impact on selection choice for the vast majority of users. For domestic luminaries used over a long period, the appropriate lamp choice will change according to the location and use of the luminaire, as well as when the user grows older and requires more light for the same task. Fashion lighting is replaced according to personal choice. In neither situation will there be a single lamp rating that will be "correct" unless it forms a physical part of the appearance or operation of the luminaire.

Increased domestic use of DLS with dimmers instead of NDLS create the ability to control light with distinct variations between light and dark that might allow screen based entertainment with better viewing conditions. This increases the number of lamps but not necessarily the electricity consumption depending on the behaviour of the consumer. In this case, simultaneous use of all the lighting sources will likely produce unpleasing lighting conditions.

Nevertheless, professional lighting designers are seldom involved in domestic lighting and many common practices found in domestic lighting cause a loss of illumination[4]. Following are two examples of how reflector lamps are used in domestic sector that illustrate the opportunity for improvement in this area.

Example 1 Poor application for reflector lamp – DLS used as NDLS:
Many reflector lamps are used for general lighting (as NDLS) without making use of the lighting that is limited to a specific beam angle. On the contrary, there might be areas not lit properly where the users thus install extra lighting.

[4] PLDA agrees that there is a lot of thoughtless application of multiple down-lights in new build and refurbishment and this needs to be controlled - they see this as a design issue not a technology issue.

Example 2 Optimum use of reflector lamps (DLS):

In this case a series of spot lamps with adjustable lamp holders are installed in the ceiling. This allows the user to control and fine tune the light in the desired direction e.g. towards the wall behind the sofa or at the table and away from the TV set. The "optimum" installation might also be dimmable so that the user can adjust lighting levels optimally for changing needs in the living room (e.g., watching TV vs. reading). This is a very common practice in the modern living room and is part of the explanation for the growth in use of DLS (see chapter 2).

3.2.4 Room surface reflection

The room surface reflection can have a significant influence on the illumination level in the task area, for more information see the preparatory study on office lighting (Lot 8)[1]. The improvement potential (e.g. using white painted walls) is outside the product scope of this study.

3.2.5 Lamp efficacy and sensitivity of the human eye

Please see chapter 3 in the final report for part 1 of the study and the new mandatory regulation 244/2009.

3.2.6 User influence on switching schemes (annual operating time)

Please see chapter 3 in the final report for part 1 of the study.

3.2.7 Lamp dimming

Please see chapter 3 in the final report for part 1 of the study.

3.2.8 Influence of the power factor and harmonic currents of a light source

Please see chapter 3 in the final report for part 1 of the study.

3.2.9 Influence of voltage change

Please see chapter 3 in the final report for part 1 of the study.

1

3.2.10 Decrease in lamp efficacy in real life operation compared to standard conditions

The lamp efficacy that is announced by manufacturers is measured after an ageing period of a number of hours burning in standard conditions as defined in the specific European standard on performance requirements for the lamp type (see chapter 1).

Due to normal ageing and deviation from lamp specification conditions when placed in a luminaire, the efficacy might be influenced – this is certainly the case for a LED luminaire.

3.2.10.1 Lumen depreciation over the life time

For all lamps except LED please see chapter 3 in the final report for part 1 of the study.

WLED retrofit lamp

For most light sources, the lamp fails before significant lumen depreciation occurs while LEDs continue to operate also at very low light levels. Therefore LED lifetime is usually defined as lumen depreciation to a certain level e.g. 70% of initial lumens (abbreviated as L70 or L_{70}) together with a particular failure rate e.g. B50 (also known as F50) (50% failure rate, see also chapter 1 and figure 3.7).

The LED industry group ASSIST[5] (Alliance for Solid-State Illumination Systems and Technologies); stated that 70% lumen maintenance is close to the threshold at which the human eye can detect a reduction in light output. LED manufacturers publish lumen depreciation curves based on testing of their products, extrapolating lumen depreciation to the 70% level because it takes too long to measure. For LEDs, this threshold might be too low because people will age by more than ten years within the long LED lifetime and people lose sensitivity of their eye with age.

Depending on the application, other depreciation levels may be appropriate as end of life limits, such as L_{50} or L_{80}.

The standard IESNA LM-80-08 – Approved Method for Measuring Lumen Maintenance of LED Light Sources (released 2008) applies to LED arrays, packages and module but **not** luminaires. It includes a test method for $L_{70,}$ including photometric measurements at three temperatures 55^{o}C, 85^{o}C and XX^{o}C (the manufacturers own choice) and a test duration of minimum 6,000 hours with measurements at 1,000 hour intervals. This standard does **not** provide guidance regarding predictive estimations or extrapolation. IES TM-21-xx which is currently under development will address this topic.

Figure 3.4 shows an example of a LED **predicted** lumen maintenance curve for a warm white LED[6] in operation at drive current 700 mA with junction temperature at or below 120^{o}C where the lumen depreciation starts right from the start and 80% depreciation occurs already around 1100 hours and 70% occurs around 25,000 hours.

[5] Details about ASSIST can be found at www.lrc.rpi.edu/programs/solidstate/assist/index.asp
[6] Atlas Lamina Series LED Light Engines, FM-0167, rev. 02.14.2007.

ELC informs[7] that especially in LED retrofits, driver components experience high temperatures as they are hidden inside or next to the heat sink. Thus, lifetime can be limited by a sudden driver failure when components like capacitors reach their end-of life. This must be taken into account when defining lifetime. Concerning lifetime stated on the package, ELC claim that manufacturers should be obliged to provide lifetime estimations or elevated-temperature measurements that predict a driver lifetime.

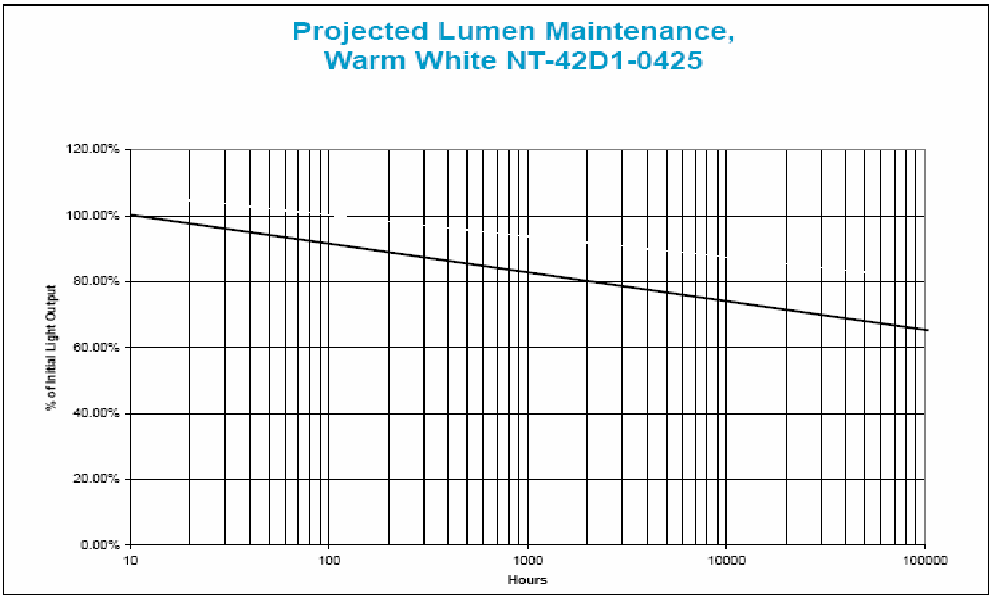


Figure 3.4: Predicted LED lumen maintenance curve for a warm white LED Source of a relatively lower quality: Atlas LED Light Engines, www.laminalighting.com

Figure 3.5 shows a **measured** LED lumen maintenance curve for the first 6000 hours provided by one of the large manufacturers[8] where 92% depreciation occurs at 6000 hours

[7] ELC comments to the first draft of the chapter.
[8] PHILIPS Technology White paper: Understanding power LED life analysis, *www.**philips**lumi**leds**.com/pdfs/WP12.pdf*

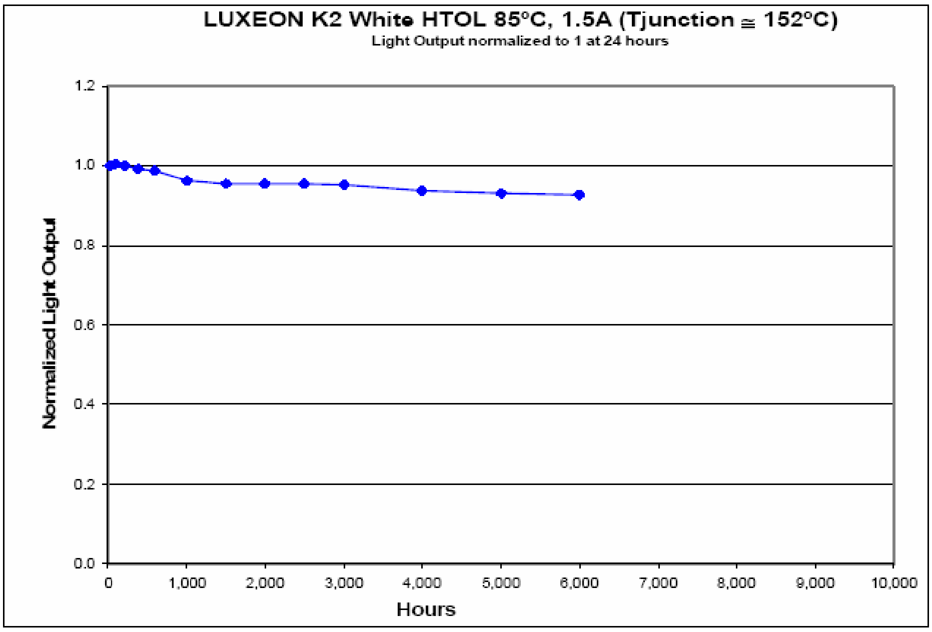


Figure 3.5: LED lumen maintenance curve for Philips Lumileds K2 LED (high quality)

The LED depreciation varies a lot depending on the quality of the product.

Conclusion

The LED chip has a lifetime of at least 50,000 hours in most application situations but as informed by ELC[9] the lamp lumen maintenance depends primarily on the materials surrounding the chip: epoxy coatings will typically not survive 10,000 hours and plastics materials in the housing tend to show browning of materials in the light path (epoxy, silicone) that will gradually decreasing light output and often with an avalanche-type browning that may lead to almost complete shadowing e.g. after 7,000 hours. In the end, only qualified lifetime data on all the components included can give a clear indication of predicted lifetime.

For the LED, a depreciation factor of 0.95 for the first 6,000 hours and 0.85 for the first 25,000 hours is good quality. For the LED lamp, the factor might be much lower depending on the use of materials besides the LED chip.

Integrated LED luminaires

This section is based on the large amount of American data available publicly and some rather new data European data provided in relation to stakeholder meeting or presented at recent conferences. The main purpose of chapter 3 is to present the quality issues from a consumer perspective. Quantitative European LED lamp data used in our calculations (see chapter 7 and 8) are shown in chapter 4 and 6.

Rated output for LED chips and LED lamps is often quoted at a temperature of 25°C which is very different from operation in a LED luminaire where the junction temperature typically will

[9] ELC comments to first draft of this chapter.

be in the interval 60-150°C. A LED manufacturer[10] informs that high thermal impedance (poor thermal conductivity) from the LED chip to the heat sink will lead to elevated junction temperatures and this will have a profound effect on lifetime and ageing characteristic of the LED. They inform that thermal resistance of a properly designed dedicated LED luminaire might be in the range 0.5 to 1°C per watt and it is possible to operate luminaires with LEDs that self-heat to only a little above ambient temperature and nowhere near the junction temperatures quoted above. Test specifications and procedures must relate to continuous operation in still air conditions e.g. a recessed downlighter would be designed to be installed in a ceiling and maybe covered with insulating material.

A European business manager[11] reports that good thermal management is the key for successful LED lighting design as both lifetime, light-output, efficiency and colour stability are directly linked to the temperature. They report the rule of thumb that every 10°C temperature rise will half the lifetime.

The DOE CALiPER program[12] began reliability testing on LED luminaires in August 2007. Figure 3.6 summarize lumen depreciation interim testing results for 13 LED products. The lumen depreciation testing is not completed for these samples, but these interim results already provide insight. The two white lines in the plot are provided as reference curves: the horizontal white line indicates 70% of the initial output, and the descending white curve represents a typical logarithmic decay that would reach L70 at 50,000 hours.

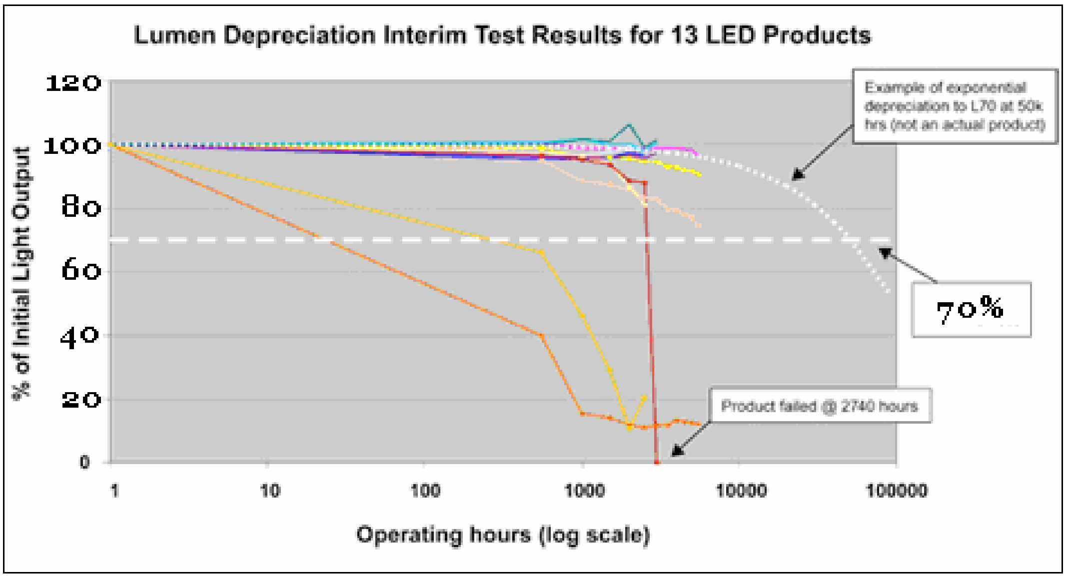


Figure 3.6: Interim results from CALIPER lumen depreciation testing. May 2008, source: CALIPER Round 5 Summary Report

Some luminaires in Figure 3.6 maintain output levels over the first 6,000 hours of operation (7 of 13 products are producing over 96% of their initial output). Others exhibit rapid lumen depreciation within the first 1,000 to 2,000 hours, and some products exhibit significant colour

[10] Information provided to the study by PhotonStar LED Ltd, UK, Robin Morris
[11] "Good Thermal Management is the key for Successful LED LIghtikng Design", Michael Stoll, The Bergquist Company GmbH, CIE Light and Lighting Conference, 25-27 May 2009.
[12] U.S. Department of Energy - Energy Efficiency and Renewable Energy, Solid-State Lighting, http://www1.eere.energy.gov/buildings/ssl/reliability_points.html

shift over the first 6,000 hours of operation. No general patterns can be observed yet (please observe these results are from 2007/2008 and LED applications are improved with a very high speed but the variation in quality at the market is huge).

The 13 products in Figure 3.6 cover a range of LED configurations, including task lamps, replacement lamps, retrofit lamps, and outdoor area luminaires. At this point of testing, and given the small sample size, one cannot draw conclusions about the lumen depreciation performance of any particular category of products (based on size or application).

A Technology institute in Korea[13] reports that LED luminaire manufacturers often claim a lifetime of 50,000 hours but this is typically only based on the LED used and do not account for other components as thermal resistance between LED chip and air, plastic encapsulation, semiconductor defects, etc. The institute performed accelerated life test using ambient temperature stress conditions for samples of 3 products and found a lifetime at room temperature as low as 5500 hours.

In June 2008, the DOE reports, there is not a standard reporting format for LED lifetime or lumen depreciation curves. A test procedure currently is in development by the Illuminating Engineering Society of North America (designated LM-80, IESNA Approved Method for Measuring Lumen Maintenance of LED Light Sources). The US Lighting Research Centre also reports[14] that their preliminary test results indicate significant performance variations among different manufacturer's products and they mention that researchers are developing alternate lifetime prediction methods to avoid long-term product testing.

The EPA Residential Light Fixture program is under development and has expanded it scope to include decorative LED fixtures[15].

3.2.10.2 Decrease in lumen output and lifetime due to temperature

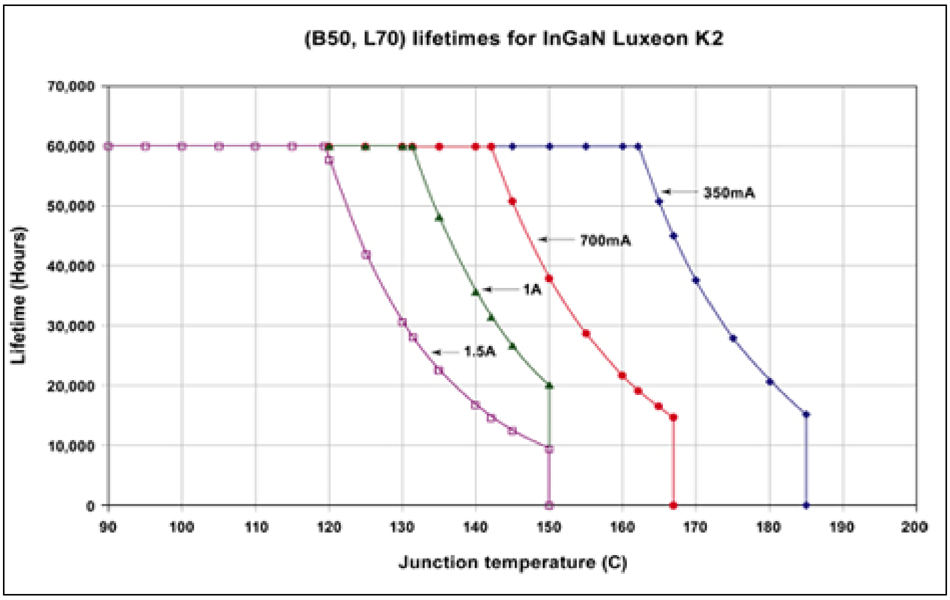
Concerning, CFLi/CFLi-R please see chapter 3 in the final report for part 1 of the study.

As mentioned above, the rated output and nominal output for an LED is often quoted at a temperature lower than the junction temperature in an LED fitting or luminaire, in which the light output and efficiency will be significantly less. It is therefore necessary to test LEDs in a complete system.

The LED lumen maintenance is dependent on drive current and junction temperature. Figure 3.7 shows published lifetime curves from a large manufacturer for their K2 LED package. According to this graph the lifetime decreases with higher junction temperature and the junction temperature has to be decreased in case the drive current is increased, e.g. to obtain a lifetime of 60,000 hours the junction temperatures has to be lower than 140°C with at drive current 700 mA where it could be up to 160°C with a drive current at 350 mA.

---

[13] "LED Reliability Test for General Lighting", Seung Hyun Park and others, Korea Photonics Technology Institute, Korea, DIE Liht and Lighting Conference, 25-27 May 2009.
14 http://www.lrc.rpi.edu/programs/solidstate/cr_highfluxleds.asp
[15] http://www.energystar.gov/index.cfm?c=revisions.fixtures_spec



B50, L70 means 50% of the products have at least 70% lumen maintenance for the projected number of operating hours.

Figure 3.7: Expected LED lifetime as a function of drive current indicated by each coloured line and target LED junction temperatures. Source: Philips Lumileds

Accurate measurements of the LED junction temperature in a fitting or luminaire will help in designing optimal thermal management of lumen output, energy efficiency and lifetime, and at the same time it will reduce the number of LEDs needed to obtain a specific lumen output. However, there are conflicting requirements as use of a larger number of LEDs improves the energy efficiency and lifetime by driving the LEDs less hard in order to obtain the same light output as for a smaller number of LEDs using more power. However, this is at the cost of using more LED chips.

Some new standards are under development by the CIE to address test methods that evaluate the junction temperature and as well IESNA standards concerning approved methods for electrical and photometric measurements of high-power LED's (please see chapter 1 for the actual status of the standards).

With high-power LEDs it is essential to remove heat from the LED through efficient thermal management by use of materials with high thermal conductivity. Unfortunately, some high thermal conductivity materials are relatively expensive, and there is a trade/off between cost, performance, manufacturability and other factors. As the efficacy of LEDs increase, a greater share of the input wattage will be converted into photons and less waste heat will be generated. Thus, heat sinks for LED luminaires will be smaller as the technology improves, and a decrease in size means luminaire size and cost will also reduce because less heat-sink is necessary.

3.2.10.3 Interactive effects of the light source on heating/cooling of the house

Please see chapter 3 in the final report for part 1 of the study.

3.2.10.4 Conclusion on correction factors used for real life lamp efficacy

Please see chapter 3 in the final report for part 1 of the study.

3.2.10.5 Luminaire maintenance factor (LMF)

This factor takes into account the soiling of luminaire surfaces and associated light depreciation. For more information about this topic please see the preparatory study on office lighting (lot 8)[1]. Luminaires in commercial installations are supposed to get dirty faster because they have higher density of people traffic, longer use-hours per day and associated dust levels. The cleaning might also be more frequent in the home. Household luminaires are used in a higher variety of circumstances than office luminaires. In the household, table, wall-mounted, floor-standing and furniture-integrated (e.g. kitchen) luminaires are likely to get dirty faster but also to be cleaned more frequent than lamp in the ceiling.

Concerning the use of reflector lamps (DLS), luminaire pollution is normally not considered to be a problem, because the complete optic system is within the lamp and replaced with the lamp. Cleaning of domestic luminaires is a common practice and in many cases straightforward. This raises LMF.

With reference to the discussion above and the office lighting study (lot 8) mentioned above, the conclusion is:

- For luminaires with DLS lamps LMF will not be used (LMF=1).
- For luminaires with NDLS the benchmark value of office lighting can be used (LMF =0.95).

3.2.11 Homogenity of the light field in sight of contrast[16]

An homogenous impression of a light field of a luminary leads to relaxed and pleasing atmosphere for the consumer. If any distortions/shadows within the light field the consumer might be try to compensate it with further luminaries in order to overlap the distortions/shadows. It might be sense to evaluate a kind of homogeneity within the light field. Independent of the adaption phase of the human eye and environment illumination, the variation of the illumination level along the initial curve should not exceed ± 5 %. Details are shown in Figure 3.8.

[16] The content of this section is provided by Auer Lighting

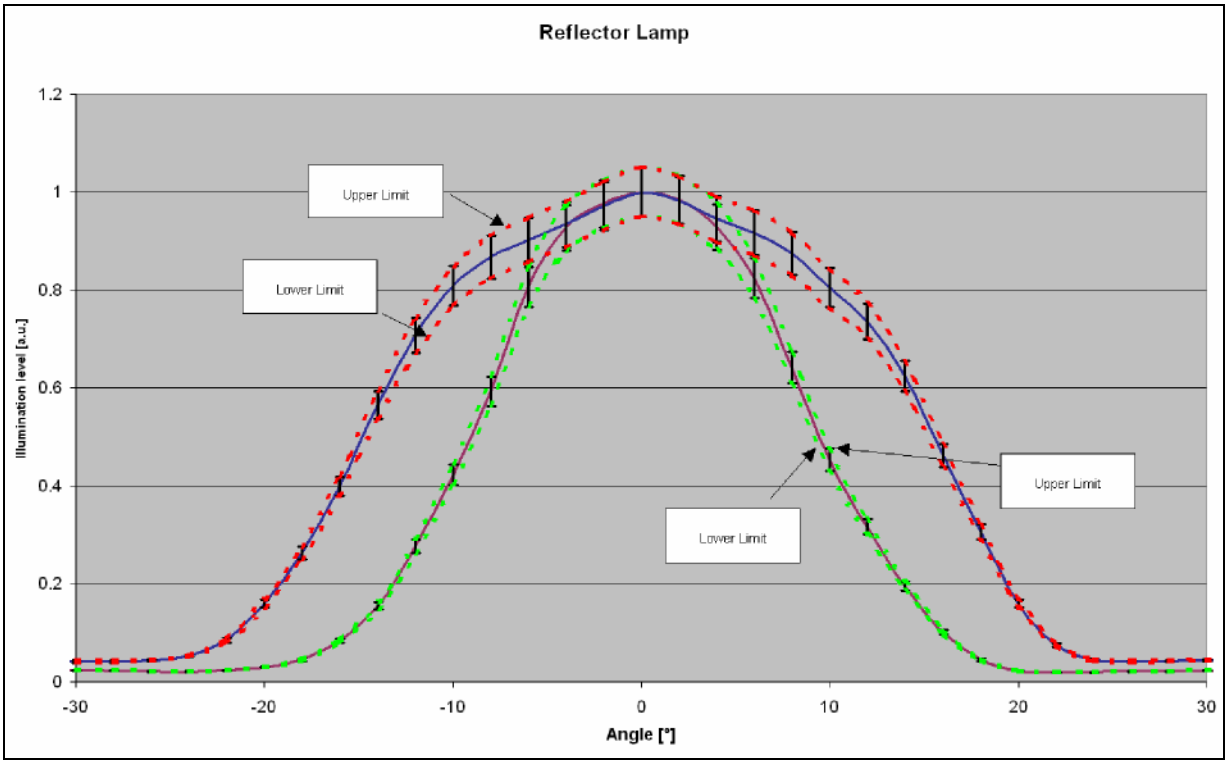


Figure 3.8: Variation of the illumination level along the initial curve should not exceed ± 5 Source: Auer Lighting

Typical light distribution curves for different types of reflector lamps are stipulated in:

- Figure 3.9 for a 50 mm Reflector lamp in combination with a halogen light source.
- Figure 3.10 for PAR 38 Reflector in combination with a halogen light source.
- Figure 3.11 for a 50 mm Reflector in combination with a discharge lamp.

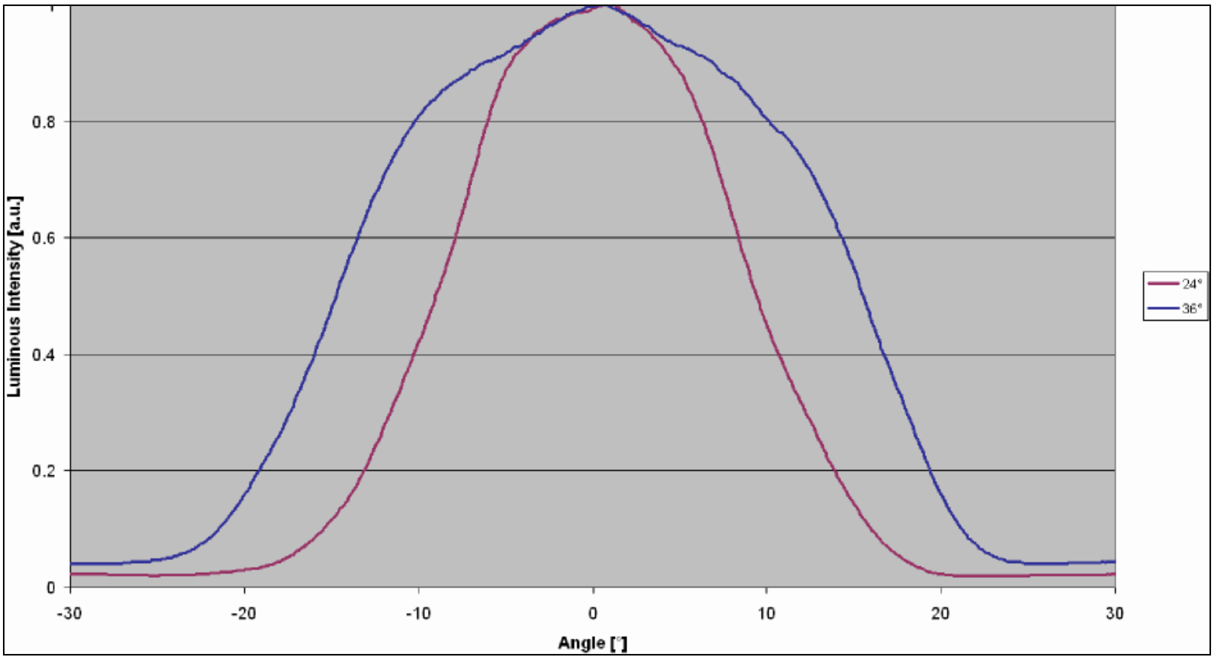


Figure 3.9: Sketch of typical light distribution curve for a 50 mm reflector lamp in combination with a halogen light source Source: Auer Lighting

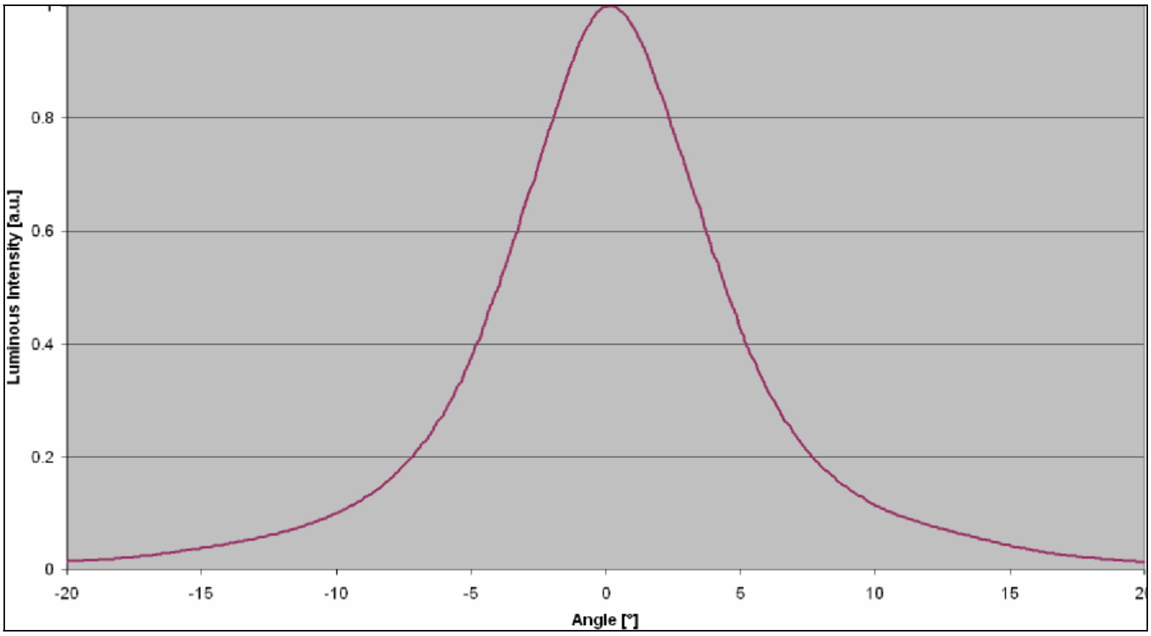


Figure 3.10: Sketch of a typical light distribution curve for a PAR38 reflector lamp in combination with a halogen light source Source: Auer Lighting

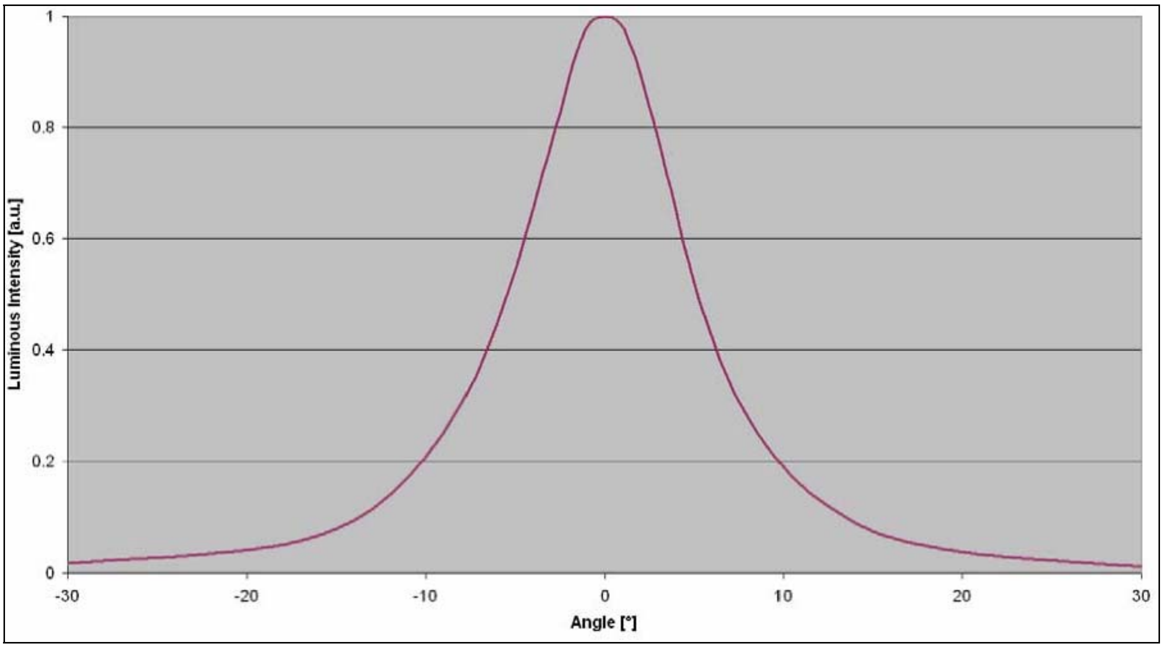


Figure 3.11: Sketch of a typical light distribution curve for a 50 mm reflector lamp in combination with a discharge lamp Source: Auer Lighting

3.2.12 Homogenity of the light field of colour impression[14]

A homogenous colour impression in the light field of the reflector lamps leads to a pleasing atmosphere as well. In order to describe the colour inhomogenity further light technical measurements were done. The maximum difference of the colour coordinates within the complete light field up to the tenth beam angle was measured for different types of reflector and light source combination. Detailed results are shown in Table 3.1.

Table 3.1: Test results: Colour coordinates within the complete light field, Source: Auer Lighting

Reflector Type	Half beam angle in [°]	Light Source	dx	dy
50 mm	10	Halogen	0.002	0.002
	24	Halogen	0.004	0.002
	36	Halogen	0.011	0.005
50 mm	24	Discharge	0.012	0.012
	36	Discharge	0.012	0.006
PAR	36	Halogen	0.004	0.002
50 mm	32	LED	0.06	0.09

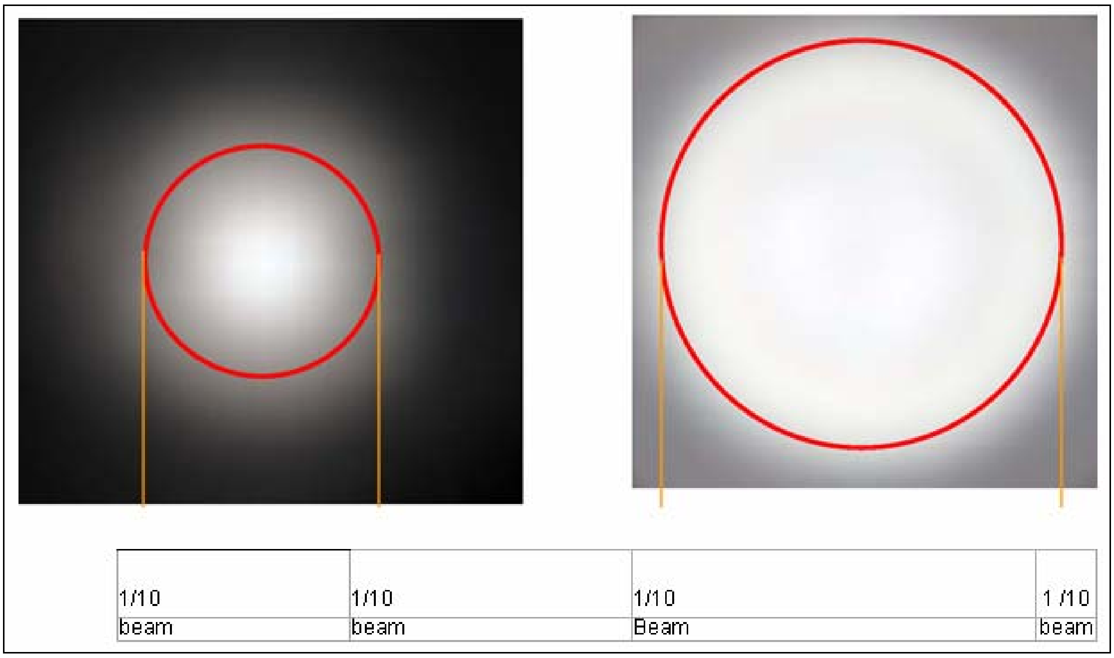


Figure 3.12: Sketch of the light field and the measurement area for the colour coordinates. Source: Auer Lighting

3.3 End of Life behaviour related to consumers

Please see chapter 3 in the final report for part 1 of the study.

3.4 Influence of local infra-structure and facilities

3.4.1 Influence of the physical room infrastructure

Please see chapter 3 in the final report for part 1 of the study.

3.4.2 Lack of skilled and informed users

A very broad range of DLS lamps for domestic application is available on the market (see chapter 1). A one to one comparison of lamp types is not always straightforward and could create a user barrier as will be discussed in more detail in 3.5. The new lamp types often have very different selection parameters that, when applied correctly, could offer more comfort and user satisfaction. For example, CFLi-R and LED might be bought in a broader product range of colour temperatures, light distribution patterns or product lifetime compared to GLS or halogen lamps. Concerning beam angles, HL-LV lamps are offered with all kind of beam angles while CFLi-R are at present only available for broad angles (down to 70 degrees) due to information from a leading market manufacturer.

The well known GLS-products might be replace by a large variety of products, but often the single store has only a few products, little knowledge and little experience. This gives a high risk of buying dissatisfying products. In this situation, cheap products with a short lifetime also seem to be important, besides the expensive long lifetime products justifying a fairly high price. Users should therefore be clearly informed about correct lamp selection parameters (start up time, light colour, light distribution, beam angle, light output, dimming method, life time, temperature sensitivity...) It is also recommended that users are informed in a timely manner about the proper energy efficient retrofit solution in case certain products become obsolete.

Designers and their organisation note that great many reflector lamps are being used inappropriately in the domestic settings when a number of down-light reflector lamps are used for general illumination of kitchen, bathroom, corridor, hall, bed rooms and even living room although reflector lamps are not made for this purpose.. In many circumstances, directional lighting typically with 24 degree beam angle might provide inadequate lighting and therefore additional lamps with more distributive characteristics are added resulting in the total electrical lighting consumption becomes unreasonable. Frequently dimmers are used to be able to reduce the light output from the down lighters that often cause discomfort glare. Use of a multitude of halogen down lighters in the kitchen often also causes thermal discomfort[17] by emitting heat. It appears as there is a large potential for energy efficient lighting.

The down lighters cause discomfort glare because of the brightness of halogen, LED and some CFLi-R lamps without an outer envelope and that the eye look up directly at the lamps without any kind of shielding – the higher wattage, the larger discomfort glare. Disability glare might also occur and might cause increased lighting consumption when an increase in the background luminance contributes to an increase in veiling luminance. Consequently, a higher luminance for the object to be perceived could be needed.

The brightness of the lamps might be adjusted with appropriate fixtures and dimmers. However, the colour temperature of the lighting from GLS and halogen lamps changes significantly when the lamp is dimmed which is undesirable when the lighting supplements daylighting.

Problems with glare might be reduced by buying lamps with smooth reflectors (with a mirror finish) as they should create a sharper fall-off to the illuminated area.

In many cases, consumers choose to install luminaires that provides functional illumination and an attractive decoration. However the knowledge to provide sufficient illumination often fails and often the selection is only made from a “decorative” point of view. In that case the consumer might end up by overcompensating a stronger lamp or with more luminaires. More information on the optical efficiency of the luminaire and its standard performance along with a recommendation of lamps at the moment of purchase could support the consumer.

[17] ELC informs that dichroitic mirrors might be used in the DLS to avoid thermal discomfort.

3.4.3 Lack of skilled service providers

This is especially important for furniture-integrated luminaires (e.g. kitchens, bathrooms...) as sales people could have a strong influence on the selection and the amount of installed luminaires in modern houses. Service providers do in many cases also install reflector lamps in down-lights for general illumination. The user often experiences that the directional light provided is inadequate to make the room feel “lit”, install additional lamps and increase the electricity consumption. The cases have not occurred if the right beam angle for the DLS or a NDLS has been used.

Service providers installing domestic lighting are not likely to use software to design their illumination strategy for a room. Rather, they would tend to over-illuminate a space and install a dimmer, so the end-user can adjust the room according to their taste and they cannot be criticised for low light levels.

Some energy retrofit solutions, e.g. replacing a dimmable GLS or halogen lamp by a CFLi-R or LED can benefit from professional advice in order to reduce trial and error by users and possible negative consumer experiences.

As discussed in part 3.1, there might be a ‘split incentive’ with no incentive for service providers to purchase high efficiency lighting because it usually has a higher first cost and operating costs are not considered as a part of their business - although it could be considered.

3.4.4 Luminaire socket and space lock-in effect

Compared to NDLS, DLS include a much greater range of caps/bases and lamp sizes and, typically, luminaires are designed to closely house the reflector lamps. When considering smaller form factor lamps such as MR16 and AR111, the lamp itself can be a structural part of the fitting. There are possibly the majority of small reflector lamp fittings that cannot operate with lamp types other than that for which they were originally designed.

Additionally the beam and field angle of the reflector lamp are key operating factors so replacement lamps have to have identical beam characteristics to the lamp they are replacing.

3.4.5 Electrical wiring lock-in effect

Consideration has to be given to internal wiring in luminaries and systems with external transformers, both wire wound and electronic[18].

To a significant extent the output voltage of transformers for lighting is governed by the resistance applied across the secondary wiring. In the case of wire wound transformers the voltage increases as the resistance is reduced. Replacing lamps with significantly lower wattage types will cause over voltage and premature lamp failure for conventional lamps. For LED or

[18] The content of this section is provided by PLDA (Professional Lighting Designers Association), May 2009.

CFLi reflector lamps with integrated electronics instant failure or fire risk are also potential results.

For many low price electronic transformers failure to provide adequate resistive load results in a flashing output as the voltage builds and cuts off. The output of electronic transformers is not sine wave and is also at high frequency, this can also cause problems for downstream electronics such as ballasts in CFLi and LED replacement lamps.

3.5 Potential barriers to possible eco-design measures

This section, dealing with the lighting source, shall be seen as complementary to the earlier sections. Particularly, the CFLi-R and the LED is in the focus with regard to quality and raised questions. Anyhow, there should also be attention paid to quality tests of halogen lamps, e.g. the performance and lumen maintenance for halogen lamps is low in a new test of 26 halogen lamps[19].

It seems reasonable not to set higher quality requirements to LED lamps than to CFLi-R in order not to discriminate.

It is very important to distinguish between LED lamps and LED luminaires.

3.5.1 CFLi-R quality

Please see chapter 3 in the final report for part 1 of the study.

3.5.2 HL-R quality

HL-MV-R and HL-LV-R reflector lamps are nowadays characterized by beam angle and peak intensity (candela). The beam angle is important for the user to assure that the light is directed to the target as intended. The peak intensity allows the user easily to calculate the centre illuminance at the target by the simple formula:

$$E = I/d^2$$

where d is the distance in meter
I is luminous intensity in candela
E is the illuminance in lux perpendicular to the lamp

Concerning beam angle, PLDA refers to the American system where reflector lamps are divided in groups as around 10°, around 24°, around 36° and from 36° to 60° beam angle.

Quality problems with reflector halogen lamps might arise and are due to lower lamp efficacy, wrong peak intensity, deviate beam angle or reduced life time.

[19] Warentest 2/2009 Test of halogenlamps

Recent test of halogen lamps[19] shows this is also very important for the consumer economy especially for HL-MV-R lamps. The test includes 6 lamps with GU10 socket: 1 lamp with xenon gas (labeled as Energy Saver) where both the energy efficiency and the economy is equal to use of GLS lamps while the consumer spend more money for the remaining 5 HL-MV-R and spend from 10% to 55% more energy (VITO has found that the calculation methode should be adjusted and that the results are even worth). The same is the case for testing of two HL-MV-R with G9 socket. The test also includes 5 HL-LV-R with GU5.3 socket where the consumer obtains a good economy plus energy saving around 30% energy saving for "normal" lamps and 44% for lamps with IRC coating (labeled as Energy Saver).

The above results are also due to that the test shows a huge difference in lifetimes and often very different from what is claimed on the package – for HL-LV-R the lifetime is often higher than claimed (typically 2000-2200 hours) but there is also a Energy Saver lamp case where the claim is 5500 hours lifetime but the test shows 3450 hours. For HL-MV-R the claim is rather low with three lamps with only 1000-1100 hours, one lamp with 1500 hours and three lamps with 2000-2200 hours (one package without this imformation). The measured lifetimes are on average a little higher than those claimed but case by case the difference is large and goes in both directions (positive and negative).

Concerning the colour of the halogen reflector lamps the recent investigation shows:

- Due to information at the package, the correlated colour temperature (CCT) is low for HL-MV-R with 2600-2750K (too warm for many people) and higher (and closer to what most consumers seems to prefer) for HL-LV-R with 2750-3200K.
- The colour rendering index (CRI) is by definition 100 for filament lamps (see also discussion in chapter 1), nevertheless very warm lamps (2600 K) are very yellowish and it can be discussed if it is the right colour (depending on the reference).

In conclusion, it is very important that the packaging includes correct information about beam angle, efficacy, peak intensity, lifetime and colour. ELC informs[20] they are preparing an ecoreport including requirements to minimum lumen level per lamp type and performance variation for 7 beam categories.

3.5.3 LED quality

The performance of WLED products (White LED called LED further on) available at the market varies within a very wide range and actually new more efficient LEDs comes on the market every six months. Some testing programs[21] have also found that the performance within individual batches of identical sources varied as much as 40%. That indicates that the actual manufacturer has not performed a proper binning. This may be caused by downward pressure on pricing increase the temptation for manufacturers to "cut corners".

---

[20] Comment at the stakeholder meeting 26 May 2009.

[21] "The Need for Independent Quality and Performance testing of Emerging Off-grid White-LED Illumination systems for Developing Countries", Evan Mills, LBNL and Arne Jacobsen, Schatz Research Center, Technical report 1, The Lumina project, August 2007, http://light.lbl.gov.

Both the correlated colour temperature (CCT) and the colour rendering index (CRI) vary within large intervals. A new study of colour rendering of LED sources[22] with a paired comparison of halogen and fluorescent to 7 different clusters of LED at 3000K (CCT). They found, that in general, that the colour rendering was found more attractive with some of the LEDs mixing than with standard light sources. They find that the neither of alternative scales to measure gives the best description of all aspects: attractiveness (Gamut best), naturalness (CRI best) and colour difference (CIECAMO2 best).

There is a high risk of "market-spoiling" if some manufacturers claims overstate their LED performance. Consumers unlucky enough to purchase a low performing LED (not performing as claimed by the manufacturer) can be very dissatisfied and they may reject the technology, and the overall reputation of LED systems could suffer. This has already been experienced when the CFLi product was introduced at the market and it took many years and a lot of work to overcome the barriers created during the first years at the market. It is very important not to repeat this failure when the LED is introduced at the market.

LED luminaires and replacement lamps available today often claim a long lifetime, usually 50,000 hours. These claims are based on the estimated lumen depreciation of the LED used in the product and often do not account for other components or failure modes. Lifetimes claimed by LED luminaire manufacturers should take into account the whole lighting system, not just the LEDs. One of the key lessons learned from early market introduction of CFLi[23] is that long life claims need to be credible and backed-up with appropriate manufacturer warranties.

Another important aspect is that LED's are often integrated permanently into the fixture/luminaire, making their replacement difficult or impossible.

The beam characteristics of LEDs are usually determined by discrete optical elements attached to the LED or LED board. The beam and field characteristics are different from a reflector optic with a single source and this might result in a non circular beam pattern, colour variation across the beam (especially for single LED devices) and failure to achieve good beam definition at beam angles below 24 degrees[24].

Formalisation of product quality and a performance testing process is needed urgently. Independent testing has to start as soon as possible and the results have to reach the key audiences. The availability of standard test procedures can support manufacturers' product development efforts, evaluation of progress towards achieving higher quality (comparison to established benchmarks) and competitive analysis.

On the other hand, it is important to ensure the cost of testing is not overly burdensome to manufacturers. High-cost testing can be less successful than a more moderate approach because small firms might be unable to afford the entry cost to high-cost testing and some manufacturers might avoid markets where quality assurance is required. Another strong argument is that LED

---

[22] "Colour Rendering of LED sources: Visual experiment on Difference, Fidelity and Preference", Jost-Boissard, Fontoynont and Blanc-Gonnet, Ecole Nationale Travaux Publics de l'Etat,CIE Light and Lighting Conference with emphasis on LED, 27-29 May 2009.
[23] US DOE. "Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market". 2006.
[24] Comment from PLDA, May 2009.

products have such long lives that lifetime testing and acquiring of real application data on long-term performance becomes problematic as new versions of products are available before current ones can be fully tested.

An overview of measurements including a number of LED lamps can be found at the Renewable Energy OliNo web site[25] including different kind of fittings. Unfortunately, most of the lamps don't fulfil the quality requirements to either efficacy, CCT and/or CRI.

3.5.3.1 ENERGY STAR Qualified LED lighting

On September 30, 2008, the ENERGY STAR Solid-State Lighting (SSL including LEDs, OLEDs and PLEDs) Criteria program went into effect as an important step towards ensuring the quality of LED lighting.

Manufacturers who are ENERGY STAR partners can begin submitting products for qualification, retailers can begin promoting these qualified products in their stores and showrooms, utilities and energy efficiency organisations can begin implementing incentive programs for these efficient products, and consumers can start looking for the ENERGY STAR on quality products. The ENERGY STAR label on SSL luminaires provides consumers with the confidence that these products meet efficiency and performance criteria established by DOE in collaboration with industry stakeholders.

The rapid pace of the technology advances led DOE to select a two-phase approach:

1. First phase allows for early participation of a limited range of market-ready products
2. Second phase sets out more rigorous performance targets for future products. The criteria are continually updated to keep pace with the technology advances.

The released requirements for obtaining to be ENERGY STAR qualified LED lighting include:

1. **Energy consumption** at least 75% less energy than incandescent (GLS) lighting for the same quantity of lighting (lumens).[26]
2. **Reduces maintenance costs** by lasting 35 - 50 times longer than incandescent (GLS) lighting and about 2 - 5 times longer than fluorescent lighting. No bulb-replacements, no ladders and no ongoing disposal program.
3. **Minimum three-year warranty** which is far beyond the industry standard.
4. **Offers convenient features** by being available with dimming on some indoor models and automatic daylight shut-off plus motion sensors on some outdoor models.
5. **Brightness equal to or greater than existing lighting technologies** (incandescent or fluorescent) and the light must be well distributed over the area lighted by the fixture.
6. **Light output remaining constant over time**, only decreasing towards the end of the rated lifetime (at least 35,000 hours or 12 years based on 8 hours use per day). The L70 criteria suggested in chapter 1 require minimum 25,000 hours for domestic indoor applications and minimum 35,000 hours for other professional and outdoor applications.

[25] http://www.olino.org/

[26] ELC mention in their comments to a draft of this report that the luminaire efficacy is for some applications required as ">20 lm/W", which is not a 75% energy reduction compared to use of a GLS-R.

7. **Color quality**. The shade of white light must appear clear and consistent over time[27].
8. **Efficiency as good as or better than fluorescent lighting**.
9. **Light coming on instantly** when turned on.
10. **No flicker** when dimmed.

In the DOE Caliper testing program[28] was found power factors within the interval 0.52-0.99 so power factor could also be a quality parameter but this is not included in the list as it is not an issue from a consumer perspective. ELC publiced[29] recently a note "Mains Power-Quality Effect by Electronic Lighting Equipment", that conclude the present IEC 61000-3-2 "Limits for harmonic current emission" are sufficient and there is no need for tightening the requirements.If this is done as suggested by some parties it would lower the lamp performance, and increase the lamp size, the electronic waste and the cost. This is in line with the content of part 1 of our study.

Until a detailed European specification is prepared, it might be worth to adopt these specifications in order to establish the market under a known and trusted mark. Next section gives a proposal of what are the most important qaulity parameters from a European consumer perspective.

3.5.3.2 Most important LED lighting quality parameters for a European consumer

Different sources describe quality requirements of importance for the consumer when buying LED lamps, modules and luminaires:

- ENERGY STAR[10]
- LBNL reports[14]
- IEC/PAS 62612 Ed.1 "Performance requirements for Self-ballasted LED lamps" giving a complete survey of relevant parameters
- CIE 127:2007 standard addressing individual LEDs.

The most important LED quality parameters from a consumer perspective are evaluated to be:

1. Lumens where the rated output for the LED luminaire is important (not for the LED). Requirements to the manufactures could be measurement of total luminous flux e.g. by use of goniometer in order to characterize the light-distribution pattern.
2. Requirements to minimum lamp efficacy in lumens/W
3. Lifetime in hours for the LED luminaire or lamp (not for the LED chip).

[27] ELC mention in their comments to a draft of this report that CRI is required to be minimum 75 for indoor applications and that CCT is limited to warm white ANSI bins.
[28] Caliper Summary Report, January 2009, Round 7 of products testing (prepared for DOE), http:apps1.eere.energy.gov/buildings/publications/pdfs/ssl/calliper round 7 summary final.pdf
[29] ELC (www.elcfed.org) (5/2009): 'ELC position paper on Mains Power-Quality Effects by Electronic Lighting Equipment'

4. Lamp efficacy as a function of time. A high-quality LED can maintain high lighting levels for tens of thousands of hours, while the output of low quality products declines more rapidly. Long-term measurements require 12+ months so it is important to find a short-term approach for measuring.
5. Requirement to how fast the light should come on instantly when turned on.
6. Colour: CCT (Correlated Colour Temperature) and CRI (Colour Rendering Index).
7. Glare: Measurement of the intensity of light from the source itself. This is important given the small size of LED lights and their corresponding brightness, which can cause discomfort glare as well as injury if users look directly into the light. A very recent test [30] reports glare varied by a factor 1.4 and that it was above the acceptable threshold in most cases. Anyhow, glare will not be greater than with "traditional" DLS. Limiting glare (UGR) values are specified for many commercial applications.
8. Information about if the lamp is available with dimming, automatic daylight shut-off and/or motion sensors (especially important for outdoor models).
9. Requirement to stroboscope effect and flicker. Power supplies using pulse-width modulation makes the LED blink/flicker with a certain frequency (typically between 100 and 150 Hz). The flicker frequency is not directly visible but may lead to: a) Stroboscopic effects on rotating objects (making it look like it is not moving or like it rotates at another speed or direction). b) "Cascades" of bright points in the visual field when moving the visual direction rapidly ie. when turning the head.
10. Minimum warranty in years.

3.5.3.3 Integrated LED luminaires

LED luminaire lifetime is not identical to estimated LED lifetime. LED luminaire lifetime is also a function of the power supply, operating temperatures, thermal management, materials, and electrical and material interfaces. DOE[31] reports that definitive lifetime ratings will not be possible until more experience is logged with a wide range of LED luminaires in the field. They recommend looking for:

- High-quality LEDs from manufacturers who publish reliability data.
- Luminaire warranty offered by the manufacturer – should be at least comparable to traditional luminaires used for the application under consideration.
- Luminaire photometric report, based on LM-79-08 test procedure, from an independent testing laboratory.
- Temperature data (for example, board, case, or solder joint temperature) for the LEDs when operated in the luminaire in the intended application; and information about how the measured temperature relates to expected lifetime of the system.

[30] "Measured off-grid lighting system performance", Evan Mills, LBNL and Arne Jacobsen, Schatz Research Center, Technical report 4, The Lumina project, December 2008, http://light.lbl.gov.

[31] http://www1.eere.energy.gov/buildings/ssl/reliability_points.html

- Any test data available about longer term performance of the LED luminaire, such as DOE CALiPER testing, manufacturer in-house testing, or field tests conducted by DOE, utilities, or other parties.

3.5.4 Luminaire socket and space lock-in effect

For this item, see section 3.4.4.

3.5.5 Electrical wiring and control system lock-in effect

Please see chapter 3 in the final report for part 1 of the study.

3.5.6 Harmonic interference in the low voltage network

Please see chapter 3 in the final report for part 1 of the study.

3.5.7 Alleged negative health effects due to optical and electromagnetic radiation from certain light sources

Please see chapter 3 in the final report for part 1 of the study.

3.5.8 Luminaire photometric data is usually not measured

Few luminaires within the scope of this study are provided with photometric data, the requirement for having a minimum LOR or LER performance or providing data about it could create additional cost and administration. In decorative luminaires such a requirement could limit the amount and light absorption of the ornaments sold with the luminaire. It is important to remember that decorative luminaires are mainly chosen by the consumer to serve an aesthetic function.

As mentioned in section 3.2.3, the efficiency of a domestic luminaire is not a basis for its selection for purchase. It is therefore doubtful if provision of information for the majority of domestic luminaries is useful or worthwhile.

Basic design rules rather than LOR requirements could avoid cost and administration but there are no public known examples so far.

Design rules for luminaries with reflectors could be[32]:

a) Rules of reflectance and allowable absorbance of reflectors

[32] Proposal received from the DEA (Danish Energy Agency) developed by their lighting advisor Hansen & Henneberg

b) Rules of opening area dependant of luminous area of the light source and dependant of directionality as “non directional luminaire”, “directional luminaire” or “directional spot luminaire”.
c) For closed luminaries rules for transmittance and allowable absorbance of screens.

Exceptions could be made for luminaires marked with a text saying it is not intended for household room illumination (as done for light sources).

4 TECHNICAL ANALYSIS EXISTING PRODUCTS

For more info see website www.eup4light.net.

5 DEFINITION OF BASE-CASE

For more info see website www.eup4light.net.

6 TECHNICAL ANALYSIS BAT

For more info see website www.eup4light.net.

7 IMPROVEMENT POTENTIAL

For more info see website www.eup4light.net.

8 SCENARIO- POLICY- IMPACT- AND SENSITIVITY ANALYSIS