Test Report – Clear, Non-Directional LED Lamps

A test report prepared for the European Commission and the Consultation Forum on the performance of clear LED lamps in the European Market in the third quarter of 2014.

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Motivation for this Test Study:

In June 2013, DG Energy published a technical study[1] prepared by consultants (VHK/VITO) on the feasibility of keeping in place an Ecodesign regulatory measure EC No 244/2009 adopted in 2009 for non-directional household lamps. The regulatory measure under review is the final stage of the European regulation on non-directional household lighting, referred to as 'Stage 6'. The VHK/VITO study included a projection of the anticipated price and performance of LED replacement lamps based on the best information available at that time. However, since that time the rate of innovation in LED products has far exceeded expectations, and the price and performance levels are exceeding the projections published in the VHK/VITO study.

In this context, it became clear that in order for policy makers make an informed decision on whether to keep, amend or delay Stage 6 of 244/2009, new evidence should be provided – including test data to verify product claims. Thus, the authors designed and conducted this testing study, purchasing lamps from vendors across Europe and testing them at the Swedish Energy Agency's lighting laboratory. It is hoped that these test results of LED lamps on the current European market will prove useful to policy makers, enabling them to make appropriate decisions with regard to Stage 6.

Acknowledgements:

The authors wish to thank the Swedish Energy Agency and CLASP for purchasing the LED lamps, the Swedish Energy Agency for conducting the tests and David Wren from PassMark Software for kindly making available data tables with test results of http://www.ledbenchmark.com.

[1] "NDLS STAGE 6 REVIEW - FINAL REPORT - Review study on the stage 6 requirements of Commission Regulation (EC) No 244/2009", by VHK (pl)/ VITO for the European Commission. Delft/Brussels, 14 June 2013.

Executive Summary

This study was undertaken because new LED products have been introduced into the European market at low prices which are claiming very high performance levels much earlier and at lower prices than was anticipated only a year ago. It was deemed necessary, therefore, to conduct a limited market study of the products available in the current European market and to present this new evidence, including test report results, to the Ecodesign Consultation Forum.

When ecodesign regulation EC No 244/2009 was introduced in 2009, the Commission forecasted that compact fluorescent lamps (CFLs) would replace the majority of frosted non-directional incandescent lamps, which were phased out starting in 2010. Clear mains-voltage halogen lamps were allowed to remain on the market as a replacement for clear incandescent lamps and they were expected to make up a relatively small share of total sales for non-directional lamps. Much of the anticipated savings from this regulation were based on this market forecast. Recently however, GfK sales data became available for several major European economies that seem to indicate the non-directional household lamp regulation has failed to move old frosted incandescent market toward CFLs, and instead has simply moved both clear and frosted incandescent lamp users to clear halogen lamps, eroding much of the anticipated energy savings.

Regulation EC No 244/2009 further introduces a final Stage 6 in September 2016, when these clear halogen lamps (D-Class) would be banned in favour of more efficient technologies (e.g., B-Class halogens and LEDs). However, the B-Class halogen lamps on the market in 2009 have disappeared from the European market and so the Commission has proposed a delay of Stage 6 in order to give LED technology more time to develop as a viable alternative to D-Class halogen lamps.

Due to the fact that clear LED lamps were identified as an issue in the context of the Stage 6 review because of the ability of tungsten filaments to create a “sparkle” effect in certain light fittings, this study focuses on testing clear LED lamp replacements, including several “LED filament lamps” such as the example shown below. The study also included other clear LED lamp designs, such as those based around optical light guides offered by companies including IKEA, OSRAM and Philips.

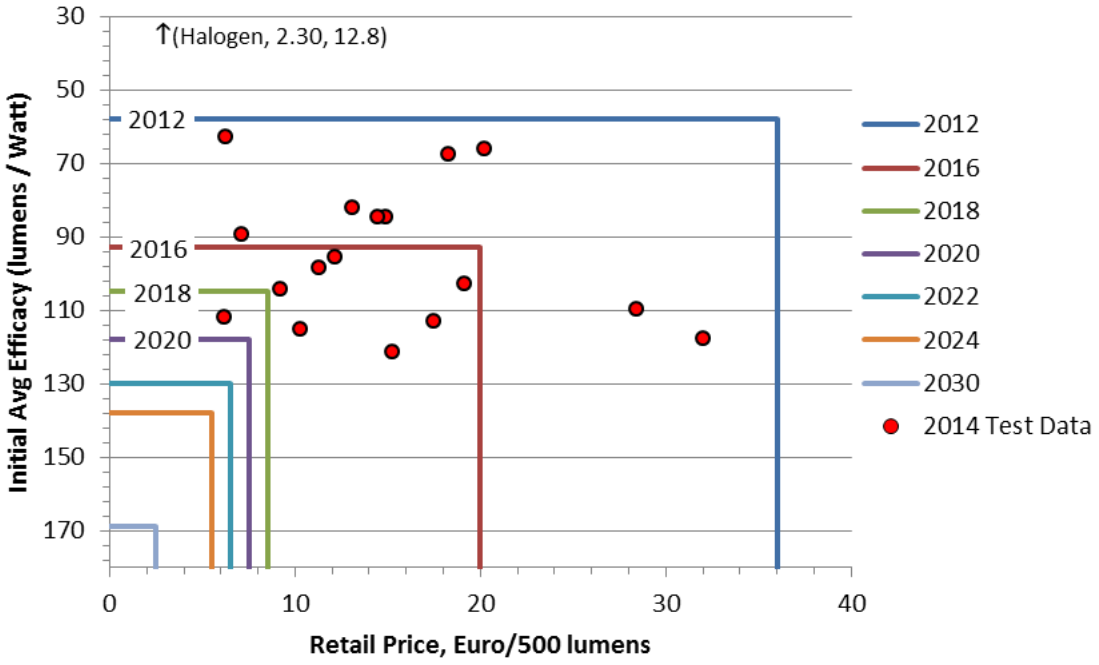
Example of an AC Mains-Voltage Non-Directional LED Filament Lamp

This study tested 170 LED lamps (sample size of 10 units of 17 different models) and 10 halogen lamps (10 units of one model), and found a wide range of average efficacy values. The clear LED

lamps tested, ranging from 62.7 lumens per watt (about the same as a CFL) to 121.4 lumens per watt (lm/W) – nearly twice as efficient as the lowest LED lamp. The halogen lamp's average efficacy was 12.8 lm/W, meaning that for the same light output, it will consume ten times more electricity than LED lamp at 121.4 lm/W. And, within the sample of ten LED lamps that averaged 121.4 lm/W, one unit had a measured efficacy of 131.5 lm/W.

In June 2013, the Commission circulated a technical report by VHK/VITO, a team of European consultants who are recognised experts on lighting products. In that technical report, VHK/VITO projected LED lamp efficacy and price in the EU from 2012 to 2030. This projection was then compared to the new test results that were generated under this study, providing price and performance information on LED lamps available in 2014. The test results found that the price and performance of mains voltage (MV) LED retrofit lamps had progressed at a much faster pace than was expected in June 2013.

The following figure shows the price and efficacy projections from the VHK/VITO report as vertical lines, drawn from the two axes of price (X-axis) and efficacy (Y-axis). The superimposed red dots present the price (including VAT) and performance of the LED lamps purchased in August/September 2014 and tested.



Example of MV LED Non-Directional Retrofit Clear LED Lamps: projections made in 2013 on price/performance ratio vs real 2014 values

The figure shows that approximately 50% of the LED lamps purchased and tested for this study already exceed the anticipated 2016 price and performance levels and one model available on the European market in 2014 already exceeds the anticipated 2018 level on efficacy and the 2020 level on price. Thus, the market of LED lamps in Europe is moving much faster than was previously expected, with many models available today are several years ahead of projected price and performance levels in the VHK/VITO report.

Extended Summary

The Swedish government, with support from the Belgian government, CLASP's European Programme and the European Council for an Energy Efficient Economy (eceee) are pleased to submit this report to the European Commission and the Consultation Forum.

This study was undertaken because new LED products have been introduced into the European market at low prices which are claiming very high performance levels. It was deemed necessary, therefore, to conduct a limited market study of the products available in the current European market and to present this new evidence, including test report results, to the Consultation Forum. Supplementing this study, the Team also compiled databases of LED lamps from other publicly available sources, which are identified separately from the measured test results.

Due to the fact that clear LED lamps were identified as an issue in the context of the Stage 6 review because of the ability of tungsten filaments to create a "sparkle" effect in certain light fittings, this study focuses on clear LED lamp replacements, including several "LED filament lamps" such as the example shown below. The study also included other clear LED lamp designs, such as those based around optical light guides offered by companies including IKEA, OSRAM and Philips.

Figure ES-1. Example of an AC Mains-Voltage Non-Directional LED Filament Lamp

Samples of ten units of each of eighteen different lamps were purchased from on-line retailers in Belgium, France, Germany, the Netherlands, Sweden, and the United Kingdom. Seventeen of those lamps were LED and one sample set was a mains-voltage halogen lamp for comparison. The prices paid for all the lamps purchased, including taxes, were normalised to the cost in Euros per 500 lumens of light output using currency exchange rates at the time of purchase.[2] These normalised prices for the LED lamps ranged from €6.16 to €28.42 per 500 lumens (including VAT). The halogen lamps purchased had a price of €2.29 per 500 lumens.

[2] This normalised level of light output was selected to be consistent with the way the price progression of LED lamps was presented in the June 2013 consultant's report, titled "NDLS STAGE 6 REVIEW - FINAL REPORT - Review study on the stage 6 requirements of Commission Regulation (EC) No 244/2009", by VHK (pl)/ VITO for the European Commission. Delft/Brussels, 14 June 2013.

This study also found a wide range of average efficacy values for the clear LED lamps tested, ranging from 62.7 lumens per watt (about the same as a compact fluorescent lamp) to 121.4 lumens per watt – nearly twice as efficient as the lowest LED lamp. The halogen lamp's average efficacy was 12.8 lm/W, meaning that for the same light output, it will consume ten times more electricity than the sample average of today's best performing LED lamp. And, within the sample of ten LED lamps that averaged 121.4 lm/W, one unit had a measured efficacy of 131.5 lm/W.

Exceeding the Price and Performance Projection

In June 2013, the Commission circulated a technical report[3] by VHK/VITO, a team of European consultants who are recognised experts on lighting products. In that technical report, VHK/VITO projected LED lamp efficacy and price in the EU from 2012 to 2030. For convenience and reference, an image of Table 2 from the consultant's review report is reproduced below. This table presents the expected projection of efficacy (in lumens per watt) and price (in Euro including VAT per 500 lumens of light) that was expected at that time (June 2013).

Table 2. MV LED retrofit lamp, efficacy and price projections EU 2012-2025

(sources: for efficacy CLASP 2013, based on US DoE MYPP projections; for EU lamp consumer prices incl. VAT (500 lm lamp) up to 2020 LightingEurope; 2021-2030 prices, extrapolation VHK)

Year	2012	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2030
lm/W	58	93	99	105	112	118	125	130	134	138	142	169
price in €	18.0	10.0	9.0	8.5	8.0	7.5	7.0	6.5	6.0	5.5	5.0	2.5

This projection was then compared to the new test results that were generated under this study, providing price and performance information on LED lamps available in 2014. The test results found that the price and performance of mains voltage (MV) LED retrofit lamps had progressed at a much faster pace than was expected in June 2013.

The following figure shows the price and efficacy projections from the above Table 2 from the VHK/VITO report as vertical lines, drawn from the two axes of price (X-axis) and efficacy (Y-axis). In that same graph, we have then superimposed red dots presenting the price (including VAT) and performance of the LED lamps purchased in August/September 2014 and tested. The efficacy values shown are averages of the sample (n=10) of each model of clear LED lamp and the one halogen lamp. The figure has inverted scales, meaning the efficacy improves and price is lower as the products move toward the origin (0,0). Although it was measured, the halogen lamp is noted but is off the scale of the graph due to its low efficacy compared to the LED lamps.

[3] "NDLS STAGE 6 REVIEW - FINAL REPORT - Review study on the stage 6 requirements of Commission Regulation (EC) No 244/2009", by VHK (pl)/ VITO for the European Commission. Delft/Brussels, 14 June 2013.

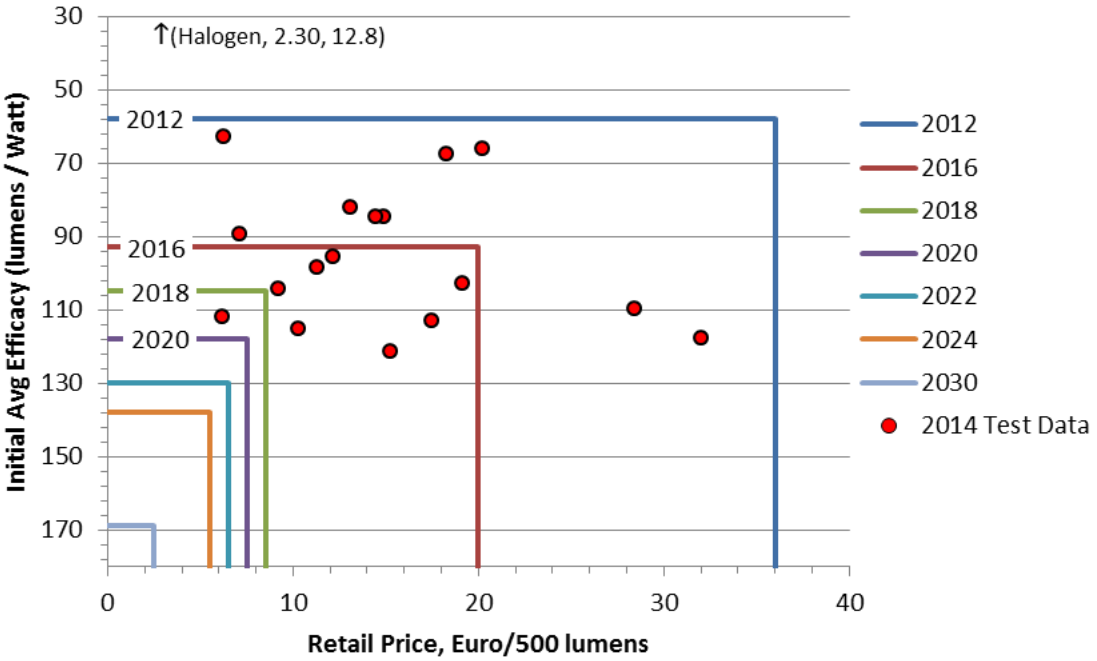


Figure ES-2. Example of MV LED Non-Directional Retrofit Clear LED Lamps: Projections made in 2013 on price/performance ratio vs. real 2014 values

The figure shows that approximately 50% of the LED lamps purchased and tested for this study already exceed the anticipated 2016 price and performance levels and one model available on the European market in 2014 already exceeds the anticipated 2018 level on efficacy and the 2020 level on price. Thus, the market of LED lamps in Europe is moving much faster than was previously expected[4], with many models available today are several years ahead of projected price and performance levels in the VHK/VITO report (see Chapter 5).

European Market – Eroding Energy Savings under 244/2009 ?

Ecodesign regulation EC No 244/2009 bifurcated the incandescent lighting market into frosted and clear lamps, and set different energy-efficiency requirements for frosted and clear replacement lamps. Frosted incandescent lamps were moved to the efficiency of a compact fluorescent lamp and clear lamps were moved to the efficiency of a mains-voltage halogen lamp (which is less efficient than a CFL). There was a concern in 2009 that the market may simply migrate toward mains-voltage halogen lamps from both frosted and clear incandescent lamp installations, by-passing compact fluorescent lamps and not capturing cost-effective energy savings.

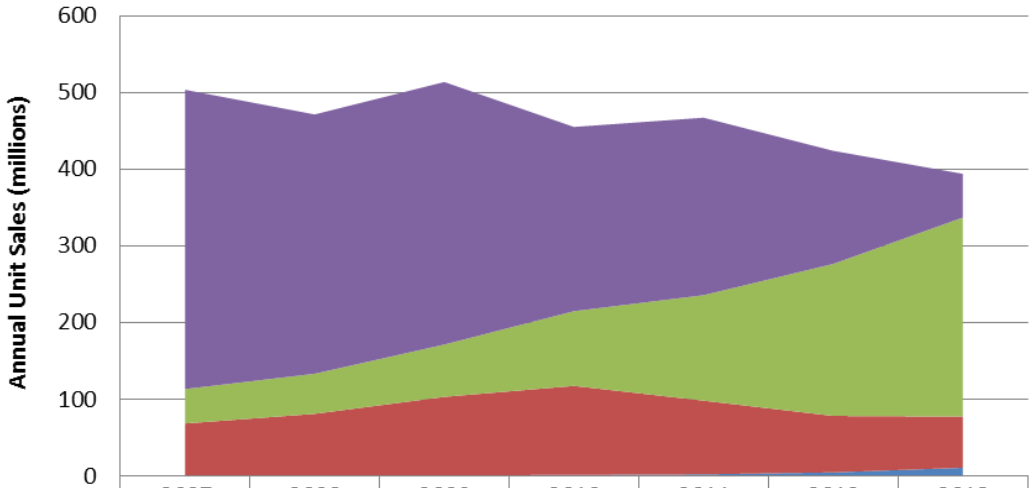
The IEA 4E Mapping & Benchmarking Annex published an update to their domestic lighting market study in September 2014, [5] based on GfK lamp sales data for Europe.[6] The mains-voltage

[4] The rate of change has taken many by surprise; on 6 November, while drafting this report, OSRAM announced that its CEO Wolfgang Dehen was stepping down in part because he had "underestimated the pace of an industry shift from traditional light bulbs to light-emitting diodes". http://www.bloomberg.com/news/2014-11-05/osram-names-berlien-new-ceo-from-2015-after-earnings-target-cut.html

[5] IEA Mapping and Benchmarking report – Domestic Lighting Update, September 2014. See: http://mappingandbenchmarking.iea-4e.org/shared_files/609/download

incandescent, mains-voltage halogen, single-ended self-ballasted CFL and retrofit-LED lamp data are reproduced below. These data show that integrally ballasted CFL sales peaked in 2010 and have been in decline across Europe ever since. In fact, CFL sales in 2013 are lower than they were in 2007, prior to the adoption of regulation EC No 244/2009. Meanwhile, sales of mains voltage halogen lamps have grown by 477% over that same time period.

These sales data seem to indicate that the non-directional household lamp regulation has failed to move frosted incandescent toward sales of CFLs, and instead has simply moved both clear and frosted incandescent lamp users to halogen lamps.[7]



	2007	2008	2009	2010	2011	2012	2013
MV Incandescents	389.9	337.9	342.1	240.1	231.3	147.4	57.0
MV Halogens (single-end)	44.9	52.2	68.2	97.3	137.4	198.0	259.4
MV Self-Ballasted CFLs	68.5	80.8	102.3	116.0	96.0	73.6	66.6
Retrofit LED Lamps	0.2	0.5	1.1	1.7	2.5	5.0	11.0

Figure ES-3. Shipments of Non-Directional Mains-Voltage Lamps in Europe, 2007-2013

The sales market in 2013 contrasts sharply with the forecasts prepared in 2009 for "Option 2 Clear B Slow" (the policy scenario that most closely resembles the regulatory option selected by the Commission in EC No 244/2009). In that market forecast, the Commission had expected CFL sales to be 4 times larger than mains voltage halogen lamps in 2013.[8] The fact that actual CFL sales are one quarter of halogen sales in 2013 means that the European market is not on track to deliver the 39 TWh of electricity savings from EC No 244/2009.

[6] These data can be found in the figure on page 5 of the IEA M&B Annex Domestic Lighting Report, September 2014. The countries represented in these GfK shipment estimate are Austria, Belgium, France, Germany, Great Britain, Italy and the Netherlands.

[7] Halogen lamps are approximately 20% more efficient than incandescent lamps while CFLs are approximately 400% more efficient. Thus, the decision to allow mains voltage halogen lamps to remain on the European market has significantly reduced the anticipated energy savings from this policy measure.

[8] Final report, Lot 19: Domestic lighting prepared by VITO for European Commission DGTREN unit D3, Andras Toth, 2009/ETE/R/069; October 2009. See shipments projection in Annexe 8-6: Main economic and environmental data for the scenario "Option 2 Clear B Slow".

Furthermore, frosted incandescent lamp sales were assumed to be nearly three-quarters of sales in 2007 (clear incandescent was approximately one-quarter of sales).[9] Although a transition from frosted incandescent to CFL was deemed cost effective for households[10], most frosted lamp sockets would not seem to have migrated to CFLs (clear halogen lamp sales were 4 times greater than CFLs in 2013). This would mean, the decision to keep clear mains voltage halogen lamps in the market has slowed the market adoption of energy-efficient lighting and undermined the expected energy savings. Given this new information about how the market seems to have responded to the policy measures (i.e., rejecting CFL lamps), the proposal to extend the sales of clear mains voltage halogen lamp sales in Europe from 2016 to 2018[11] could further delay the introduction of energy-efficient lighting into Europe.

Supplementary Databases for Comparison

In parallel with the laboratory tests on the procured samples of lamps, additional research was conducted on published databases and sources of data. Data were gathered from five different sources, only importing omni-directional, general lighting service lamps (both clear and frosted). There are 1808 models in the databases (more information in section 2.1.1), some of which will be duplicated across the three US databases. Most of the performance data in the database is self-reported. The figure below shows a scatterplot of the data, focused on a view between 2 and 12 Watts and 0 to 1200 lumens.

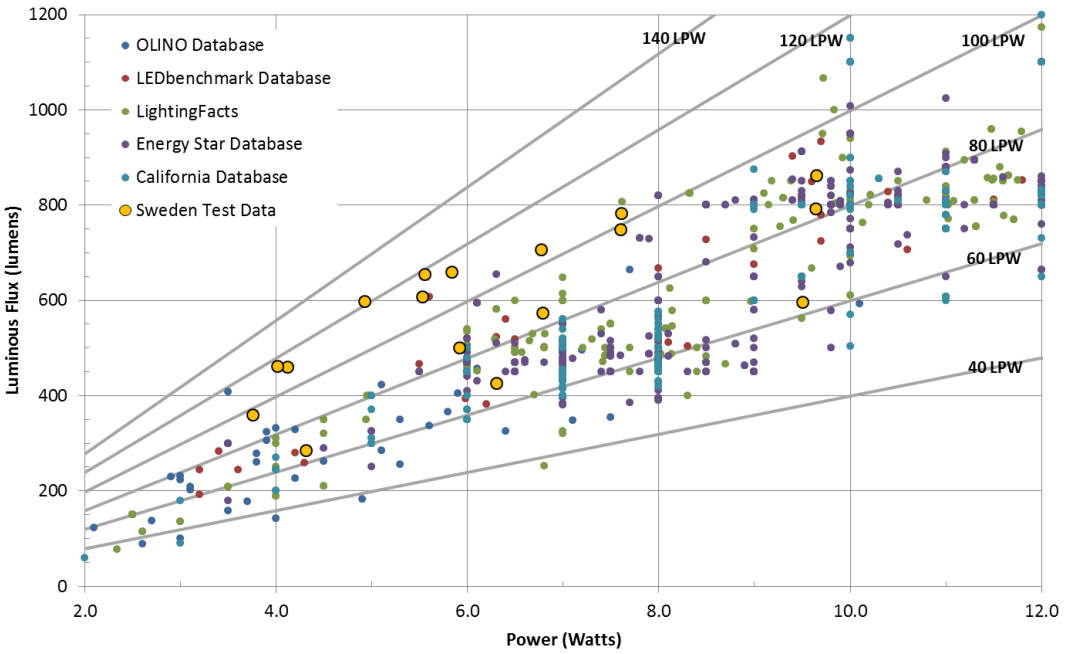


Figure ES-4. Comparison of Test Data (2014) with Public Databases of LED Lamps (2012-2014)

[9] Final report, Lot 19: Domestic lighting prepared by VITO for European Commission, 2009/ETE/R/069; October 2009. Annexe 8-6: Main economic and environmental data for the scenario "Option 2 Clear B Slow".

[10] Full Impact Assessment, Commission Staff Working Document, on ecodesign requirements for nondirectional household lamps, 18.3.2009. Quote on page 16: "In the frosted lamps category, the analysis has shown that it is cost-effective to only allow class A level lamps (= CFLs)."

[11] 5 November 2014, Commission issued an email which stated the following: EU TBT notification concerning the Draft Commission Regulation amending Regulation (EC) No 244/2009 has now been published on the WTO website under the following reference: G/TBT/N/EU/248 and can be found here (click on this link)

The Swedish Test Data, prepared for this report, tend toward the higher efficacy models in the dataset which includes LED lamps from 2012 to 2014. The test data from this study tends to be more efficient because they were all purchased in the last few months and thus are using the most recent and energy-efficient LEDs. Furthermore, the LED filament lamps seem to be new models, just emerging onto the market in volume this year, and so the databases don't yet reflect those models.

Six Key Questions

Finally, as stated in the email announcement informing the Commission and Consultation Forum about this study, the authors have attempted to address six key questions that constitute the principal outcomes of this work. These questions and answers are discussed in Chapter 6 of this report, with very brief summary answers given below:

Q: What is the current cost and performance of clear LED lamps?

A: The data for LED Lamps tested in this study have exceeded the expected progression of LED technology published in the VHK/VITO Report. The table below presents the comparison between an estimate of the VHK/VITO Report forecast and the sample average from lamps purchased in August/September 2014.

Table ES-1. Current Price and Efficacy of Mains-Voltage Retrofit LED Replacement Lamps

Source of estimate	Price (Euro) per 500 lumens of light in 2014	Efficacy (lumens per watt) in 2014
VHK/VITO Report (June 2013)*	€14.00 / 500 lumen	76 lm/W
Test data average, this study	€12.52 / 500 lumen	98 lm/W
Difference, test data average in 2014 compared with VHK/VITO projected	11 percent lower	29 percent higher

* The VHK/VITO report did not provide actual values for 2014, therefore the figures shown in this table are derived from linear interpolation between the 2012 and 2016 values.

The values are 11% lower on price and 29 percent higher on efficacy compared to a linearly-interpolated estimate from the VHK/VITO Technical Report. See section 5.9 for discussion on these estimates.

Q: Do they give an aesthetic pleasant light?

A: The LED lamps tested in this study were found to have CCT values that were around 2700K to 2900K, which is consistent with the baseline technology they seek to replace (i.e., incandescent and halogen). The CRI value for most LED lamps exceeded 80 CRI (with a few exceptions, where the CRI was measured at 79). Two of the LED lamps tested had CRIs values in the 90's (IKEA and vosLED). The flicker index and percent flicker of the lamps were measured and many lamps had no flicker. The lamps were also tested for their light distribution pattern, and there was a very good resemblance to the halogen reference lamp (see Annex B). Thus, it would appear that the LED Lamps can meet the optical requirements of luminaires currently using halogen lamps. For all of these reasons, it would appear that these clear LED lamps do offer consumers an aesthetic, pleasant light. And, a limited review of website comments was conducted (see section 2.2.6), which indicated the early-adopters of LED filament lamps are satisfied.

Q: Are the "dimmable" lamps compatible with leading edge and trailing edge dimmers?

A: Although these two dimmers do not represent all dimmers in Europe, they do represent two of the most common types found in the market. Five of the LED lamps purchased for this study were marketed as 'dimmable'. Of these, two of those lamps were able to be dimmed on both dimmers (#6 IKEA, #13 Star Trading). The other three lamps had issues with one of the dimmers. Lamp #5 from LED Connection was not compatible with the leading edge dimmer and Lamps #14 from OSRAM and #15 from Philips were not compatible with the trailing edge dimmer. Overall, the results indicate that the industry is working on better LED drivers to make them compatible with the main types in Europe, and there are still be some manufacturing / quality control issues to work out in production.

Q: Do these lamps meet the LED quality requirements in EU No 1194/2012?

A: In order to ensure that the manufacturers of these new high-performance, low-cost LED lamps are not sacrificing light quality aspects that are important to European consumers, the Swedish Energy Agency's test laboratory also conducted tests to investigate whether the lamps complied with the quality requirements for LED lamps under EU No 1194/2012[12] (see Chapter 5). The sample size (n=10) was not sufficiently large for market surveillance testing, therefore the findings should only be taken as indicative as to whether these lamps would meet the requirements. Furthermore, all of the test are not complete (some require 6000 hours of data), for most of those that are done the answer is 'yes', the new LED lamps do meet the quality requirements of EU No 1194/2012:

- Lamp survival factor at 6000 h - tests are on-going
- Lumen maintenance at 6000 h – tests are on-going
- Number of switching cycles before failure – yes, tested for all lamps; no failures in LED, but one failure in a halogen lamp.
- Starting time – yes, all LED lamps passed
- Lamp warm-up time to 95% - yes, all LED lamps passed
- Premature failure rate at 1000 h – not complete yet; but is being tested and so far, all but one LED lamp (#11 LED24.cc) passed the test
- Colour rendering index – yes, tested and all LED lamps met the minimum requirement with two models being within the allowable tolerance and two models in the 90's.
- Colour consistency – yes, tested and most LED lamps met the six MacAdam step requirement; #9 (Panasonic) and #17 (Calex) exceeded this requirement.
- Lamp Power Factor – yes, tested and all lamps met the requirements with many exceeding them.

Overall, the LED lamps were all found to be compliant with the ecodesign requirements under 1194/2012, except a few models exceeded the six MacAdam[13] step limit and one premature

[12] Commission Regulation (EU) No 1194/2012 of 12 December 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for directional lamps, light emitting diode lamps and related equipment.
EN link: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:342:0001:0022:EN:PDF

[13] The six step Macadam requirement comes from ecodesign regulation EU No 1194/2012: when a light source is measured from multiple directions, all measurements x, y coordinates should be grouped within a 6 step Macadam ellipse.

failure. The lamps performed exceptionally well yet some importers omitted energy labels and one had developed their own energy label with an A+++ class (which does not exist in EU 874/2012) [14]. This labelling violation was reported to the UK NMO.

Q: Are LED filament lamps reliable products for consumers?

A: To assess reliability, the lamps were subjected to a switching-cycle test and an operational test which is on-going, but so far has completed 200 hours of testing. In the future, the Team collaborating on this study intends to publish additional test information on reliability at 3000 hours and 6000 hours. All the LED lamps finished the switching cycle test successfully (one halogen lamp in the sample of ten failed the switching cycle test). While 3 of the 170 LED lamps tested were defective and did not operate out of the box (and thus could have been returned for a refund / replacement). Two individual LED lamps sold by ccLED (both sample #11) failed during the burn-in. Lamp #12 had one unit fail during measurements, but all the other LED lamps so far have not have problems.[15] The longer-hour lifetime testing is continuing in parallel with the publication of this report. The data gathered so far, show a mixed picture with LED filament lamps complying with switching-cycle tests, but one model showing premature failure above the Ecodesign threshold. This doesn't mean LED filament lamps are worse than other lamps; the halogen lamp had difficulties in the switching-cycle test. For the consumer, the early failures should not pose a big problem, where they are covered by commercial or legal minimum product warranties.

Q: What trends in price and performance of LED filament lamps have been observed in the last two years and what is expected in the future?

A: Although LED filament technology was originally developed in 2008, [16] it hasn't been a popular LED lamp type until more recently, in 2014. The performance of LED filament lamps is linked to the performance of LEDs themselves, which it is shown in Chapter 2 are simply mounted in a chain under the phosphor coating of the filament. These emerging lamp designs have simplified the electronic drivers and the optics, resulting in an energy-efficient lamp which exceeds the price and performance that was envisaged in the VHK/VITO report. More specifically, the retail LED lamp price of these LED filament lamps is approximately 11 % lower than the forecast and efficacy is 29 % better. Given that the consultant's June 2013 report was the basis for the Commission's recent proposal to delay the implementation of Stage 6 of EC No 244/2009 by 2 years,[17] that proposed amendment would now seem to be redundant because the technological progress of LED lamps has exceeded expectations. Already now LED filament lamps are available that can replace many halogen applications.

[14] Commission Delegated Regulation (EU) No 874/2012 of 12 July 2012 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of electrical lamps and luminaires;
EN link: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012R0874&from=EN

[15] The verification procedure in Annex IV of EU/1194/2012 has a tolerance of maximum 1 failure out of every 20 lamps.

[16] Tevaja Lighting Corporation, China. See: http://www.tevaja.com/?page_id=11

[17] 5 November 2014, Commission issued an email which stated the following: EU TBT notification concerning the Draft Commission Regulation amending Regulation (EC) No 244/2009 has now been published on the WTO website under the following reference: G/TBT/N/EU/248 and can be found here (click on this link)

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Acronyms and Abbreviations

4E	Energy Efficient End-use Equipment (IEA Annex)
AC	Alternating Current
ANSI	American National Standards Institute
CCT	Correlated Colour Temperature
CEM	Clean Energy Ministerial
CFL	Compact Fluorescent Lamp
CLASP	Collaborative Labelling and Appliance Standards Program
CO_2	Carbon Dioxide
CRI	Colour Rendering Index
DC	Direct Current
DG	Directorate General
EC	European Commission
EU	European Union
IEA	International Energy Agency
kg	kilogram
LED	Light Emitting Diode
lm	Lumens
MEPS	Minimum Energy Performance Standards
MRSP	Manufacturer Recommended Sales Price
OEM	Original Equipment Manufacturer
PCB	Printed Circuit Board
R09	*a measure of saturated red* (colour rendering)
R&D	Research and Development
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RoHS	Regulation on Hazardous Substances
UK	United Kingdom
UNEP	United Nations Environment Programme
US	United States / United States of America
V	Voltage
VHK	Van Holsteijn en Kemna B.V.
VAT	Value Added Tax
W	Watts

1 Introduction

On Monday, 15 September, Bram Soenen of the Belgian Ministry for Health, Food Chain Safety and the Environment circulated an email to all the stakeholders of the European Commission's Consultation Forum for non-directional household lamps to inform them of this study. This email highlighted the fact that LED technology has continued to evolve at a very rapid pace, with the recent introduction of competitively priced (<10€) "LED filament" clear non-directional lamps into the European market. Several of these lamps claimed to have very high efficacies – and if those performance values are correct, then the actual product performance will have exceeded the anticipated rate of price and performance improvement used as a basis for DG Energy's proposal on the treatment of Stage 6 of EC No 244/2009. A copy of the 15 September email and the two-page attachment informing stakeholders about the study can be found in Annex A of this report.

This study provides a market snap-shot of clear LED lamps on the European market from August 2014, looking at their measured price and performance. The objective of the study is to examine the following key questions:

- What are the current cost (lumen/€) and performance (lm/W) of clear LED lamps?
- Do they give an aesthetic pleasant light (warm white, high CRI, no flicker)?
- Are the "dimmable" lamps compatible with leading edge and trailing edge dimmers?
- Do these lamps meet the LED quality requirements in EU No 1194/2012?
- Are LED filament lamps reliable products for consumers? (i.e., failure rate, switching test)
- What trends in price and performance of LED filament lamps have been observed in the last two years and what is expected in the future?

This report is structured as follows:

Chapter 1. Introduction – this chapter provides an overview and context for the test study and this report.

Chapter 2. Market and Technology Assessment – provides an overview of the European lamp market including data from the recent IEA 4E Mapping & Benchmarking Annex report. This chapter includes information on how LED filament and other clear lamps are being marketed in Europe and some information on the consumer response. This chapter also includes some information about LED filament technology.

Chapter 3. Lamps Purchased and Tests Conducted – provides information about the lamps that were selected, the test laboratory (the Swedish Energy Agency's lighting test laboratory) and the tests conducted.

Chapter 4. Test Results – presentation of test results for each individual lamp model and a comparison between the different models. It should be noted that not all the planned testing is complete at this time, therefore updates to these findings will be provided in the future as new data becomes available.

Chapter 5. Discussion of Test Results – compares the test results of the different lamps, looking at the differences in performance – both averages and minimum and maximum values.

Chapter 6. Key Question Examination and Discussion – the key questions mentioned above and included in the original email message of 15 September are discussed in this chapter. The responses to these questions constitute the outcomes and conclusions of this study.

As indicated in Chapter 4, due to the fact that some of the lifetime tests require 6000 hours (i.e., approximately 8 months) to complete, the authors are intending to publish updated test results on this sample of test lamps in the future. Like this study, any future updates will be provided to the Commission and the Consultation Forum, and posted in the public domain.

2 Market and Technology Assessment

This chapter provides information about the lamps that were selected for testing and their claimed performance levels. It includes photographs of the lamps as well as information about where the lamps were sourced and the prices paid. It also contains information about this new technology referred to as "LED filament" lamps.

2.1 European Lamp Market

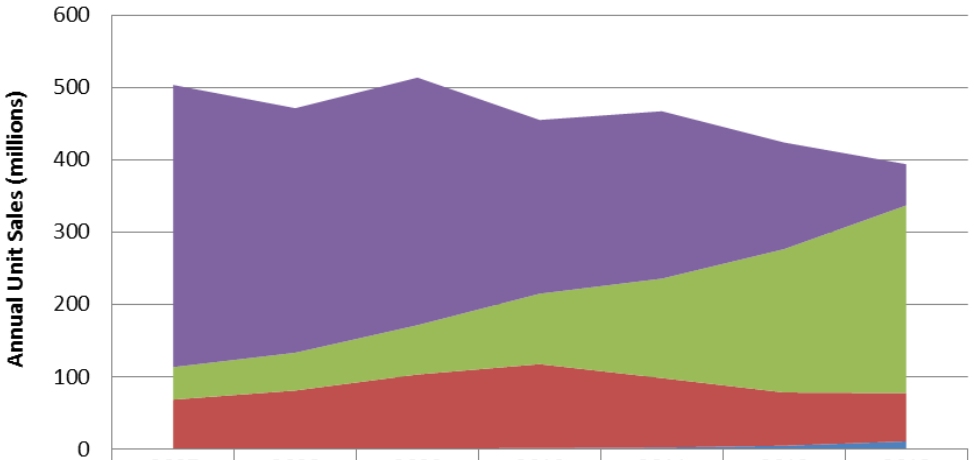
Ecodesign regulation EC No 244/2009 bifurcated the incandescent lighting market into frosted and clear lamps, and set different energy efficiency requirements for frosted and clear replacement lamps. The intention of the policy measure was that frosted incandescent lamps would be replaced with compact fluorescent lamps (A-class energy label) and clear incandescent lamps would be replaced by mains-voltage halogen lamps (D-class energy label). Then, in September 2016, the final stage of 244/2009 would phase out mains-voltage halogen lamps in favour of B-class halogen lamps, which are no longer available on the European market. Therefore, Stage 6 is being interpreted as a phasing out of mains voltage halogen lamps in favour of LED lamps, of which there are models on the market in 2014 in the A, A+ and A++ classes.

In a recent publication, the IEA 4E Mapping & Benchmarking Annex published an update to their domestic lighting market study, including Europe.[18] They published an update in September 2014, which includes GfK sales data for Europe. Some of that data is reproduced below, only including the mains-voltage incandescent and replacement lamps – namely mains voltage halogen, integrally ballasted CFL and LED lamps. The data shows that CFL sales peaked in 2010 and have been in decline ever since. In fact, CFL sales in 2013 are lower than they were in 2007, prior to the adoption of regulation EC No 244/2009. Meanwhile, mains voltage halogen lamp sales have grown by 477% over that same time period.

These sales data seem to indicate that the non-directional household lamp regulation has failed to advance sales of CFLs, and instead has simply moved the European non-directional household lighting market from incandescent to halogen lamps.[19]

[18] IEA Mapping and Benchmarking report – Domestic Lighting Update, September 2014. See: http://mappingandbenchmarking.iea-4e.org/shared_files/609/download

[19] Halogen lamps are approximately 20% more efficient than incandescent lamps while CFLs are approximately 400% more efficient. Thus, the allowance made for halogen mains voltage clear lamps has become a loop-hole that has undermined the original regulation and wiped out the anticipated savings.

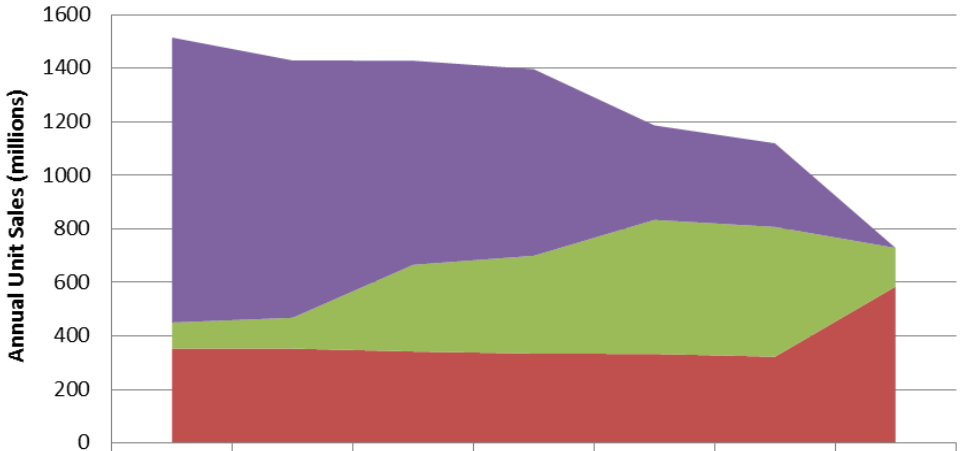


	2007	2008	2009	2010	2011	2012	2013
MV Incandescents	389.9	337.9	342.1	240.1	231.3	147.4	57.0
MV Halogens (single-end)	44.9	52.2	68.2	97.3	137.4	198.0	259.4
MV Self-Ballasted CFLs	68.5	80.8	102.3	116.0	96.0	73.6	66.6
Retrofit LED Lamps	0.2	0.5	1.1	1.7	2.5	5.0	11.0

Figure 2-1. GfK shipment estimate of Non-Directional Mains-Voltage Lamps , 2007-2013 (Austria, Belgium, France, Germany, Great Britain, Italy and the Netherlands)

The actual market in 2013 contrasts sharply with the market forecasts prepared in 2009 for "Option 2 Clear B Slow" (the scenario selected by the Commission for regulation EC No 244/2009, see Figure 2-2 below), which had expected CFL sales to be 4 times larger than mains voltage halogen lamps in 2013.[20] The fact that actual CFL sales are one quarter of halogen sales in 2013 (see Figure 2-1 above) would mean that the European market is not on track to deliver the anticipated 39 TWh of electricity savings in 2020 from EC No 244/2009. When making a comparison between the two graphs, it is important to focus on the relative shares of lamp types rather than the absolute numbers. This is because the GfK shipment data is reported to represent about 70 percent of seven large EU Member States while the 2009 lamp forecast used to calculate energy savings represents the whole EU market. The contrast in the relative share of halogen to CFL between the 2009 projection (Figure 2-2) and GfK lamp shipment data (Figure 2-1) is notable.

[20] Final report, Lot 19: Domestic lighting prepared by VITO for European Commission DGTREN unit D3, Andras Toth, 2009/ETE/R/069; October 2009. See shipments projection in Annexe 8-6: Main economic and environmental data for the scenario "Option 2 Clear B Slow".



	2007	2008	2009	2010	2011	2012	2013
MV Incandescents	1064.4	961	762.2	696.7	353	312.5	0
MV Halogens (single-end)	97.4	115.2	323.8	365.3	500.5	484.7	144.6
MV Self-Ballasted CFLs	353	353.1	342.3	334.6	333.2	322.7	584.6
Retrofit LED Lamps							

Figure 2-2. Lot 19 Impact Assessment Shipments Projection of Non-Directional Mains-Voltage Lamps for Europe, 2007-2013

Furthermore, frosted incandescent lamp sales were estimated to be nearly three-quarters of sales in 2007 (clear incandescent was approximately one-quarter of sales).[21] Although a transition from frosted incandescent to CFL was deemed cost effective for households[22], most frosted lamp sockets would not seem to have migrated to CFLs (clear halogen lamp sales were 4 times larger than CFLs in 2013). This would mean, the decision to keep clear mains voltage halogen lamps in the market has slowed the market adoption of energy-efficient lighting and undermined the energy savings. Given this new information about how the market seems to have responded to the policy measures (i.e., rejecting CFL lamps), the proposal to extend the sales of clear mains voltage halogen lamp sales in Europe from 2016 to 2018[23] could further delay the introduction of energy-efficient lighting into Europe.

2.1.1 Comparison of Europe with other databases

In parallel with the laboratory tests on the procured samples of lamps, additional research was conducted on published databases and sources of data that may also be included in this report to supplement the information and evidence being submitted to the Commission and Consultation Forum. These additional data represent self-reported, published and tested results thus they are given a different colour in the plots to differentiate them from the performance values of the lamps tested by the Swedish Energy Agency. The data were gathered from five different sources:

[21] Final report, Lot 19: Domestic lighting prepared by VITO for European Commission, 2009/ETE/R/069; October 2009. Annexe 8-6: Main economic and environmental data for the scenario "Option 2 Clear B Slow".
[22] Full Impact Assessment, Commission Staff Working Document, on ecodesign requirements for nondirectional household lamps, 18.3.2009. Quote on page 16: "In the frosted lamps category, the analysis has shown that it is cost-effective to only allow class A level lamps (= CFLs)."
[23] 5 November 2014, Commission issued an email which stated the following: EU TBT notification concerning the Draft Commission Regulation amending Regulation (EC) No 244/2009 has now been published on the WTO website under the following reference: G/TBT/N/EU/248 and can be found here (click on this link)

- Olino Database (NL): http://www.olino.org/
- LED benchmark (AU): http://www.ledbenchmark.com
- LightingFacts (US): http://www.lightingfacts.com/Products
- ENERGY STAR (US): http://www.energystar.gov/
- California (US): http://www.appliances.energy.ca.gov/

Only omni-directional, general lighting service lamps (both clear and frosted) were imported into the database for this study. There are 1808 models in the database, although some will be duplicated across the three US sources. The figure below shows a scatterplot of the data, zoomed-in to between 2 and 12 Watts and 0 to 1200 lumens. The test data from this study are included in the plot, as yellow circles (labelled "Sweden Test Data" in the figure legend).

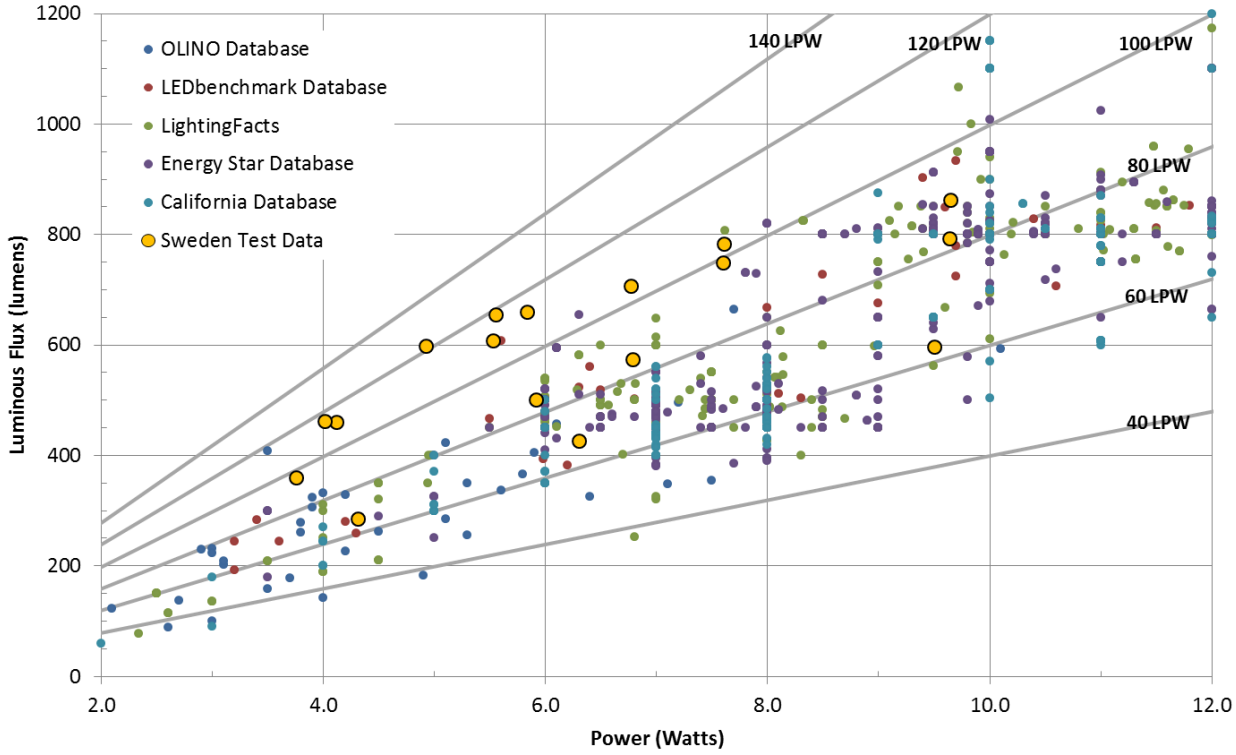


Figure 2-3. Comparison of Test Data (2014) with Public Databases of LED Lamps (2012-2014)

The Swedish Test Data, prepared for this report, tend toward the higher efficacy models in the dataset which includes LED lamps from 2012 to 2014. The test data from this study tends to be more efficient because they were all purchased in the last few months and thus are using the most recent and energy-efficient LEDs. Furthermore, the LED filament lamps seem to be new models, just emerging onto the market in volume this year, and so the databases don't yet reflect those models.

The data gathered from these five public data sources either didn't include price information or it was only available for a few models, therefore no meaningful comparison could be made on price.

2.2 Marketing LED Lamps

This section of the report provides some screen captures of the LED lamps from the websites where they were purchased. The marketing information is provided to show the performance attributes which are being emphasised when promoting these lamps in the market such as low power consumption, long service life, beam angle, correlated colour temperature and colour rendering index, and lumen output.

2.2.1 Lamp 2 – Maplin "LED filament" / A15QF

The following is a screen capture of the claimed performance characteristics of Maplin's six watt LED filament lamp which was purchased from Maplin in the UK.

Product details

LED Filament Technology GLS 662LM Bayonet Cap (B22)

- Revolutionary LED filament technology
- Ultra efficient, up to twice as efficient as traditional LED
- Full glass to cap construction offers identical appearance to traditional lamps
- Perfect for open fixtures such as chandeliers and decorative fittings
- Cool running, almost no heat generated
- Bayonet Cap (B22) Fitting
- 662LM output (110/W)
- 6W power consumption
- 360° beam angle
- 50,000 hour lifespan
- 2750K colour temperature
- CRI >80
- Non dimmable
- 2 year warranty

Not all LEDs are created equal. LED filament technology allows for a near identical appearance to traditional incandescent lamps while delivering ultra efficient light across a 360 degree beam angle. The traditional appearance makes these lamps ideal for use in decorative fittings such as chandeliers and design-lead lighting.

All our LED filament bulbs are rated for 50,000 hours of life and are guaranteed for 2 years as standard.

2.2.2 Lamp 5 - LED Connection "Classic LED blub"

The following is a screen capture of the claimed performance characteristics of the LED Connection's six watt LED filament lamp which was purchased from LED Connection in the UK.

Additional Information

Lumens	550
Power Consumption	6w
Input Power	AC 220-240v
Average Life in Hrs	40000
Base	E27
Beam Angle	360
Dimension	60mm diameter x 108mm Length
Cutout Size	N/A
Voltage Range	AC 220-240v
Dimmable	NO
Colour	Warm White
Product Warranty	2 Years
Certifications	CE, RoHS

2.2.3 Lamp 6 – IKEA Ledare LED lamp

The following is a screen capture of the claimed performance characteristics of the IKEA Ledare lamp that was purchased at the Edmonton (UK) IKEA store.

2.2.4 Lamp 15 – Philips Clear LED Lamp

The following is a screen capture from the press release of the Philips Clear LED lamp. Please note that the retail price quoted in the Philips press release is lower than the retail price paid for this lamp when it was purchased for this testing study. (The price paid was €14.93.)

The clear LED 40W replacement bulb is available from July 2014 for RSP of EUR 8.99.

Features of the Philips' clear LED bulb:

- Innovative lens for sparkling (filament like) light effect
- Dimmable
- Shape: A60
- Lifetime: 25.000 hrs
- Color temperature: 2700K (warm white light)
- Lumen: 470 lm (equivalent to 40W)
- Energy efficient and cost-saving: 85% energy efficiency (6W input wattage: 78 lumen per watt ratio
- Perfect light distribution (omnidirectional): > 240D
- Ideal for homes, hospitality and retail.

2.2.5 Lamp 17 – Calex "LED Filament GLS"

The following is a screen capture of the claimed performance characteristics of the Calex LED filament lamp which was purchased from ELV in Belgium.

474732

Calex LED Filament GLS-lamp 240V 6,5W B22 A60, Clear 2700K

Cat. no.	474732	Dimmable	Nee
Cap Base	B22	Frequency	50/60Hz
Shape Description	A60	Voltage	240V
Energy Label	A+	Wattage	6,5W
Lumen Output	650	Lifetime	50000 hour
Nominal life time	50000 hour	Colour Description	Warm White
Lumen maintenance factor at the end norm. life	0,7	Colour Temperature	2700 °K
		Number of switching cycles	25000
Warm up time up to 60% of full light output	1,9	Wattage x,1 W precision	6,5W
		Lamp power factor	0,67
		Starting time x,x sec	0,4
		Colour Rending Index	89

2.3 LED Filament Technology

An LED filament lamp is a retrofittable, mains-voltage replacement lamp that uses LEDs as its light-emitting filaments. These filaments are designed so that light is produced uniformly and evenly, usually in all directions. Multiple filaments are then arranged in the glass envelope in order to maximise the light emission pattern in all directions (see polar plots in Chapter 4). The resulting product resembles light emission patterns and optical ('sparkle') effects normally attributed to traditional incandescent and halogen (tungsten) filament lamps.

The figure below is a close-up photograph taken of one of the lamps tested in this study. This particular lamp had 8 LED filaments contained within the glass bulb. Each of these filaments consumes approximately 1 watt of power, thus this lamp is about an 8 watt LED lamp. And the filaments are typically operating around 110 lumens per watt, thus this lamp will have approximately an 880 lumen output.

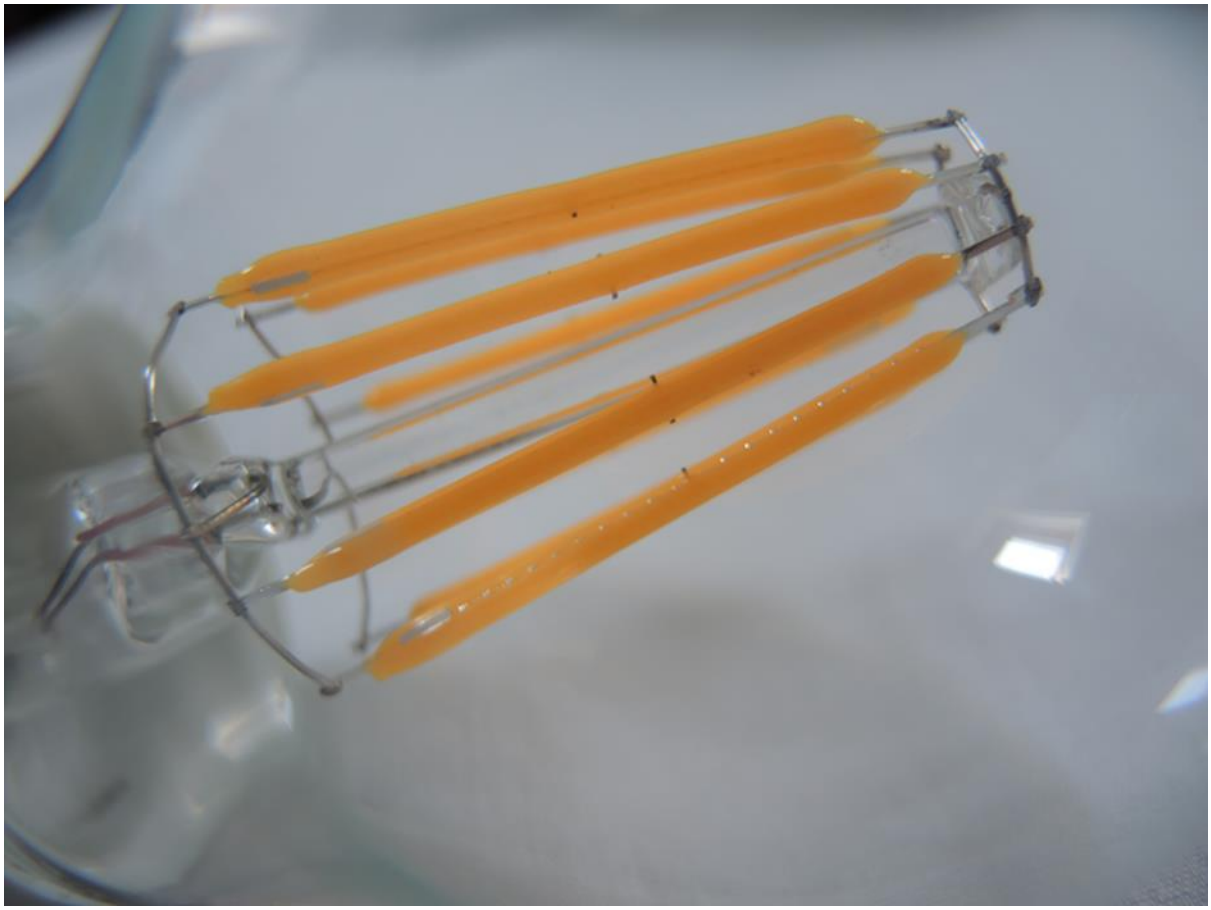


Figure 2-4. Close-up photograph of LED filaments from LED Connection (UK) 8W lamp

According to one manufacturer's website, the filament LED lamp was first produced by the Japanese lighting company, Ushio in 2008.[24] The original design bent the tube into a U-shape and used six filaments to duplicate the appearance of incandescent bulbs, with 3 LED chips in each of the six filaments. When the LED filaments are operating, they resemble a concentrated small point source, similar to an incandescent or halogen filament, thus offering a familiar and traditional look while creating the 'sparkle' optical effect where light from these sources interacts with cut glass and crystal in decorative and ornamental lighting fixtures. As described in the vosLED 2014 product catalogue, Gerhard Liebscher, Managing Director of vosLED says "The Edison bulb is a truly great design: an almost perfect point light source that can be adapted to any lighting situation with the use of lamp shades. And now it's energy efficient too – Edison would be delighted with the new vosLED bulbs!"[25]

Companies adapted and improved upon the original Ushio design, and in 2013 several products introduced to the global lighting market by different manufacturers. For example, Tevaja Lighting Company (China), uses a longer filament which incorporates 30 LED chips into each filament, enabling a greater light output from each filament.[26] The photo below shows a cut-view of one of

[24] Tevaja Lighting corporation, China. See: http://www.tevaja.com/?page_id=11
[25] VOSLED Kompromisslos Besser, vosLED Glühbirnen Light bulbs, 2014 Catalogue. Plauen, Germany. www.vosla.com website visited 5 September 2014.
[26] Tevaja Lighting corporation, China. See: http://www.tevaja.com/?page_id=11 ; also, it should be noted that manufacturers may vary the number of LEDs in the filament to create the desired light output level and forward voltage.

these filaments, both with the yellow phosphor and with the phosphor removed, revealing the string of LED die mounted on the substrate. These LEDs are GaN, emitting a blue light, and they are connected in series on a transparent substrate before the whole assembly is coated in phosphor. Light is emitted out the front and back of the LEDs, enhancing the luminous flux and efficacy. The photo below shows a cut-away view of an LED filament, with the arrangement of LEDs in series.

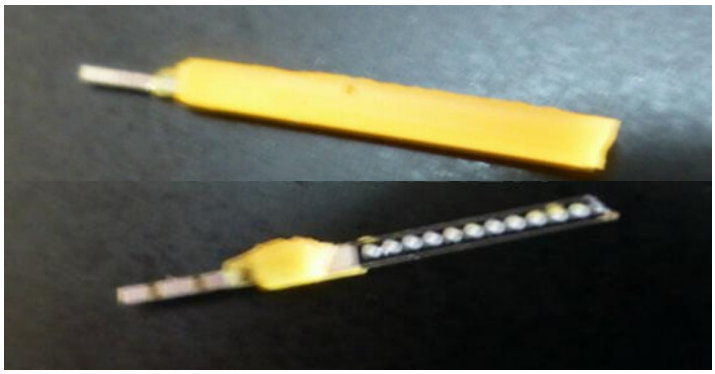


Figure 2-5. Cut-away view of LED filament on transparent substrate

The LED filament designs use LED chips encapsulated on a transparent substrate[27] of glass or synthetic sapphire, and coated with phosphor. The Tevaja Company refers to this new packaging technology as a "chip-on-glass" design. The filament of glass or synthetic sapphire is very thin, with a diameter of approximately 1.5mm, but with a length of approximately 30mm. The LED filament is formed by connecting the LEDs in series on the substrate, adding the connectional terminals at each end and encapsulating the LED part in the yellow phosphor. The following figure shows a dimensioned diagram of an LED filament from a product catalogue[28], where all dimensions shown are in millimetres.

Shenzhen Harrison Optoelectronics Technology Co. for example, offers a filament that uses 28 LED chips on a sapphire substrate. See: http://harrisonled.en.alibaba.com/product/1965954604-800193353/2014_NEW_Technology_Epistar_chip_Sapphire_substrate_4W_6W_120LM_W_Warm_cool_white_Filament_clear_glass_cover_Globe_bulb_lights.html

[27] There are several different types of mounting substrates for the LEDs in these filaments. In addition to glass and synthetic sapphire, some manufacturers are using a ceramic substrate and others metal – although the metal will have obvious implications in light emission patterns. See for example: http://www.diytrade.com/china/pd/12716819/Patent_Product_High_power_COB_COG_EPISTAR_chips_Blue_sapphire_Led_filament.html

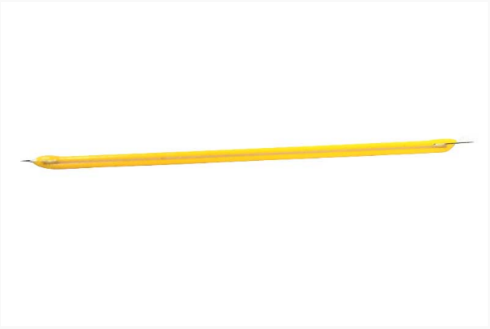
[28] To view the catalogue, click on this link: http://ecatalog.oodii.com/26783.html

Figure 2-6. Dimensioned (mm) diagram of LED filament and close-up photograph

The following is a screen capture of another manufacturer's catalogue[29] who sells the LED filaments as an Original Equipment Manufacturer (OEM) supplier to lamp assembly companies. In this table, the LED filament is described as following the chromaticity binning requirements of the ANSI standard and certified by LM-80. The website states that these filaments are compliant with the European Regulation on Hazardous Substances (RoHS) and REACH. The filament is available in a number of different colour temperatures.

LED Filament Home >> Filament >> LED Filament

led filament



Feature:

1.Chromaticity Bin by ANSI standard.
2.**LM-80** certified
3.Low thermal resistance and high light output.
4.EN 62471,ROHS and REACH compliant
5.Available in warm,neutral and cool white.

Technical Characteristics:

Product Type	Luminous Flux lm	Efficiency lm/w	CRI Ra	CCT (Kelvin)	Forward Current mA	Input Voltage v	degree
FSS1-JG-CEEF-D0	110-120	160	80up	6020-6530K	10	75-80	360°
FSS1-JG-NBFF-D0	120-130	160	80up	4060±163K			
FSS1-JG-WJDF-D0	100-110	150	80up	2940±85K			
FSS1-JG-WIDF-D0	110-120	150	80up	2725±80K			
size:38*1.6*0.7mm							

Figure 2-7. Example of an LED filament specification from the Runlite Catalogue (2014)

One approach to making different colour temperatures, such as from 2800K to 6500K, would be to change the proportion of coloured LED chips mounted on the substrate of the filament. For warmer whites (e.g., 2700K) there may be more red and amber LED chips included with the blue LEDs. For

[29] This catalogue was accessed on 15 October 2014; see: http://www.runlite.cn/en/product-detail-145.html

cooler whites (e.g., 6500K), there would be a larger proportion of blue LED chips driving the phosphor.

The design of LED filament lamps contrasts with traditional LED lamp designs in that there is no heat sink connected to the LED Lamp. It is thought that this is possible because of the very high efficacies relative to some of the traditional designs – for example, the most efficient LED filament is approximately twice as efficient as the least efficient clear LED lamp tested, thus using half the watts for the same light output and consequently halving the waste heat. In order to assess this aspect in this test study, the operating temperature of the lamps were measured under steady-state performance. In this study, the highest bulb surface temperatures were found and measured for each lamp using an infrared camera. Compared with the halogen reference lamp, the LED lamps had a cooler surface temperature (see Section 5.7).

Manufacturers of these LED filaments claim that they have a very long lifespan, typically ten times longer (20,000 hours) than halogen lamps (2,000 hours). This claim is also being tested in this study, up to 6,000 hours of testing which will be completed and published in May/June 2015.

The driver operating the LED filaments is physically small compared to the circuits operating other LED lamps. In some designs tested in this study, the entire driver fit within the space of the end-cap of the lamp (i.e., the E27 screw base or the B22 bayonet fitting). In other designs, a very small white plastic housing extended up from the screw base of only about 15 mm containing the driver. Either way, there are substantially less electronic components with the associated environmental resource efficiency benefits that are associated with these simplified designs.

These simple drivers appear to be rectifying bridge circuits, where four diodes are arranged in a bridge so that they provide the same polarity of output as the polarity of the input changes. In other words, these simple rectifying bridges convert alternating current (AC) and into something that resembles direct current (DC). The figures below are copied from Wikipedia and show the two possible scenarios and current pathways, where red represents the positive polarity and blue the negative.

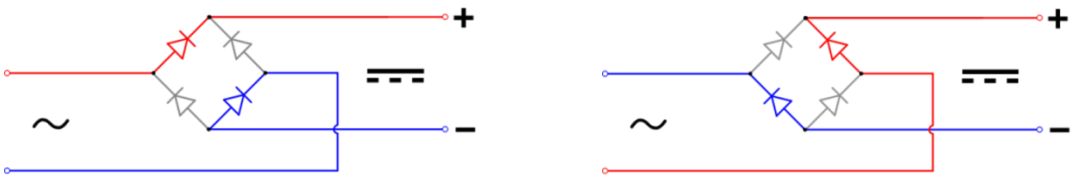


Figure 2-8. Illustration of a simple bridge rectifier used in driving some of these lamps

For more information on LED filament lamps, please see the following resources:

- Product example: http://www.vosla.com/upload/downloads/kataloge/vosled-katalog-2014b.pdf
- Close-up examination: https://www.youtube.com/watch?v=25j2C4jq2HI

- Explanation on the filaments: http://www.designingwithleds.com/novel-led-packaging-adds-filaments-retro-bulbs/
- LED filament lamps: https://app.box.com/s/78emee997g7ltplc5xab
- Bridge rectifier circuits: http://en.wikipedia.org/wiki/Diode_bridge
- Chip-on-glass packaging: www.epistar.com
- Phosphor for LED products: http://www.intematix.com/products/led-phosphors

3 Lamps Purchased and Tests Conducted

This chapter provides some information about the lighting test laboratory at the Swedish Energy Agency where the tests were conducted. It also provides information on which tests were conducted by the lab, including electrical, light quality and other tests.

3.1 Lamp Selection and Procurement

All of the lamps purchased for this study were procured online. The map below shows the countries from which the lamps were sourced from retailers located in Belgium, France, Germany, the Netherlands, Sweden, and the United Kingdom.

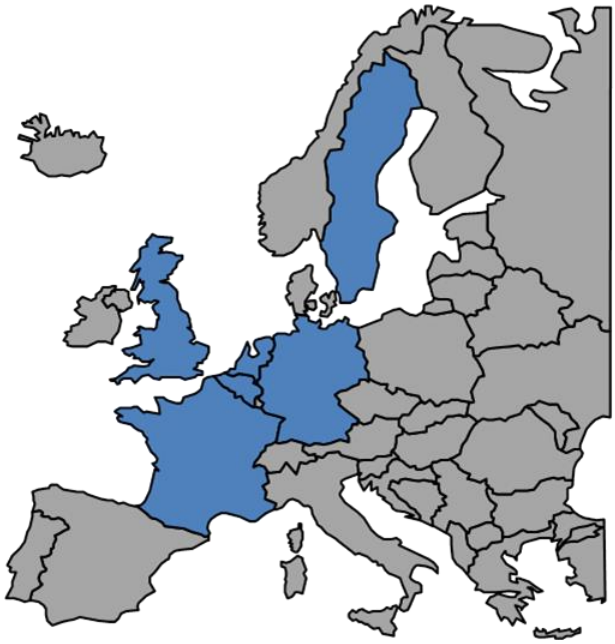


Figure 3-1. Map of Europe showing countries where LED lamps were procured

Due to some comments that were raised by stakeholders in 2013 about the lack of replacement products that could offer a 'sparkle' effect in decorative fixtures and luminaires such as those which incorporate refractive glass and crystal, this study sought to identify and source lamps that offered a clear glass envelope where the LED emitting part of the light could create this effect.

There were two general types of clear LED lamps on the European Market at this time:

1) a clear optical light guide, such as the lamps produced by IKEA, Philips and OSRAM and
2) LED filament lamps, such as those sold by Maplin (UK), Wholesale Lighting (UK) and Vosla (DE).

Both types of LED lamps offer consumers the benefit of creating a 'sparkle' effect when installed in those luminaires that interact optically with the lamp. The following table is a list of all the lamps purchased for this study and their claimed performance attributes. The measured test results for these products are presented in Chapter 4 and Annex B.

Table 3-1. Lamps purchased for testing and some of the performance characteristics claimed on the websites

#	Make / Model	Lumen	Watts	CCT	CRI	Life	Dim?	Retailer	Price each	Euros	€/500 lm
1	Wholesale Lighting / MS-B22-6W-OMNI	650	6	3000	--	30k	No	WLL(UK)	£14.62	€ 18.28	€ 15.29
2	Maplin “LED filament” / A15QF	662	6	2750	>80	50k	No	Maplin UK	£18.42	€ 23.03	€ 17.48
3	Osram Halogen Classic A ECO 64543 (46W)	700	46	2700	100	2k	Yes	Amazon	£2.13	€ 2.66	€ 2.29
4	Lighting Ever “LED Filament” / 100047-WW-EU	560	4	2700	>80	50k	No	LE UK	£6.99	€ 8.74	€ 12.17
5	LED Connection “Classic LED bulb”	600	7	?	--	30k	Yes	LED Conn.	£12.49	€ 15.61	€ 18.31
6	IKEA LEDARE / 602.553.62	600	10	2700	--	25k	Yes	IKEA UK	£6.00	€ 7.50	€ 6.30
7	Vosla GmbH (DE), vosLED-light bulb clear, 5.5W	550	5.5	2700	>90	25k	No	vosLED	(Germany)	€ 34.49	€ 28.42
8	LED Connection 8W warm white filament LED	880	8	2700	--	40k	No	LED Conn.	£24.00	€ 30.00	€ 19.17
9	Panasonic “Nostalgic Clear” / LDAHV10L27CGBEP	806	10	2700	80	25k	No	Panasonic FR	(France)	€ 20.80	€ 13.12
10	NCC-Licht / LED Filament 6W warmweiß 2700K	750	6	2700	80	20k	No	Amazon.de	(Germany)	€ 12.98	€ 9.18
11	LED24.cc / E27 LED Glühfaden Birne 8w 2700K	800	8	2700	80	--	No	Amazon.de	(Germany)	€ 16.95	€ 12.79
12	LED filament lampa E27 #338-71	440	4	2900	80	--	No	Star Trading	52,00 SEK	€ 5.66	€ 6.16
13	LED filament lampa E27 #338-09 (candelabra)	470	5	2700	80	--	Yes	Star Trading	106,00 SEK	€ 11.53	€ 20.21
14	Osram PARATHOM Classic A ADV 10W 827	810	10	2700	80	20k	Yes	LEDLightbulbs	£9.88	€ 12.35	€ 7.16
15	Philips “Clear LED bulb” - GLS 6W A60 E27 Clear	470	6	2700	80	25k	Yes	LEDLIghtbulbs	11.94	€ 14.93	€ 14.89
16	Led lampen direct (NL) / “Polaris 4 Watt”	450	4.2	2700	>80	15k	No	LED Lampen	(NL)	€ 9.50	€ 10.25
17	Calex (NL) “LED Filament GLS” / 474732	650	6.5	2700	89	50k	No	ELV Belgium	(BE)	€ 16.58	€ 14.46
18	Segula LED Lamp / E27 5.5W	720	5.5	2600	80	20k	No	LEDitLight	(NL)	€ 41.95	€ 32.04
									Min:	€ 5.66	€ 6.16
									Max:	€ 41.95	€ 32.04

3.2 Test Laboratory

All of the testing was conducted at the Swedish Energy Agency's lighting test laboratory in Stockholm. This laboratory was established in 2013 in cooperation with the UNEP Collaborating Global Efficient Lighting Centre in Beijing. The laboratory also participated in the International Energy Agency's 4E Solid State Lighting Annex's 2013 Interlaboratory Comparison.[30]

The main activity of this laboratory is for conducting testing as part of on-going market surveillance activities in Sweden to ensure compliance with the European Commission's ecodesign lighting product regulations EC No 244/2009 (non-directional household lighting), EC No 245/2009 (tertiary sector lighting), EU No 874/2012 (energy labelling for lighting products) and EU No 1194/2012 (directional lighting and LEDs).

In terms of testing equipment, the laboratory currently has a wide range of equipment for testing all types of lighting products, including:

- two 1.8 meter integrating spheres;
- a near field photogoniometer (that can test up to 1400mm luminaires);
- life test and stress cycling equipment for E14- and E27-lamps, linear fluorescent tubes and LED-modules; and
- a wind cap for luminaire temperature measurements.

The parameters most often measured in the lighting laboratory are luminous flux (lumens), correlated colour temperature (CCT in K), colour rendering (including colour rendering index, colour quality scale and gamut area index), efficacy (lumens per watt), colour shift over time (MacAdam ellipse) and flicker (including percent flicker and flicker index).

3.3 Tests Conducted

The Swedish Energy Agency's laboratory conducted a range of tests on the samples of lamps procured for this study. The study looked at the lamps under test as compared to the requirements of EU No 1194/2012, although the sample size and procurement practices may not be aligned with procedures followed by the Swedish Market Surveillance Authority. Thus, **the results of this study should not be viewed as market surveillance test results**, but rather as indicative findings that may offer unofficial test results on a few models of clear LED Lamps to European market surveillance authorities. This may help them to target their compliance and enforcement procurement practices more accurately.

The screen-capture below presents the requirements from EU No 1194/2012 for all non-directional and directional LED lamps.

[30] This project compares the ability of 110 laboratories worldwide to test Light Emitting Diode (LED) lamps and luminaires. The outcome of this large-scale interlaboratory comparison will help governments and manufacturers around the world ensure that new LED products sold to consumers and companies are of high quality and meet the claimed performance. http://ssl.iea-4e.org/files/otherfiles/0000/0067/IC2013_Final_Report_final_10.09.2014a.pdf

2.2. **Functionality requirements for non-directional and directional LED lamps**

The lamp functionality requirements are set out in Table 5 for both non-directional and directional LED lamps.

Table 5

Functionality requirements for non-directional and directional LED lamps

Functionality parameter	Requirement as from stage 1, except where indicated otherwise
Lamp survival factor at 6 000 h	From 1 March 2014: ≥ 0,90
Lumen Maintenance at 6 000 h	From 1 March 2014: ≥ 0,80
Number of switching cycles before failure	≥ 15 000 if rated lamp life ≥ 30 000 h otherwise: ≥ half the rated lamp life expressed in hours
Starting time	< 0,5 s
Lamp warm-up time to 95 % Φ	< 2 s
Premature failure rate	≤ 5,0 % at 1 000 h

Functionality parameter	Requirement as from stage 1, except where indicated otherwise
Colour rendering (Ra)	≥ 80 ≥ 65 if the lamp is intended for outdoor or industrial applications in accordance with point 3.1.3(l) of this Annex
Colour consistency	Variation of chromaticity coordinates within a six-step MacAdam ellipse or less.
Lamp power factor (PF) for lamps with integrated control gear	P ≤ 2 W: no requirement 2 W < P ≤ 5 W: PF > 0,4 5 W < P ≤ 25 W: PF > 0,5 P > 25 W: PF > 0,9

The following is a list of tests conducted, although some of the tests are not yet complete – such as lumen maintenance and colour shift at 6000 hours – as these will take several months to complete. However, some interim results are presented in this report. Please note that the test metrics marked with a star (*) are the ones required by the European regulation EU No 1194/2012 (table above).

<u>Recorded physical information</u>

- Test Lamp Identification Number
- Manufacturer Name
- Model Number
- Width, Length and Weight

<u>Steady-state operation</u>

- Voltage (V)
- Current (mA)
- Power (Watts)
- Luminous flux (lumens)
- Efficacy (lm/W)

- Power factor*
- Lamp max temperature, °C
- Flicker index
- Percent flicker

Light and colour quality

- Chromaticity x
- Chromaticity y
- Correlated colour temperature (CCT)
- Colour rendering index* and individual scores for CRI01 through CRI16
- Minimum measured Duv (negative values are below Planck)
- Maximum measured Duv
- MacAdam centre x
- MacAdam centre y
- Colour consistency - within six MacAdam steps?* (yes/no)
- Number of MacAdam ellipses containing all points?
- Gamut Point

Lifetime

- Premature failure rate to 1000 hours*
- Switching cycles* - 30 second on + 30 second off
- Lumen maintenance at 1000, 2000, 4000 and 6000 hours
- Colour shift at 1000, 2000, 4000 and 6000 hours
- Lamp survival factor at 6000 hours* - tests are on-going
- Lumen maintenance at 6000 hours* - tests are on-going

Dimmer compatibility (only on those lamps marketed as 'dimmable')

- Leading edge dimmer (ELKO 400GLI)
- Trailing edge dimmer (ELKO 315GLE)

* Test parameters marked with a (*) are regulated quantities under EU No 1194/2012.

In addition to these, CLASP (who managed the procurement of the lamps) also recorded the prices paid and the sources from which the samples were obtained for the study. These data were used to help plot the current price and performance of LED lamps relative to the projected performance given in Table 2 of the VHK/VITO technical report published in June 2013.

4 Test Results

This chapter presents a summary of the individual lamp test results. As previously noted, not all the testing is complete at this point, therefore updates to this report will be provided as more test data on the samples of lamps becomes available. In Chapter 5, a comparison of some of the key test parameters across the different lamp models is provided and in Annex B, more detailed test results are shown. The purpose of providing these results is to be as transparent as possible about the tested performance findings for these lamps.

4.1 Wholesale Lighting MS-B22-6W-OMNI

This lamp was purchased from a UK-based on-line retailer (see link in the table below). Although the box and lamp were labelled 6 watts, the measured power consumption of the lamps purchased was approximately 5 watts. The packaging for the lamp was simply a white, blank box, with a sticker giving the Lamp ID. The box did not have an EU energy label. These lamps were purchased in August 2014 for €15.29 per 500 lumens including VAT, however at the time of this report (three months later) the same UK retailer had reduced the price by 17% to €12.63 per 500 lumens including VAT.

Table 4-1. Summary of Test Results for Sample of Lamp #1

Item	Quantity Declared	Quantity Measured	Units	Difference
Power	6	4.9	*Watts*	-18%
Light Output	650	598	*Lumens*	-8%
Efficacy	108.3	121.4	*lm/W*	12%
CCT	3000	3045	*K*	2%
CRI	--	81	*Ra*	--
R09 (red)	--	16.2	*(Red)*	--
Max ellipse	--	3.8	*MacAdam steps*	--
Price paid	--	€ 15.29	*€ / 500 lm*	--
Current Price	--	€ 12.63	*€ / 500 lm*	--
Website	Click on this link			

4.2 UK LED Standard Bulb

This lamp was purchased from Maplin's, a UK electronics retailer with an on-line shop (see link in the table below). The lamp came in a black and green coloured UK LED box, and an energy label that did not comply with EU regulations. The label indicated that the lamp was an A+++ class non-directional lamp, although the highest class is actually A++. The lamps were purchased in August 2014 for €15.29 per 500 lumens including VAT, however at the time of this report (two months later) the same UK supplier had reduced the price by 17% to €12.63 per 500 lumens including VAT. It should be noted that the colour consistency for the lamp measured exceeded six MacAdam steps, the maximum number allowed under regulation EU No 1194/2012.

Table 4-2. Summary of Test Results for Sample of Lamp #2

Item	Quantity Declared	Quantity Measured	Units	Difference
Power	6	5.8	*Watts*	-3%
Light Output	662	659	*Lumens*	0%
Efficacy	110.3	112.9	*lm/W*	2%
CCT	2750	2765	*K*	1%
CRI	>80	82	*Ra*	3%
R09 (red)	--	12	*(Red)*	--
Max ellipse	--	7.6	*MacAdam steps*	--
Price paid	--	€ 17.48	*€ / 500 lm*	--
Current Price	--	(no change)	*€ / 500 lm*	--
Website	Click on this link			

4.3 Osram Halogen Classic A ECO

This lamp was purchased from Amazon (UK) – dispatched from and sold by Amazon (see link in the table below). These lamps were purchased as a basis for comparison between the clear LED lamps and mains-voltage halogen lamps. The lamps were supplied with the traditional OSRAM boxes, and compliant labelling information, including the energy class rating D. The lamps were purchased in August 2014 for €2.29 per 500 lumens including VAT, however at the time of this report (two months later) the same UK supplier has increased the price considerably – by 88% to €4.29 per 500 lumens including VAT. The light output of this halogen lamp appears to be lower than the labelled value, and may require further investigation (please note, this measurement is the average of 10 units, not the required 20 units for verification testing).

Table 4-3. Summary of Test Results for Sample of Lamp #3

Item	Quantity Declared	Quantity Measured	Units	Difference
Power	46	45.5	*Watts*	-1%
Light Output	700	583	*Lumens*	-17%
Efficacy	15.2	12.8	*lm/W*	-16%
CCT	--	2747	*K*	--
CRI	100	100	*Ra*	0%
R09 (red)	--	99.2	*(Red)*	--
Max ellipse	--	1.7	*MacAdam steps*	--
Price paid	--	€ 2.29	*€ / 500 lm*	--
Current Price	--	€ 4.29	*€ / 500 lm*	--
Website	Click on this link			

4.4 Lighting Ever "LED Filament Bulb"

This lamp was purchased from Lighting Ever, a UK on-line lighting retailer (see link in the table below). The lamp came in colourful packaging, including an EU energy label and a scale indicating the colour temperature of the lamp. The lamp was labelled as an A+ class. These lamps were purchased in August 2014 for €12.17 per 500 lumens including VAT, and there was no change in price two months later. This lamp offers a low wattage consumption, but also a modest light output of only 359 lumens. The measured light output of this LED Lamp is 36 percent lower than is advertised on the packaging.

Table 4-4. Summary of Test Results for Sample of Lamp #4

Item	Quantity Declared	Quantity Measured	Units	Difference
Power	4	3.8	*Watts*	-5%
Light Output	560	359	*Lumens*	-36%
Efficacy	140.0	95.6	*lm/W*	-32%
CCT	2700	2730	*K*	1%
CRI	>80	80	*Ra*	*0%*
R09 (red)	--	2.1	*(Red)*	--
Max ellipse	--	5.0	*MacAdam steps*	--
Price paid	--	€ 12.17	*€ / 500 lm*	--
Current Price	--	(no change)	*€ / 500 lm*	--
Website	Click on this link			

4.5 LED Connection "Classic LED bulb"

This lamp was purchased from LED Connection, a UK on-line lighting retailer who specialises in LED lighting products. This lamp was the only clear model tested which uses surface-mounted LEDs emitting directly from the PCB board. As shown in the photo, the lamp is constructed around a rectangular box which has LED die mounted on all surfaces – all four sides and the top and bottom of the cube. The lamp is sold in a clear plastic package and uses an outdated EU energy label on the back (note: these lamps may predate the effective date of the new lamp labelling requirements that took effect in September 2013). These lamps were purchased in August 2014 for €18.31 per 500 lumens including VAT, and there was no change in price two months later.

Table 4-5. Summary of Test Results for Sample of Lamp #5

Item	Quantity Declared	Quantity Measured	Units	Difference
Power	7.0	6.3	*Watts*	-10%
Light Output	430	426	*Lumens*	-1%
Efficacy	85.7	67.5	*lm/W*	-21%
CCT	2700	2830	*K*	5%
CRI	>80	80	*Ra*	0%
R09 (red)	--	5.2	*(Red)*	--
Max ellipse	--	1.7	*MacAdam steps*	--
Price paid	--	€ 18.31	*€ / 500 lm*	--
Current Price	--	(no change)	*€ / 500 lm*	--
Website	Click on this link			

4.6 IKEA "LEDARE" / 602.553.62

This sample of lamps was purchased from IKEA's retail store in Edmonton, North London, UK. This lamp design uses a light guide / diffuser to create a filament effect when installed in certain luminaires. The individual LEDs are visible through this optical guide, as shown in the picture below. This lamp is sold in a clear plastic 'blister' pack, and incorporates a current EU energy label. These lamps were purchased in August 2014 for €6.30 per 500 lumens including VAT, and there was no change in price two months later.

Table 4-6. Summary of Test Results for Sample of Lamp #6

Item	Quantity Declared	Quantity Measured	Units	Difference
Power	10	9.5	*Watts*	-5%
Light Output	600	596	*Lumens*	-1%
Efficacy	60.0	62.7	*lm/W*	5%
CCT	2700	2673	*K*	-1%
CRI	--	90	*Ra*	--
R09 (red)	--	52.2	*(Red)*	--
Max ellipse	--	4.7	*MacAdam steps*	--
Price paid	--	€ 6.30	*€ / 500 lm*	--
Current Price	--	(no change)	*€ / 500 lm*	--
Website	Click on this link			

4.7 vosLED Light Bulb Clear, 5.5W

This sample of lamps was purchased from VOSLA's on-line retail shop based in Germany. As shown in the photos, this is an LED filament lamp which has six filaments in each lamp. The product is marketed as having good quality light, and this is reflected in the measured results of 91 CRI and an R09 (red) of 60.1. The lamps have an efficacy rating typical of the LED filament lamps at this time, but they are more expensive than some of the other lamps in this study. The packaging for these lamps includes a EU energy label with an A+ rating and a guide for CCT scale. These lamps were purchased in August 2014 for €28.42 per 500 lumens including VAT, and there was no change in price two months later.

Table 4-7. Summary of Test Results for Sample of Lamp #7

Item	Quantity Declared	Quantity Measured	Units	Difference
Power	5.5	5.5	*Watts*	0%
Light Output	550	607	*Lumens*	10%
Efficacy	100	109.8	*lm/W*	10%
CCT	2700	2761	*K*	2%
CRI	>90	91	*Ra*	1%
R09 (red)	--	60.1	*(Red)*	--
Max ellipse	--	4.6	*MacAdam steps*	--
Price paid	--	€ 28.42	*€ / 500 lm*	--
Current Price	--	(no change)	*€ / 500 lm*	--
Website	Click on this link			

4.8 LED Connection Filament Lamp

This sample of lamps was purchased from LED Connection, the same UK specialist on-line lighting retailer who supplied Lamp #5 for this study. This model was introduced into the market in September 2014 and is the third highest flux of the LED lamps tested. This 7.6W model has eight filaments and the sample average was measured as having a luminous flux of 782 lumens. The lamp was supplied in a blank (white) box with only a sticker on one end that matched the same information on the sticker on the lamp (see photo below). These lamps were purchased in September 2014 for €19.17 per 500 lumens including VAT, and there was no change in price at the time of this report being issued.

Table 4-8. Summary of Test Results for Sample of Lamp #8

Item	Quantity Declared	Quantity Measured	Units	Difference
Power	8	7.6	*Watts*	-5%
Light Output	880	782	*Lumens*	-11%
Efficacy	100.0	102.8	*lm/W*	3%
CCT	2700	2889	*K*	7%
CRI	--	83	*Ra*	--
R09 (red)	--	18.8	*(Red)*	--
Max ellipse	--	5.6	*MacAdam steps*	--
Price paid	--	€ 19.17	*€ / 500 lm*	--
Current Price	--	(no change)	*€ / 500 lm*	--
Website	Click on this link			

4.9 Panasonic "Nostalgic Clear" LED Lamp

This sample of lamps (model number LDAHV10L27CGBEP) was purchased from Panasonic's on-line retail shop based in France. This lamp is among the three highest wattage lamps measured (9.6 watt average), but is also one of the higher light outputs (792 lumens). The lamp was shipped in a clear plastic box that is larger at the top of the package. The packaging includes a current Energy Label for lighting, indicating that these lamps at A+. Inside the lamp, the design has LEDs mounted on a platform and coated in yellow phosphor. There are four strips – two on top of the platform and two below. The light quality of this lamp appears to be lower than some of those tested, with a CRI that failed to meet the requirement under EU No 1194/2012 of a CRI of 80. The lamps also scored a negative result on the R09 red tile. Furthermore, the number of MacAdam ellipse steps far exceeds the limit of 6 steps. These lamps were purchased in September 2014 for €13.12 per 500 lumens including VAT, and there was no change in price at the time of this report being issued.

Table 4-9. Summary of Test Results for Sample of Lamp #9

Item	Quantity Declared	Quantity Measured	Units	Difference
Power	10	9.6	*Watts*	-4%
Light Output	806	792	*Lumens*	-2%
Efficacy	80.6	82.3	*lm/W*	2%
CCT	2700	2717	*K*	1%
CRI	80	79	*Ra*	-1%
R09 (red)	--	- 4.7	*(Red)*	--
Max ellipse	--	33.8	*MacAdam steps*	--
Price paid	--	€ 13.12	*€ / 500 lm*	--
Current Price	--	(no change)	*€ / 500 lm*	--
Website	Click on this link			

4.10 NCC-Licht / LED Filament

This sample of lamps (model number Glühbirne 6W = 60W E27 Glühlampe Glühfaden warmweiß 2700K 360° A++) was purchased from a German retailer (NCC-Licht) through the German-based Amazon.de website. The lamps were supplied in colourful boxes that indicate their light output, wattage consumption and equivalent halogen lamp. The lamps also include a current EU energy label, marking these lamps as the highest energy class – A++. The lamps themselves have six LED filaments as shown in the photo. The lamps offer a warm white (around 2600K CCT), have a CRI slightly lower than the requirement (79 CRI instead of 80) and a low score on the R09 red tile. The lamps were purchased in September 2014 for €9.18 per 500 lumens including VAT, and there was no change in price at the time of this report being issued.

Table 4-10. Summary of Test Results for Sample of Lamp #10

Item	Quantity Declared	Quantity Measured	Units	Difference
Power	6	6.8	*Watts*	13%
Light Output	750	707	*Lumens*	-6%
Efficacy	125.0	104.1	*lm/W*	-17%
CCT	2700	2587	*K*	-4%
CRI	80	79	*Ra*	-1%
R09 (red)	--	1.8	*(Red)*	--
Max ellipse	--	6.4	*MacAdam steps*	--
Price paid	--	€ 9.18	*€ / 500 lm*	--
Current Price	--	(no change)	*€ / 500 lm*	--
Website	Click on this link			

4.11 LED24.cc / E27 LED Glühfaden Birne

This sample of lamps (model number B00JSP665G) was purchased from a German retailer (LED24.cc) through the German-based Amazon.de website. The lamps were supplied in white cardboard boxes with a sticker that covered two sides of the box (see photo). The sticker applied to the box includes the current EU energy label, marking these lamps as being A+ class. The lamps themselves have six LED filaments as shown in the photo, with a total light output of 748 lumens. The CRI values for this lamp exceed the requirement of 80 and the R09 value is 19.7. The number of MacAdam steps is also within the limit of 6 steps. The lamps were purchased in September 2014 for €11.33 per 500 lumens including VAT. The lamps are no longer stocked by this retailer and it is unknown whether any new stock will be sold. The website says: "Derzeit nicht verfügbar. Ob und wann dieser Artikel wieder vorrätig sein wird, ist unbekannt."

Table 4-11. Summary of Test Results for Sample of Lamp #11

Item	Quantity Declared	Quantity Measured	Units	Difference
Power	8	7.6	*Watts*	-5%
Light Output	800	748	*Lumens*	-7%
Efficacy	100	98.4	*lm/W*	-2%
CCT	2700	2907	*K*	8%
CRI	80	83	*Ra*	4%
R09 (red)	--	19.7	*(Red)*	--
Max ellipse	--	5.4	*MacAdam steps*	--
Price paid	--	€ 11.33	*€ / 500 lm*	--
Current Price	--	--	*€ / 500 lm*	--
Website	Click on this link			

4.12 Star Trading Direct - LED filament lampa E27 Nr. 338-71

This sample of lamps (model number 338-71) was purchased from Star Trading Direct, a Swedish-based retailer. These lamps have a very good efficacy, reaching 112 lumens per Watt. The colour and light quality requirements for this lamp are all achieved, with a CRI of 81 and the number of MacAdam steps less than 6. The lamps were purchased in September 2014 for €6.16 per 500 lumens including VAT.

Table 4-12. Summary of Test Results for Sample of Lamp #12

Item	Quantity Declared	Quantity Measured	Units	Difference
Power	4	4.1	*Watts*	2%
Light Output	440	459	*Lumens*	4%
Efficacy	100.0	111.9	*lm/W*	12%
CCT	2900	2731	*K*	-6%
CRI	80	81	*Ra*	1%
R09 (red)	--	19.8	*(Red)*	--
Max ellipse	--	3.4	*MacAdam steps*	--
Price paid	--	€ 6.16	*€ / 500 lm*	--
Current Price	--	No change	*€ / 500 lm*	--
Website	Click on this link			

4.13 Star Trading LED filament lampa candelabra shape

This sample of lamps (model number 338-09) was purchased from Star Trading Direct, a Swedish-based retailer. These lamps are dimmable, as some of the applications that call for a candle-shaped lamp would be on dimming circuits. The lamp was tested with both a leading edge (ELKO 400GLI) and trailing edge dimmer (ELKO 315GLE), and performed well (no noticeable flicker or other light quality issue). The lamps have a relatively low efficacy – about the same as a compact fluorescent lamp, but they exceed the minimum CRI values and are well within the maximum MacAdam steps. The lamps were purchased in September 2014 for €20.21 per 500 lumens including VAT.

Table 4-13. Summary of Test Results for Sample of Lamp #13

Item	Quantity Declared	Quantity Measured	Units	Difference
Power	5	4.3	*Watts*	-14%
Light Output	470	285	*Lumens*	-39%
Efficacy	94.0	66.2	*lm/W*	-30%
CCT	2700	2825	*K*	5%
CRI	80	83	*Ra*	4%
R09 (red)	--	21.3	*(Red)*	--
Max ellipse	--	3.3	*MacAdam steps*	--
Price paid	--	€ 20.21	*€ / 500 lm*	--
Current Price	--	No change	*€ / 500 lm*	--
Website	Click on this link			

4.14 Osram PARATHOM Classic A ADV 10W 827

This sample of lamps was purchased from LED Lightbulbs, a UK-based on-line retailer who specialises in LED products. These lamps are among some of the least expensive lamps purchased for this study, costing only €7.16 per 500 lumens in 2014 – a price point that is was not expected until 2020 in the Commission's consultant's study published in June 2013. These lamps are marketed as dimmable on certain dimmers, and they were found to work successfully on the leading edge dimmer but not the trailing edge dimmer used in this test. The packaging includes the current EU energy label, which ranks these lamps as an A+ class. The efficacy of these lamps is about 50% better than a compact fluorescent lamp, at 89.5 lumens per watt, and the colour rendering meets the requirement of 80. The lamp itself has a light guide designed to create a sparkle effect. The lamps were purchased in September 2014 for €7.16 per 500 lumens including VAT and their price had not changed at the time this report was issued.

Table 4-14. Summary of Test Results for Sample of Lamp #14

Item	Quantity Declared	Quantity Measured	Units	Difference
Power	10	9.6	*Watts*	-4%
Light Output	810	863	*Lumens*	7%
Efficacy	81.0	89.5	*lm/W*	10%
CCT	2700	2739	*K*	1%
CRI	80	80	*Ra*	0%
R09 (red)	--	3.4	*(Red)*	--
Max ellipse	--	3.3	*MacAdam steps*	--
Price paid	--	€ 7.16	*€ / 500 lm*	--
Current Price	--	No change	*€ / 500 lm*	--
Website	Click on this link			

4.15 Philips "Clear LED bulb" - GLS 6W A60 827 Clear

This sample of lamps was purchased from LED Lightbulbs, a UK-based on-line retailer who specialises in LED products. These lamps were advertised in a March 2014 press release from Philips as having a suggested retail price of €8.99, however we were unable to locate these lamps at that sales price. The purchase price paid was higher than the manufacturer's suggested retail price (MSRP). The packaging includes the current EU energy label, which ranks these lamps as an A+ class. The efficacy of these lamps is about 40% better than a compact fluorescent lamp, at 84.7 lumens per watt, and the colour rendering exceeds the requirement of 80. These lamps are marketed as dimmable on certain dimmers, and they were found to work successfully on the leading edge dimmer but not the trailing edge dimmer used in this test. The lamp itself has a light guide designed to create a sparkle effect (see Philips press release for information about this). The lamps were purchased in September 2014 for €14.89 per 500 lumens including VAT and their price had not changed from that same retailer at the time this report was issued. The MSRP for this lamp is €8.99 per 500 lumens light.

Table 4-15. Summary of Test Results for Sample of Lamp #15

Item	Quantity Declared	Quantity Measured	Units	Difference
Power	6	5.9	*Watts*	-2%
Light Output	470	501	*Lumens*	7%
Efficacy	78.4	84.7	*lm/W*	8%
CCT	2700	2705	*K*	0%
CRI	80	82	*Ra*	3%
R09 (red)	--	17.3	*(Red)*	--
Max ellipse	--	6.2	*MacAdam steps*	--
Price paid	--	€ 14.89	*€ / 500 lm*	--
Current Price	--	No change	*€ / 500 lm*	--
Philips MSRP	--	€8.99	*€ / 500 lm*	--
Website	Click on this link			

4.16 LED Lampen Direct, 4 Watt Polaris

This sample of lamps was purchased from LED Lampen Direct, a Dutch-based on-line retailer who specialises in LED lighting products. This product is called the "Polaris 4 Watt" lamp, advertised as a replacement for a 50W incandescent lamp, and was manufactured by a company named YPHIX. This lamp has lower light colour quality specifications - a CRI measurement slightly below 80 and a negative R09 red score meaning this light source will not render red coloured objects very well. It does, however, have only 2.9 MacAdam steps, well within the limit of 6 steps. The lamps were purchased in September 2014 for €10.27 per 500 lumens including VAT and their price had not changed from that same retailer at the time this report was issued.

Table 4-16. Summary of Test Results for Sample of Lamp #16

Item	Quantity Declared	Quantity Measured	Units	Difference
Power	4.2	4.0	*Watts*	-5%
Light Output	450	462	*Lumens*	3%
Efficacy	107.1	115.2	*lm/W*	8%
CCT	2700	2637	*K*	-2%
CRI	>80	79	*Ra*	-1%
R09 (red)	--	-5.2	*(Red)*	--
Max ellipse	--	2.9	*MacAdam steps*	--
Price paid	--	€ 10.27	*€ / 500 lm*	--
Current Price	--	No change	*€ / 500 lm*	--
Website	Click on this link			

4.17 Calex LED Filament GLS

This sample of lamps (Model number 474732) was purchased from Electrocirkel n.v., an electrical whole supplier based in Belgium. The brand of this model is “Calex”. This lamp has a relatively high light colour quality specification - a CRI measurement of 88 and R09 red score of 38.9. It has, however, 9.5 MacAdam steps, which is greater than the regulatory limit of steps. The lamps were purchased in October 2014 for €14.46 per 500 lumens including VAT and their price had not changed from that same retailer at the time this report was issued.

Table 4-17. Summary of Test Results for Sample of Lamp #17

Item	Quantity Declared	Quantity Measured	Units	Difference
Power	6.5	6.8	*Watts*	5%
Light Output	650	573	*Lumens*	-12%
Efficacy	100.0	84.5	*lm/W*	-16%
CCT	2700	2671	*K*	-1%
CRI	89	88	*Ra*	-1%
R09 (red)	--	38.9	*(Red)*	--
Max ellipse	--	9.5	*MacAdam steps*	--
Price paid	--	€ 14.46	*€ / 500 lm*	--
Current Price	--	No change	*€ / 500 lm*	--
Website	Click on this link			

4.18 Segula

This sample of lamps (Model number 474732) was purchased from LEDitLight.net in the Netherlands, a specialty on-line retailer for LED lamps. This lamp was the most expensive LED lamp purchased for the test, which was bought in October 2014 for €32.04 per 500 lumens including VAT. The price of the lamp had not changed from that same retailer at the time this report was issued.

Table 4-18. Summary of Test Results for Sample of Lamp #18

Item	Quantity Declared	Quantity Measured	Units	Difference
Power	5.5	5.6	*Watts*	2%
Light Output	720	655	*Lumens*	-9%
Efficacy	130.9	117.8	*lm/W*	-10%
CCT	2600	2558	*K*	-2%
CRI	80	81	*Ra*	1%
R09 (red)	--	10.5	*(Red)*	--
Max ellipse	--	5.1	*MacAdam steps*	--
Price paid	--	€ 32.04	*€ / 500 lm*	--
Current Price	--	No change	*€ / 500 lm*	--
Website	Click on this link			

5 Discussion of Test Results

In this chapter, the test results are presented and discussed, allowing a comparison of performance levels across the sample of 17 models of LED lamps and 1 halogen lamp tested.

5.1 Power Consumption

The figure below shows the average power consumption in watts of the lamps tested (blue diamond) and then an error bar that gives the minimum and maximum values observed in the sample of 10 units for each of the 18 lamp models (a total of 180 lamps).

For the most part, the units tested were found to have power measurements that do not deviate significantly from the sample average. The LED lamps were all found between approximately 4 and 10 watts. The power consumption for the halogen lamp (#3) is off the scale of the Y-axis, with an average power consumption of 45.5 Watts.

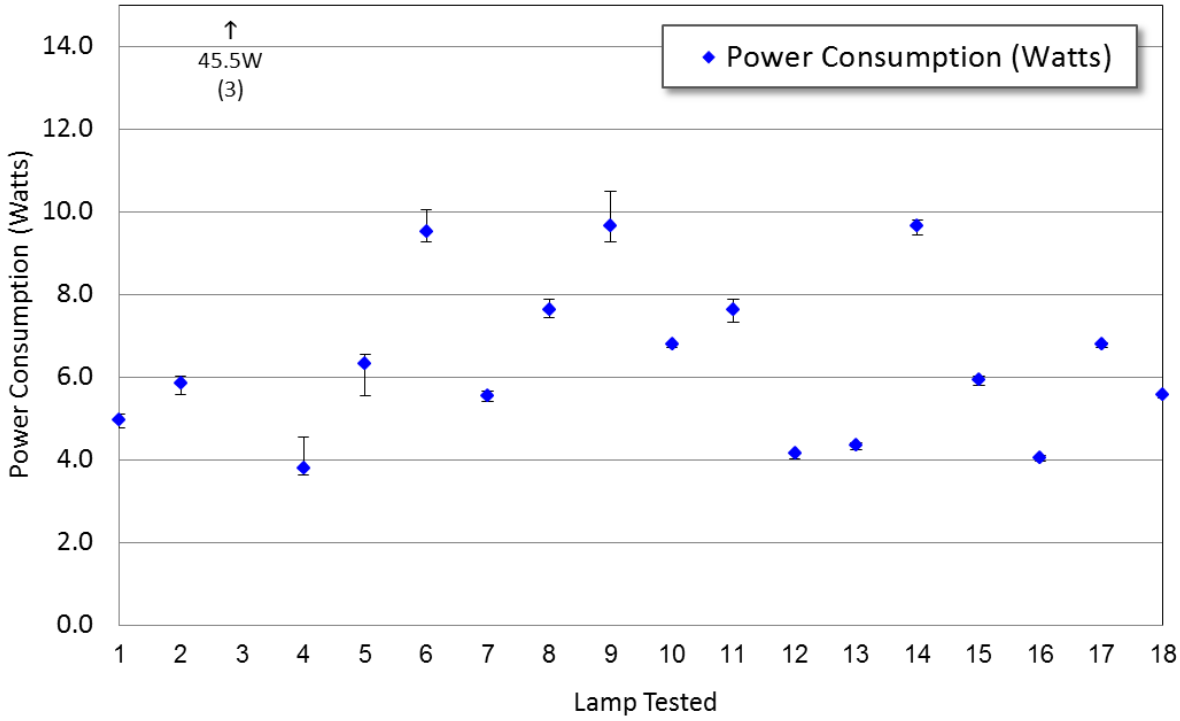


Figure 5-1. Power Consumption Distribution of Lamp Models Tested (Watts)

5.2 Light Output

The light output distribution is presented below, with a range of outputs from approximately 300 to 850 lumens. Unlike the power consumption distribution figure, these test results exhibited variance for some of the models between the average for the sample and the min/max of specific units in the sample. In particular, lamps #1 (Wholesale Lighting), #10 (NCC Licht) and #17 (Calex) exhibited a range that was larger than the other lamps. Several LED lamps had deviations that were within 10% of the sample average. The OSRAM halogen lamp (#3) has a very consistent lumen output profile, similar to that of the LED lamp #14 (OSRAM).

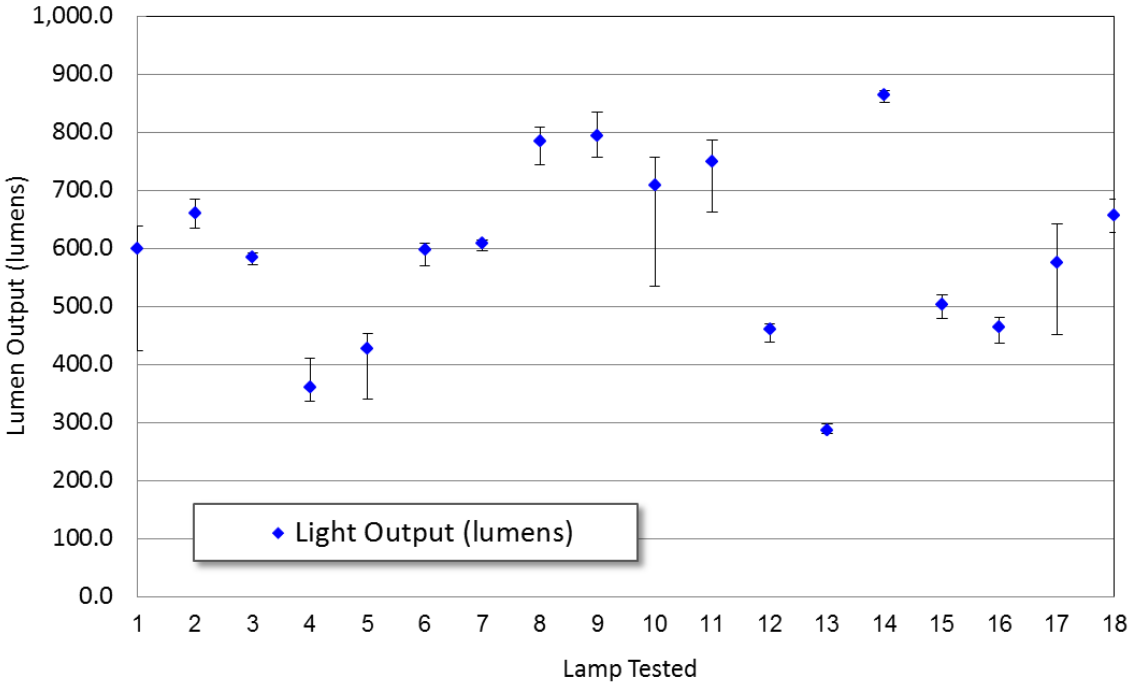


Figure 5-2. Distribution of Light Output Lamp Models Tested (Lumens)

5.3 Efficacy

The efficacy distribution pattern varied significantly for LED lamps. Those lamps that employed light guides tended to have slightly lower efficacy than some that simply emitted light directly from the LED filament through a clear glass envelope. The three lamps with the highest variance in efficacy are #1 (Wholesale Lighting), #10 (NCC Licht) and #17 (Calex) – the same three lamps with the highest variance in measured power. The reference halogen lamp sample (#3) is shown with an efficacy of 12.8 lumens / Watt – 5 to 10 times less than the LED lamps tested.

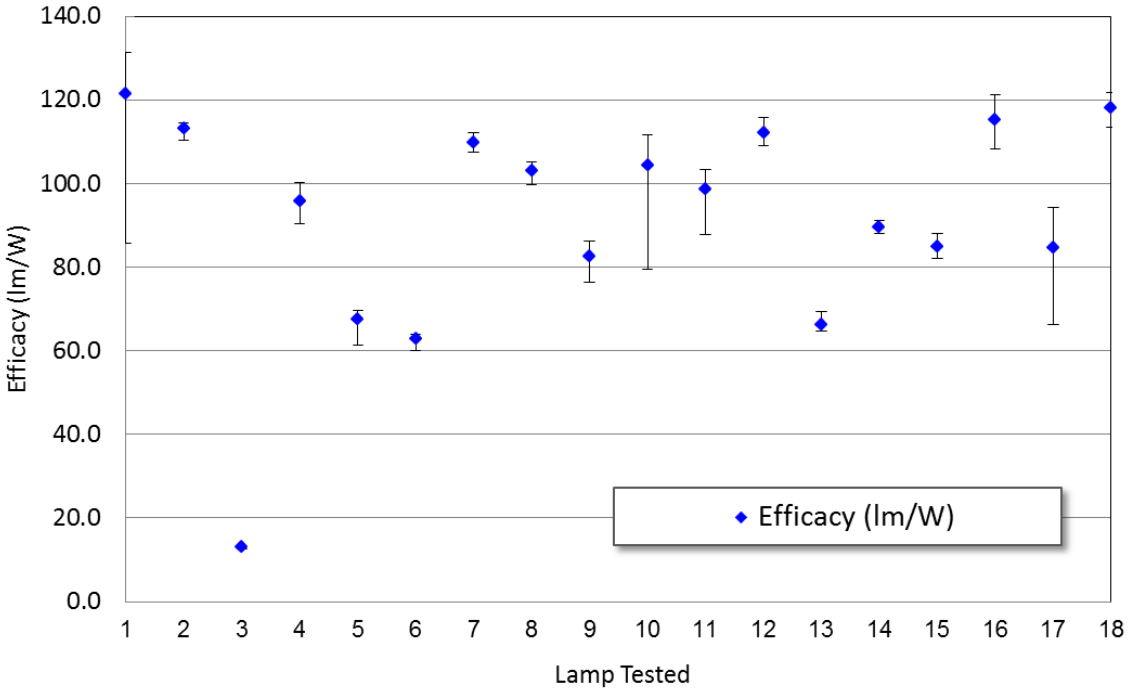


Figure 5-3. Distribution of Efficacy Measurements for Lamp Models Tested (lumens/Watt)

5.4 Correlated Colour Temperature

The figure below provides the sample averages and distribution of the correlated colour temperature (CCT) measurements. Most of the LED lamps tested have a CCT between 2600 and 2900K, approximately the same as a tungsten filament CCT. Lamp #3, the halogen lamp, has a CCT just under 2800 K, and several lamps – such as #12 (Star Trading) appear to match the CCT of halogen perfectly.

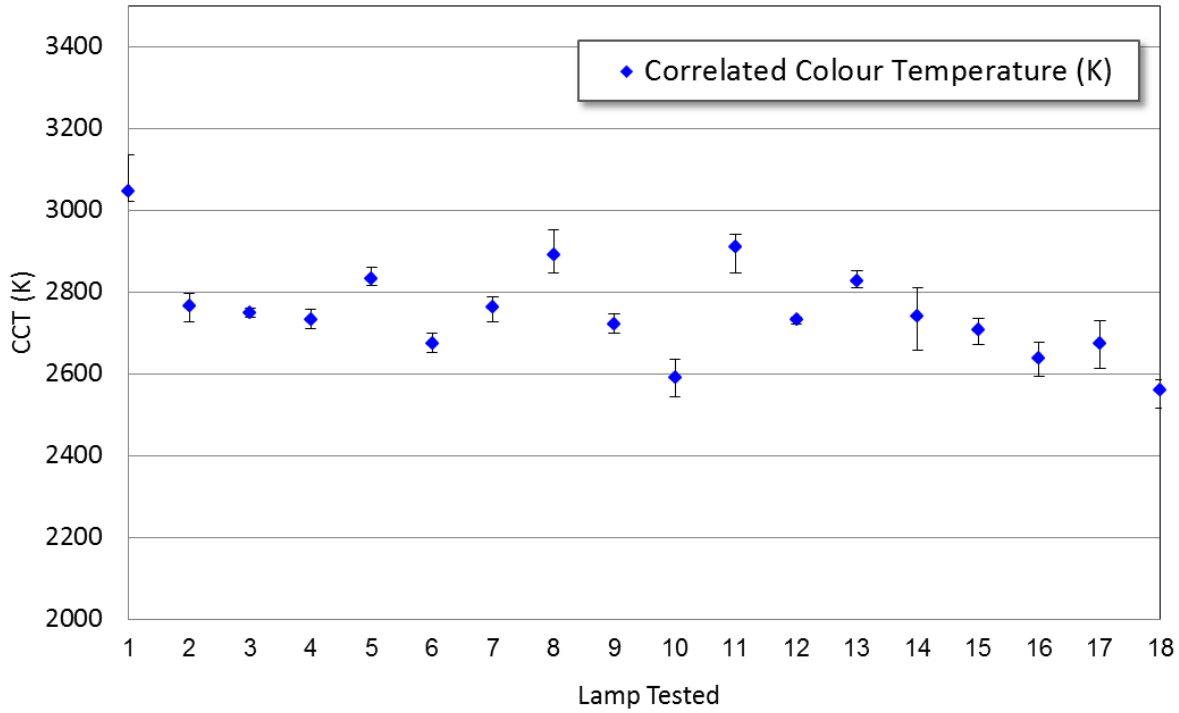


Figure 5-4. Distribution of CCT Measurements for Lamp Models Tested (K)

5.5 Colour Rendering Index

The figure below provides the sample averages and distribution of the colour rendering index results. Here, the halogen lamp (#3) is clearly visible, with a 100 CRI value, due to the fact that CRI is a measurement metric based on tungsten-filament technology. The LED lamps are required to achieve a CRI of 80, and most do, although some appear to fall slightly below the requirement. Two of the LED lamps tested – lamps #6 (IKEA) and #7 (Vosla) – have CRI values that are greater than 90.

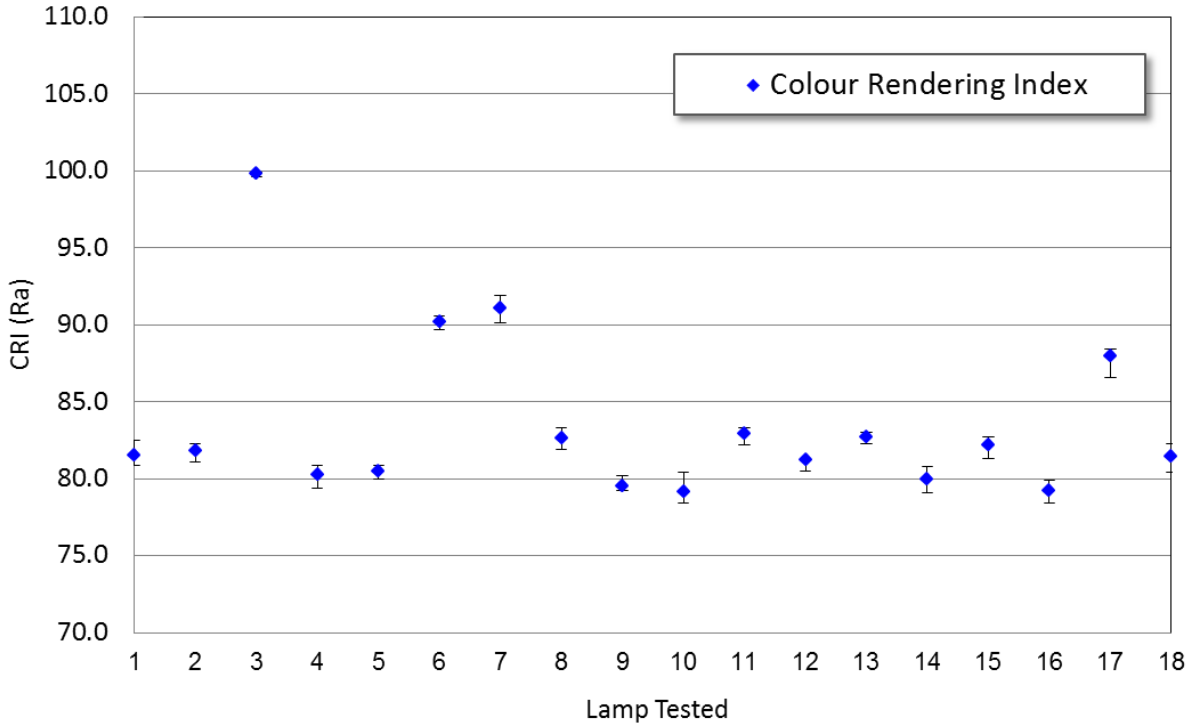


Figure 5-5. Distribution of Colour Rendering Index for Lamp Models Tested (Ra)

5.6 Lamp Weight and Dimensions

One of the issues that was identified as a potential problem with LED replacement lamps was the higher weight and unusually large dimensions. It is understood that this issue was due, in large part, to the fact that LED lamps do not project heat in their light emission, thus any waste heat generated in the conversion of electricity to light has to be conducted away from the LED through a heat sink and cooling fins. However, as LED lamps improve their efficacy (e.g., moving from 60 lumens per watt to 120 lumens per watt), the conversion efficiency improves, and the heat sinks can be reduced in size and can potentially reach a point where the surfaces of the existing lamps are sufficient to radiate and convect the heat away from the lamp surface. At that point, heat sinks are no longer necessary.

The figure below shows the weight of the 18 lamps tested, compared to a red line which represents the weight of a standard 60W incandescent lamp (28 grams). The halogen lamp (#3) is a slightly smaller lamp than the standard 60W, thus it has a slightly lower mass. Many of the LED filament lamps have very similar weights to the incandescent reference point – within 10 to 20 grams. At these weights, there is no risk that the LED replacement lamps would cause problems in existing

fixtures and sockets due to the higher mass. There are a few LED lamps – notably #6, 9, 14 and possibly 15 which are heavier than the others – but all lamps are less than 160 grams, which and the vast majority are less than 50 grams.

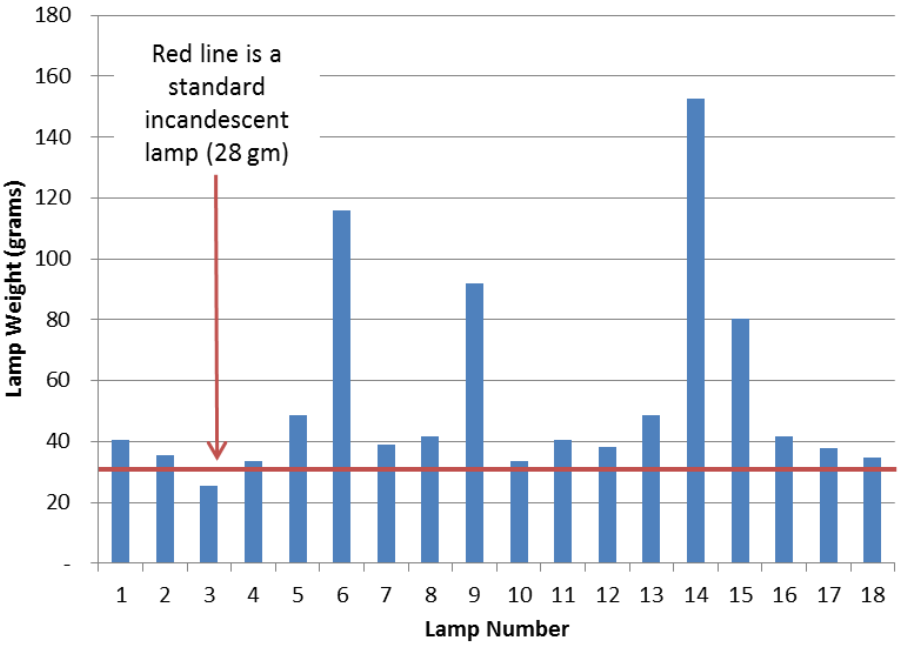


Figure 5-6. Weight of the lamps tested, compared to an Incandescent Lamp

In the figure below, the lamp length (X-axis) and widest width (Y-axis) are plotted for all eighteen lamps that were tested. The reference incandescent lamp is shown as a red square in the midst of this scatter plot. Again, several LED replacement lamps are either shorter or narrower than incandescent lamp, and three LED lamps are longer but the same width, with just one LED lamps that is both larger and wider than the incandescent reference lamp.

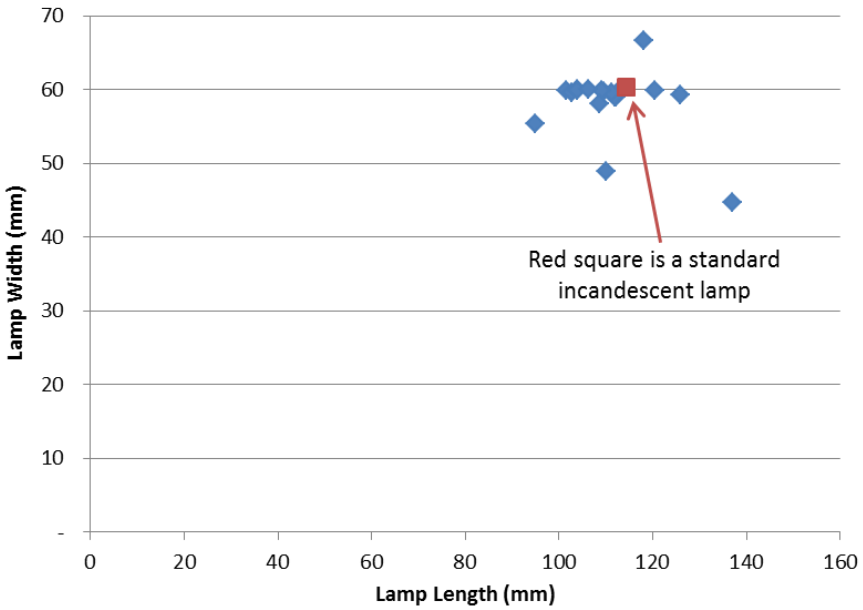


Figure 5-7. Length and Width of the lamps tested, compared to an Incandescent Lamp

5.7 Lamps and Heat

Measurements were made of the maximum surface temperature of the lamps while in steady-state operation. The figure below presents the results of the measurements, plotting the lamps by wattage over temperature. The halogen lamp is not shown because of the very high wattage, but the measured surface temperature was 89.3 degrees Celsius, just slightly higher than the 10 watt LED lamps.

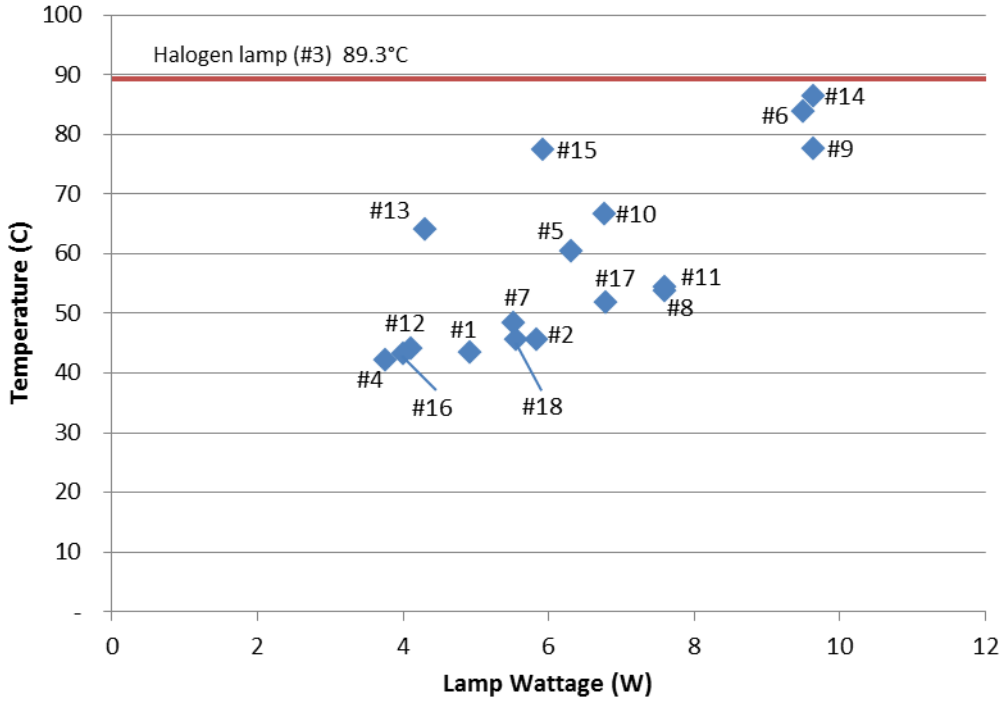


Figure 5-8. Maximum surface temperature of the lamps while in steady-state operation

5.8 EU No 1194/2012 Performance Requirements

The testing conducted under this study **should not be interpreted as enforcement testing of the products, the sample sizes were not sufficient**. These test results should be seen as indicative of the actual performance of those lamps tested, and may be used by market surveillance authorities to help better target their own respective sampling and testing programmes for lighting.

The screen-capture below presents the requirements from EU No 1194/2012 for all non-directional and directional LED lamps.

2.2. **Functionality requirements for non-directional and directional LED lamps**

The lamp functionality requirements are set out in Table 5 for both non-directional and directional LED lamps.

Table 5

Functionality requirements for non-directional and directional LED lamps

Functionality parameter	Requirement as from stage 1, except where indicated otherwise
Lamp survival factor at 6 000 h	From 1 March 2014: ≥ 0,90
Lumen Maintenance at 6 000 h	From 1 March 2014: ≥ 0,80
Number of switching cycles before failure	≥ 15 000 if rated lamp life ≥ 30 000 h otherwise: ≥ half the rated lamp life expressed in hours
Starting time	< 0,5 s
Lamp warm-up time to 95 % Φ	< 2 s
Premature failure rate	≤ 5,0 % at 1 000 h

Functionality parameter	Requirement as from stage 1, except where indicated otherwise
Colour rendering (Ra)	≥ 80 ≥ 65 if the lamp is intended for outdoor or industrial applications in accordance with point 3.1.3(l) of this Annex
Colour consistency	Variation of chromaticity coordinates within a six-step MacAdam ellipse or less.
Lamp power factor (PF) for lamps with integrated control gear	P ≤ 2 W: no requirement 2 W < P ≤ 5 W: PF > 0,4 5 W < P ≤ 25 W: PF > 0,5 P > 25 W: PF > 0,9

Of the complete list of functionality parameters given in the ecodesign implementing measure, this study was able to measure the following:

- Lamp survival factor at 6000 h - tests are on-going, interim results available
- Lumen maintenance at 6000 h – tests are on-going
- Number of switching cycles before failure – yes, tested
- Starting time – yes, tested
- Lamp warm-up time to 95% - yes, tested
- Premature failure rate at 1000 h – yes, tested
- Colour rendering index – yes, tested
- Colour consistency – yes, tested
- Lamp Power Factor – yes, tested

The table below shows the measured results for all the LED lamps tested (note: omitting the halogen lamp, which is #3). The measured results that comply with the test requirements are shaded in green and those that do not are shaded in red. There was one lamp (#11) which failed on the initial 100h burn-in and three lamps which had colour coordinates in excess of six MacAdam ellipse steps.

Table 5-1. Unofficial Quality Check (sample size only 10 units) for LED Lamps Under Test

Sample Number:	1	2	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Lamp survival 6000h	-- test results not available yet --																
Lumen maint. 6000h	-- test results not available yet --																
Switching cycles																	
Premature failure																	
CRI																	
Colour consistency																	
Power factor																	

5.9 Price and Efficacy in 2014

This study has found that the price and performance of LED lighting exceeded the anticipated rate of improvement that was originally presented Table 2 from the consultant's review report.[31] The report provided a projection in Table 2 of efficacy (in lumens per watt) and price (in Euro including VAT per 500 lumens of light) that was expected at the time of publication (June 2013). For this study, LED replacement lamps were purchased in August and September 2014 at price points and performance levels that exceeded the levels anticipated by Table 2.

The year 2014 is not presented in Table 2 of the June 2013 consultant's report, however if a linear interpolation is drawn between the values in 2012 and 2016, then the efficacy value would be 76 lm/W for 2014. Table 2 of the VHK/VITO report identifies "CLASP 2013, based on US DoE MYPP projections", making reference to an efficacy projection that CLASP had shared with the consultant. It is therefore notable that CLASP is one of the co-authors of this testing report, and wishes to make a correction to the forecast due to the fact that CLASP was too conservative our earlier estimate; LED technology has moved faster than was anticipated.

In this report, test results are presented for 17 LED lamps that were tested in a Member State market surveillance laboratory. The sample average efficacies of these LED lamps varied from 62.7 to 121.4 lm/W – a range where the highest value is nearly double the lowest. Of all the lamps tested, the single lowest LED lamp tested at 60.14 lm/W and the single highest LED lamp was 131.48 lm/W. Although this sample is not a comprehensive review of the total European market, it does include models from major manufacturers such as OSRAM, Philips and IKEA, and it also includes models from small start-up importers. Taking the seventeen LED lamps and dropping the three highest and three lowest efficacy values, the average of the sample of lamps tested is 98 lumens/Watt.

The original efficacy forecast cited in Table 2 of the June 2013 consultant's report identifies "LightingEurope" as the source of the price projection up to 2020, with the extrapolation from 2021 to 2030 being done by VHK. Again, 2014 is not presented in the VHK/VITO report, however if a linear interpolation is drawn between the values in 2012 and 2016, then the price estimate for 2014 would be €14.00 per 500 lumens. While this price point is within the range of prices observed in 2014 (there were lamps purchased that were above and below €14), prices for LED lamps continue to

[31] "NDLS STAGE 6 REVIEW - FINAL REPORT - Review study on the stage 6 requirements of Commission Regulation (EC) No 244/2009", by VHK (pl)/ VITO for the European Commission. Delft/Brussels, 14 June 2013.

decline making them more competitive with mains voltage halogen and CFLs, as indicated by the sample of recent LED lamps that were purchased for this study in August and September 2014 – for example:

lamp #6: €6.30 / 500 lumen
lamp #10: €9.18 / 500 lumen
lamp #12: €6.16 / 500 lumen
lamp #14: €7.16 / 500 lumen
lamp #16: €10.27 / 500 lumen

Compared with the interpolated price of €14.00 for 2014 in Table 2 of the consultant's report, two of the lamps purchased in 2014 are less than half that price. In order to calculate the best LED replacement lamp prices for 2014 from this testing study, the prices of the seventeen LED lamps were sorted in price order. The three highest priced lamps were dropped because these would be less attractive to consumers (who have equal access to less expensive models) and the average of the remaining 14 LED lamps tested was €12.52 / 500 lumens. This price point is approximately 10 percent (or €1.50) less expensive than the interpolated 2014 price from the VHK/VITO technical study.

6 Key Question Examination and Discussion

In this chapter, the key questions listed in the original email message of 15 September are addressed.

6.1 What is the current cost and performance of clear LED lamps?

As discussed in this report, the projection provided in Table 2 of the Consultant's report published in June 2013 has been surpassed by LED product innovation in the market. The figure below shows the projections from the above Table 2 as threshold lines of price and efficacy. It then superimposes the actual, measured test results as red dots, which are sample average efficacies (n=10) of the clear LED lamps tested in this study. The halogen lamp is off the Y-axis scale due to its low efficacy. The figure has reversed the X and Y axes, so efficacy improves and price is lower as the products move toward the origin.

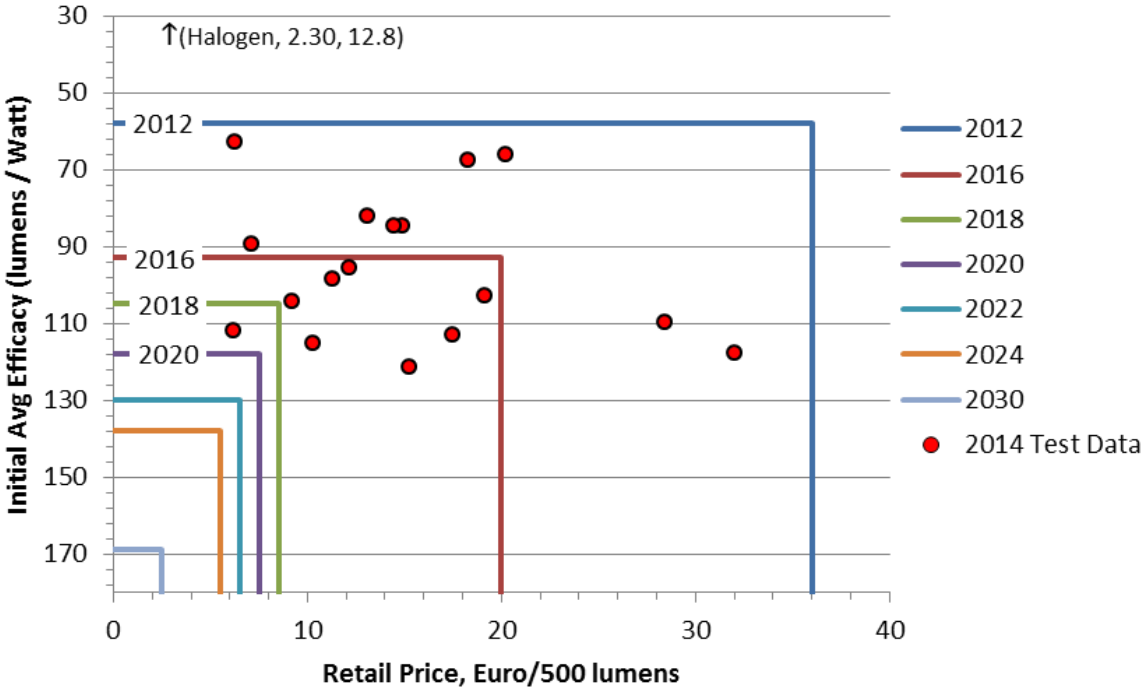


Figure 6-1. Example of MV LED Non-Directional Retrofit Clear LED Lamps: Projections made in 2013 on price/performance ratio vs. real 2014 values

Thus, it is clear from this graph the current cost of performance of LED Lamps tested in this study have exceeded the expected progression of LED technology published in June 2013 by the Commission's contractor. The reference values used in this analysis for 2014 are: a price point of €12.52 / 500 lumens of light output and an efficacy of 98 lumens per watt. These values are 11% lower on price and 29 percent higher on efficacy compared to a linearly-interpolated estimate from the VHK/VITO Technical Report. See section 5.9 for discussion on these estimates.

Table 6-1. Current Price and Efficacy of Mains-Voltage Retrofit LED Replacement Lamps

Source of estimate	Price (Euro) per 500 lumens of light in 2014	Efficacy (lumens per watt) in 2014
VHK/VITO Report (June 2013)*	€14.00 / 500 lumen	76 lm/W
Test data average, this study	€12.52 / 500 lumen	98 lm/W
Difference, test data average in 2014 compared with VHK/VITO projected	11 percent lower	29 percent higher

* The VHK/VITO report did not provide actual values for 2014, therefore the figures shown in this table are derived from linear interpolation between the 2012 and 2016 values.

6.2 Do they give an aesthetic pleasant light?

In Europe, consumers of non-directional household lamps tend to have a preference for warm colour temperatures with high colour rendering and no flicker. A recent report by the IEA 4E Mapping and Benchmarking Annex found that the European market has shifted away from CFL sales and instead is now migrating toward clear halogen lamp sales.

The LED lamps tested in this study were found to have CCT values that were around 2700K to 2900K, which is consistent with the baseline technology they seek to replace (i.e., incandescent and halogen). The CRI value for most LED lamps exceeded 80 CRI (with a few exceptions, where the CRI was measured at 79). Two of the LED lamps tested had CRIs values in the 90's (IKEA and vosLED). The flicker index and percent flicker of the lamps were measured and many lamps had no flicker. The lamps were also tested for their light distribution pattern, and there was a very good resemblance to the halogen reference lamp (see Annex B). Thus, it would appear that the LED Lamps can meet the optical requirements of luminaires currently using halogen lamps. For all of these reasons, it would appear that these clear LED lamps do offer consumers an aesthetic, pleasant light. And, a limited review of website comments was conducted (see section 2.2.6), which indicated the early-adopters of LED filament lamps are satisfied.

6.3 Are the "dimmable" lamps compatible with leading edge and trailing edge dimmers?

Of the LED lamps purchased for this test study, five of them were identified as 'dimmable' in the manufacturer literature. For those lamps that were labelled as 'dimmable', the LED lamps were tested on both a leading edge dimmer (ELKO 400GLI) and a trailing edge dimmer (ELKO 315GLE). Although these two dimmers do not represent all dimmers in Europe, they do represent two of the most common types found in the market.

The table below presents the results of the testing of these five "dimmable" LED Lamps on the two dimmers.

Table 6-2. Dimmer Compatibility Check for Five "dimmable" LED Lamps

Lamp	Description	Leading Edge (ELKO 400GLI)	Trailing Edge (ELKO 315GLE)
#5	LED Connection "Classic LED bulb"	No	Yes
#6	IKEA "LEDARE" / 602.553.62	Yes	Yes
#13	Star Trading LED filament lampa candelabra shape	Yes	Yes
#14	Osram PARATHOM Classic A ADV 10W 827	Yes	No
#15	Philips "Clear LED bulb" - GLS 6W A60 827 Clear	Yes	No

The testing found that two of those lamps were able to be dimmed on both dimmers (#6 IKEA, #13 Star Trading). The other three lamps had issues with one of the dimmers. Lamp #5 from LED Connection was not compatible with the leading edge dimmer and Lamps #14 from OSRAM and #15 from Philips were not compatible with the trailing edge dimmer. Overall, the results indicate that the industry is working on better LED drivers to make them compatible with the main types in Europe, and there are still be some manufacturing / quality control issues to work out in production.

6.4 Do these lamps meet the LED quality requirements in EU No 1194/2012?

In order to ensure that the manufacturers of these new high-performance, low-cost LED lamps are not sacrificing light quality aspects that are important to European consumers, the Swedish Energy Agency's test laboratory also conducted tests to investigate whether the lamps complied with the quality requirements for LED lamps under EU No 1194/2012[32] (see Chapter 5). The sample size (n=10) was not sufficient large for market surveillance testing, therefore the findings should only be taken as indicative as to whether these lamps would meet the requirements. Furthermore, all of the test are not complete (some require 6000 hours of data), for most of those that are done the answer is 'yes', the new LED lamps do meet the quality requirements of EU No 1194/2012:

- Lamp survival factor at 6000 h - tests are on-going
- Lumen maintenance at 6000 h – tests are on-going
- Number of switching cycles before failure – yes, tested for all lamps; no failures in LED, but one failure in a halogen lamp.
- Starting time – yes, all LED lamps passed
- Lamp warm-up time to 95% - yes, all LED lamps passed
- Premature failure rate at 1000 h – not complete yet; but is being tested and so far, all but one LED lamp (#11 LED24.cc) passed the test
- Colour rendering index – yes, tested and all LED lamps met the minimum requirement with two models being within the allowable tolerance and two models in the 90's.
- Colour consistency – yes, tested and most LED lamps met the six MacAdam step requirement; #9 (Panasonic) and #17 (Calex) exceeded this requirement.

[32] Commission Regulation (EU) No 1194/2012 of 12 December 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for directional lamps, light emitting diode lamps and related equipment.
EN link: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:342:0001:0022:EN:PDF

- Lamp Power Factor – yes, tested and all lamps met the requirements with many exceeding them.

Overall, the LED lamps were all found to be compliant with the ecodesign requirements under 1194/2012, except a few models exceeded the six MacAdam[33] step limit and one premature failure. The lamps performed exceptionally well yet some importers omitted energy labels and one had developed their own energy label with an A+++ class (which does not exist in EU 874/2012) [34]. This labelling violation was reported to the UK NMO.

6.5 Are LED filament lamps reliable products for consumers?

There are a few different ways to assess consumer reliability. One approach is to look at the duration of the warranty offered by a manufacturer when the lamps are sold and the other is to conduct lifetime-measurements that assess reliability through testing.

For warranties, many of the LED lamps do not state a warranty on their packaging, thus it is unclear whether these products are covered by a warranty or not. Three of the lamps did clearly state warranties on their packaging – lamp #14, the Osram Parathom, had the longest warranty, offering consumers 4 years of coverage. Lamps #2 (UK LED Standard) and #9 (Panasonic nostalgic) each offered consumers 2 years. However, it should be noted that in general, these LED lamps are marketed to last for 20,000 hours or more, which in a typical domestic household would be in excess of 20 years of service.

For testing for reliability, there are two tests that were evaluated – (1) the switching cycle test, where the lamp is switched on for 30 seconds and off for 30 seconds fifteen-thousands times; (2) the failure rate test, where the lamps are operated for extended periods of time to determine whether they are still operating at 200 hours, 1000 hours and 6000 hours. The table below presents the findings of this analysis. Note that all samples of LED lamps were subject to the 200 hours of failure rate test, but after that the samples of ten lamps were split in half with 5 units being put onto the switching cycle test and 5 units on longer-term operational test for the 1000-hour and 6000-hour test results.

[33] The six step Macadam requirement comes from ecodesign regulation EU No 1194/2012: when a light source is measured from multiple directions, all measurements x, y coordinates should be grouped within a 6 step Macadam ellipse.
[34] Commission Delegated Regulation (EU) No 874/2012 of 12 July 2012 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of electrical lamps and luminaires;
EN link: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012R0874&from=EN

Table 6-3. LED Lamp Consumer Reliability Test Results

#	Brand	Switching Cycles	200 hours*	Notes
1	Wholesale Lighting	5 - pass	9 - pass	Sample size reduced, as one lamp not working on delivery (flashing)
2	UK LED	5 - pass	10 - pass	
4	Lighting Ever	5 - pass	10 - pass	
5	LED Connection	5 - pass	8 - pass	Sample size reduced as two lamps did not work on delivery
6	IKEA	5 - pass	10 - pass	
7	vosLED	5 - pass	10 - pass	
8	LED Connection	5 - pass	10 - pass	
9	Panasonic	5 - pass	10 - pass	
10	Ncc-Licht	5 - pass	10 - pass	
11	LED24.cc	5 - pass	8 - fail	Two lamps failed during 100 hour burn-in.
12	Star Trading	5 - pass	9 - pass	One lamp failed after sphere measurements
13	Star Trading	5 - pass	Not complete	
14	Osram	5 - pass	10 - pass	
15	Philips	5 - pass	10 - pass	
16	LED Lampen	5 - pass	10 - pass	
17	Calex	5 - pass	10 - pass	
18	Segula	5 - pass	10 - pass	

* In the future, failure rates at longer operating hours will be reported, up to 6000 hours.

On the switching cycle test, all of the LED lamps that completed testing all survived the 15,000 switching cycles without any issues. Oddly enough, the only lamp to fail the switching cycle test was one halogen lamp (#3, not reported in the above table).

On the 200-hour failure rate test, two individual LED lamps sold by ccLED (both sample #11) failed during the burn-in. There was only one LED lamp (#12) that experienced failure during testing, and thus was not able to complete the 200-hour testing. Lamp #1 had one defective lamp and #5 had two defective lamps that did not work as intended from the start. These are manufacturing defects and would seem to indicate better quality control being needed in the supply chain, however they were not premature failures that occurred due to operating the lamp.

The data gathered so far, show a mixed picture with LED filament lamps complying with switching-cycle tests, but one model showing premature failure above the Ecodesign threshold. This doesn't mean LED filament lamps are worse than other lamps; the halogen lamp had difficulties in the switching-cycle test. For the consumer, the early failures should not pose a big problem, where they are covered by commercial or legal minimum product warranties.

6.6 What trends in price and performance of LED filament lamps have been observed in the last two years and what is expected in the future?

Although LED filament technology was originally developed in 2008, [35] it hasn't been a popular LED lamp type until more recently, in 2014. The performance of LED filament lamps is linked to the performance of LEDs themselves, which it is shown in Chapter 2 are simply mounted in a chain under the phosphor coating of the filament. These emerging lamp designs have simplified the electronic drivers and the optics, resulting in an energy-efficient lamp which exceeds the price and performance that was envisaged in the VHK/VITO report.

More specifically, the retail LED lamp price of these LED filament lamps is approximately 11 % lower than the forecast and efficacy is 29 % better. Given that the consultant's June 2013 report was the basis for the Commission's recent proposal to delay the implementation of Stage 6 of EC No 244/2009 by 2 years,[36] that proposed amendment would now seem to be redundant because the technological progress of LED lamps has exceeded expectations. Already now LED filament lamps are available that can replace many halogen applications.

[35] Tevaja Lighting corporation, China. See: http://www.tevaja.com/?page_id=11

[36] 5 November 2014, Commission issued an email which stated the following: EU TBT notification concerning the Draft Commission Regulation amending Regulation (EC) No 244/2009 has now been published on the WTO website under the following reference: G/TBT/N/EU/248 and can be found here (click on this link)

Annex A. Announcement to Stakeholders of this Study

Mon 15/09/2014 – email from Bram Soenen, Attaché senior Product policy, DG5 Environment, Product policy; Belgian Federal Public Service, Health, Food Chain Safety and Environment

Dear Colleagues,

We hope you all had refreshing holidays. It has been a while since we last discussed the review of EC No 244/2009 Stage 6 review for lighting and we wanted to get in touch to inform you about a small LED product testing study that Sweden and Belgium are leading, with support from CLASP and eceee.

LED technology continues to evolve at a very rapid pace, and recently, competitively priced (<10€) "LED filament" clear non-directional lamps have entered the EU market claiming very high efficacies. If correct, these claims exceed the projected price and performance currently used as a basis for the upcoming revision of the existing lighting regulations.

This testing study is intended to provide a market snap-shot from August 2014, looking at price and performance of LED lamps on the EU market. The test results will be presented in a technical / factual report, addressing a set of key questions on performance – including efficacy, CRI, CCT, flicker and other important performance metrics. The report will be made publicly available for all members of the Consultation Forum to review.

The outline of the study is based on discussions between the parties above, whereas Sweden will provide funding for purchase of lamps as well as conducting tests of the lamps in their lighting laboratory.

In contacting you today, we wanted to inform you about this study and ask if any of you have other ideas to contribute at this stage, after looking at the attachment. The budget and timeline for this effort is tight, however there is a possibility of some minor adjustments, so please let us know.

In the meantime, if you'd like to learn more about these LED filament lamps, please see the following resources:

- Product example: http://www.vosla.com/upload/downloads/kataloge/vosled-katalog-2014b.pdf
- Close-up examination: https://www.youtube.com/watch?v=25j2C4jq2HI.
- Explanation on the filaments: http://www.designingwithleds.com/novel-led-packaging-adds-filaments-retro-bulbs/.

We look forward to hearing from you and seeing you soon at a meeting in Brussels.

Kind regards,

Bram Soenen
Peter Bennich
Mike Scholand
Nils Borg

Test Report on Clear, Non-Directional LED Lamps

This study will assess the current price and performance of mains-voltage, non-directional, clear LED lamps with B22 or E27 sockets in Europe.

Motivation / Context:
In June 2013, the "Review study on the stage 6 requirements of Commission Regulation (EC) No 244/2009" was issued. Table 2 in that report provided a projection of efficacy and price of a 500 lumen LED lamp, as shown below:

Table 2. MV LED retrofit lamp, efficacy and price projections EU 2012-2025
(sources: for efficacy CLASP 2013, based on US DoE MYPP projections; for EU lamp consumer prices incl. VAT (500 lm lamp) up to 2020 LightingEurope; 2021-2030 prices, extrapolation VHK)

Year	2012	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2030
lm/W	58	93	99	105	112	118	125	130	134	138	142	169
price in €	18.0	10.0	9.0	8.5	8.0	7.5	7.0	6.5	6.0	5.5	5.0	2.5

For 2018, this table presents an efficacy of 105 lumens per watt and €8.50 per 500 lumen lamp. However, the prices and (claimed) efficacy values for clear "LED filament" lamps in August 2014 appear to already be meeting or approaching those targets. If true, then LED technology is advancing much faster than anyone envisaged and this new evidence needs to be made available to policy makers reviewing Stage 6.

Key questions to examine in this study:

- What are the current cost (lumen/€) and performance (lm/W) of clear LED lamps?
- Do they give an aesthetic pleasant light (warm white, high CRI, no flicker)?
- Are the "dimmable" lamps compatible with leading edge and trailing edge dimmers?
- Do these lamps meet the LED quality requirements in EU No 1194/2012?
- Are LED filament lamps reliable products for consumers? (i.e., failure rate, switching test)
- What trends in price and performance of LED filament lamps have been observed in the last two years and what is expected in the future?

Methodology:
The study will be led by Sweden and Belgium with support from CLASP and eceee. The following are the key steps:

1) Purchase 10 units each of 16 different models of clear LED Lamps, and 10 units of one halogen lamp for reference / comparison, for a total of 170 non-directional lamps in the study.
2) The Swedish Energy Agency will test the lamps in their laboratory, conducting the following tests:
    a. Power consumption, voltage and current, measured separately
    b. Power factor – ratio of real power over apparent power
    c. Current and voltage harmonics
    d. Luminous flux – total lumens
    e. Luminous intensity distribution – uniformity of light distribution, measurements taken in three vertical symmetric ("C") planes, 0°, 45°, 90° and at 1° gamma angles
    f. Colour rendering index (CRI) and the R9 value
    g. Colour consistency – measurement of 49 coordinate pairs (x,y) and plotting the most deviating pairs in a six step Macadam ellipse.

h. Correlated colour temperature (CCT)
i. Chromaticity tolerance (Duv); allowable deviation in CCT, the distance of a light's chromaticity from the Planckian (black body) locus
j. Flicker – measure the flicker index
k. Temperature measurement – measure the surface temperature of the lamp during steady-state operation
l. Dimmer compatibility – check compatibility with a leading edge and a trailing edge dimmer, only for those models marketed as 'dimmable'
m. Switching cycle test – number of switching cycles based on rated lifetime, ≥ 15 000 if rated lamp life ≥ 30 000 h otherwise: ≥ half the rated lamp life expressed in hours**
n. Lumen maintenance test – sphere measurements of lumens, CCT and efficacy at 500, 1000, 2000, 3000, 4000, 5000 and 6000h. Goniometer measurement at 6000h (colour consistency and luminous intensity distribution)**
o. Dimensions – max diameter and length
p. Weight – grams

** Note: Due to the limitations in sample size, 5 lamps will be subjected to the switching cycle test and 5 lamps will be subjected to the lumen maintenance test.

3) Report – based on the test results of the lamps, a report will be created including sections on the following (draft outline):
    a. Executive Summary
    b. Introduction and Context
    c. Lamps Selected and Technical Discussion
    d. Test Lab and Tests Conducted
    e. Test Results
        i. Comparison of variation within the 16 LED models and 10 unit samples
        ii. Comparison of average values for sample of 16 LED models and 1 halogen
    f. Discussion of Test Results
    g. Key Question Examination and Discussion
        i. (See Key Questions in this memo above)

4) Peer review of draft report prior to being published to the full Consultation Forum. Note that the immediate results will be reported as soon as possible, and the lumen maintenance test results will be reported as updates over the course of the testing.

<u>Roles and responsibilities:</u>

- **Sweden** will lead the project, including coordinating and overseeing the purchasing of lamps, the testing of the lamps in-house and the analysis and preparation of the report.
- **Belgium** will provide guidance on the work and assist with the analysis and reporting.
- **CLASP and eceee** will assist with the selection and purchase of the lamps, the analysis and the report.

Annex B. Detailed Test Results of the Study

This Annex provides a summary of the detailed test results for the lamps tested in this study.

Table B1. Test Results for Wholesale Lighting Mirrorstone / MS-B22-6W-OMNI

Manufacturer	Wholesale Lighting		**Parameter**	**Average Value**
Retailer	www.wholesaleledlights.co.uk		MacAdam centre x	0.4403
Model	MS-B22-6W-OMNI		MacAdam centre y	0.4082
Parameter	*Units*	**Average Value**	Within MacAdam 6	Yes
Efficacy	*(lm/Watt)*	121.4	Max ellipses**	3.82
Light output	*(lumens)*	598	CRI01	80.0
CCT	*(K)*	3045	CRI02	88.1
CRI	*(Ra)*	81.5	CRI03	93.4
Voltage	*(VAC)*	230.3	CRI04	78.8
Current	*(I mA)*	38.1	CRI05	78.1
Wattage	*(Watts)*	4.93	CRI06	82.5
Power Factor	*(pF)*	0.56	CRI07	86.4
Length	*(mm)*	113	CRI08	64.5
Width	*(mm)*	60	CRI09	16.2
Weight	*(grams)*	40	CRI10	70.1
Max Op Temp	*(C)*	43.5	CRI11	74.6
Dimmer - Leading	*(yes/no)*	n/a	CRI12	57.7
Dimmer - Trailing	*(yes/no)*	n/a	CRI13	81.5
Min Duv	*(+ / -)**	0.0036	CRI14	95.7
Max Duv	*(+ / -)**	-0.0012	CRI15	75.2
x		0.4350	CRI16	74.5
y		0.4055	Gamut Point	0.41

* A negative number for the Duv means that the lamp tested is below the Planckian Locus.
** Max ellipses are the number of MacAdam ellipses necessary to contain all test points.

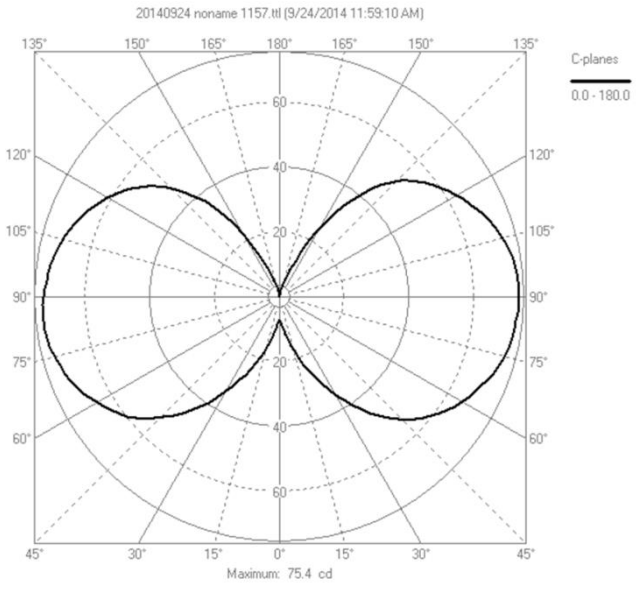


Table B2. Test Results for Maplin "LED filament" / A15QF

Manufacturer	UKLED Standard Bulb		**Parameter**	**Average Value**
Retailer	Maplin UK		MacAdam centre x	0.4681
Model	"LED filament" / A15QF		MacAdam centre y	0.4158
Parameter	*Units*	**Average Value**	Within MacAdam 6	No
Efficacy	*(lm/Watt)*	112.9	Max ellipses**	7.58
Light output	*(lumens)*	659	CRI01	79.8
CCT	*(K)*	2765	CRI02	90.7
CRI	*(Ra)*	81.8	CRI03	96.5
Voltage	*(VAC)*	230.3	CRI04	77.5
Current	*(I mA)*	53.4	CRI05	79.2
Wattage	*(Watts)*	5.83	CRI06	87.8
Power Factor	*(pF)*	0.47	CRI07	83.0
Length	*(mm)*	102	CRI08	59.8
Width	*(mm)*	60	CRI09	12.0
Weight	*(grams)*	36	CRI10	78.1
Max Op Temp	*(C)*	45.7	CRI11	74.5
Dimmer - Leading	*(yes/no)*	n/a	CRI12	69.3
Dimmer - Trailing	*(yes/no)*	n/a	CRI13	82.1
Min Duv	*(+ / -)**	-0.0009	CRI14	98.7
Max Duv	*(+ / -)**	0.0051	CRI15	73.9
x		0.4545	CRI16	72.2
y		0.4091	Gamut Point	0.41

* A negative number for the Duv means that the lamp tested is below the Planckian Locus.
** Max ellipses are the number of MacAdam ellipses necessary to contain all test points.

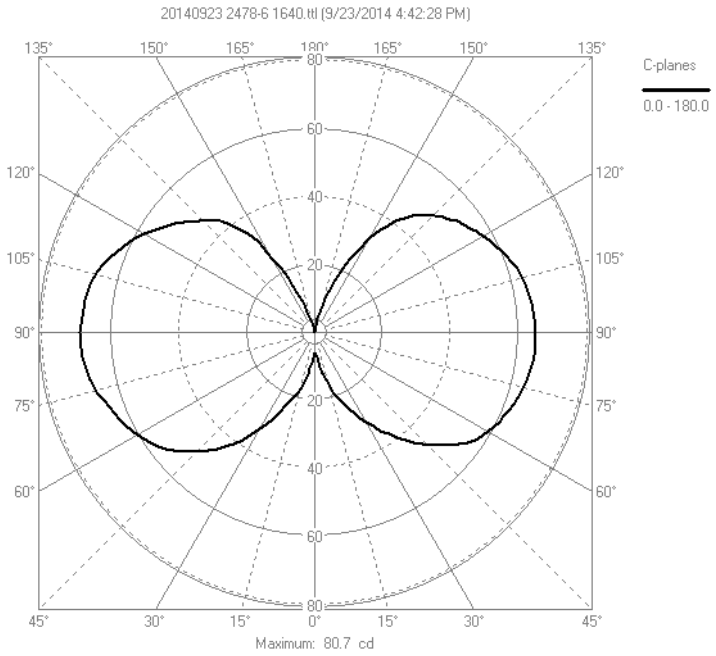


Table B3. Test Results for Osram Halogen Classic A ECO 64543 (46W)

Manufacturer	Osram		**Parameter**	**Average Value**
Retailer	Amazon.co.uk		MacAdam centre x	0.4591
Model	Halogen Classic A ECO 64543		MacAdam centre y	0.4086
Parameter	*Units*	**Average Value**	Within MacAdam 6	Yes
Efficacy	*(lm/Watt)*	12.8	Max ellipses**	1.73
Light output	*(lumens)*	583	CRI01	99.8
CCT	*(K)*	2747	CRI02	99.9
CRI	*(Ra)*	99.8	CRI03	99.7
Voltage	*(VAC)*	230.2	CRI04	99.7
Current	*(I mA)*	197.7	CRI05	99.8
Wattage	*(Watts)*	45.52	CRI06	99.9
Power Factor	*(pF)*	1.00	CRI07	99.8
Length	*(mm)*	95	CRI08	99.5
Width	*(mm)*	55	CRI09	99.2
Weight	*(grams)*	26	CRI10	99.7
Max Op Temp	*(C)*	89.4	CRI11	99.7
Dimmer - Leading	*(yes/no)*	Yes	CRI12	99.8
Dimmer - Trailing	*(yes/no)*	Yes	CRI13	99.8
Min Duv	*(+ / -)**	-0.0009	CRI14	99.8
Max Duv	*(+ / -)**	0.0001	CRI15	99.6
x		0.4557	CRI16	98.3
y		0.4092	Gamut Point	0.41

* A negative number for the Duv means that the lamp tested is below the Planckian Locus.
** Max ellipses are the number of MacAdam ellipses necessary to contain all test points.

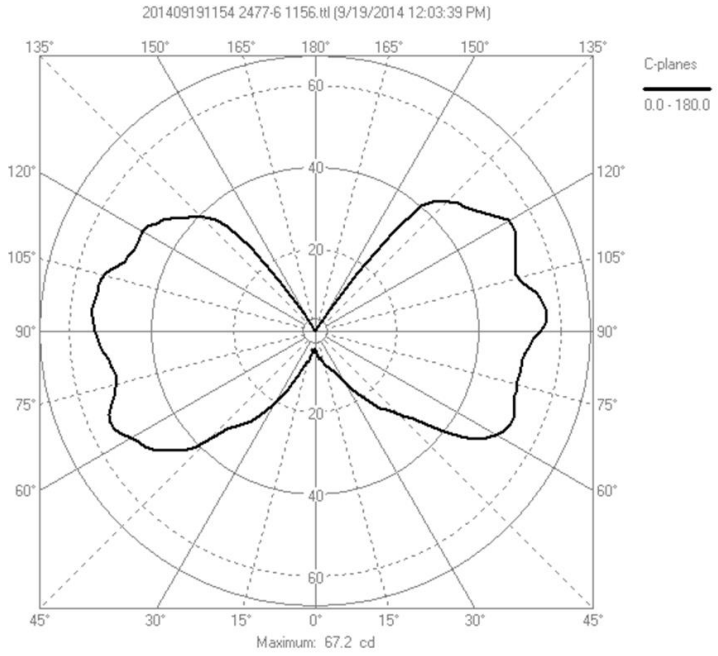


Table B4. Test Results for Lighting Ever "LED Filament Bulb" / 100047-WW-EU

Manufacturer	Lighting Ever		**Parameter**	**Average Value**
Retailer	www.lightingever.co.uk		MacAdam centre x	0.4678
Model	100047-WW-EU		MacAdam centre y	0.4207
Parameter	*Units*	**Average Value**	Within MacAdam 6	Yes
Efficacy	*(lm/Watt)*	95.6	Max ellipses**	5.02
Light output	*(lumens)*	359	CRI01	78.8
CCT	*(K)*	2730	CRI02	92.6
CRI	*(Ra)*	80.2	CRI03	92.1
Voltage	*(VAC)*	230.3	CRI04	74.5
Current	*(I mA)*	33.2	CRI05	78.8
Wattage	*(Watts)*	3.76	CRI06	91.9
Power Factor	*(pF)*	0.49	CRI07	79.1
Length	*(mm)*	103	CRI08	53.9
Width	*(mm)*	60	CRI09	2.6
Weight	*(grams)*	34	CRI10	83.2
Max Op Temp	*(C)*	42.2	CRI11	72.0
Dimmer - Leading	*(yes/no)*	n/a	CRI12	73.5
Dimmer - Trailing	*(yes/no)*	n/a	CRI13	82.1
Min Duv	*(+ / -)**	0.0005	CRI14	96.1
Max Duv	*(+ / -)**	0.0055	CRI15	70.8
x		0.4613	CRI16	67.4
y		0.4170	Gamut Point	0.42

* A negative number for the Duv means that the lamp tested is below the Planckian Locus.

** Max ellipses are the number of MacAdam ellipses necessary to contain all test points.

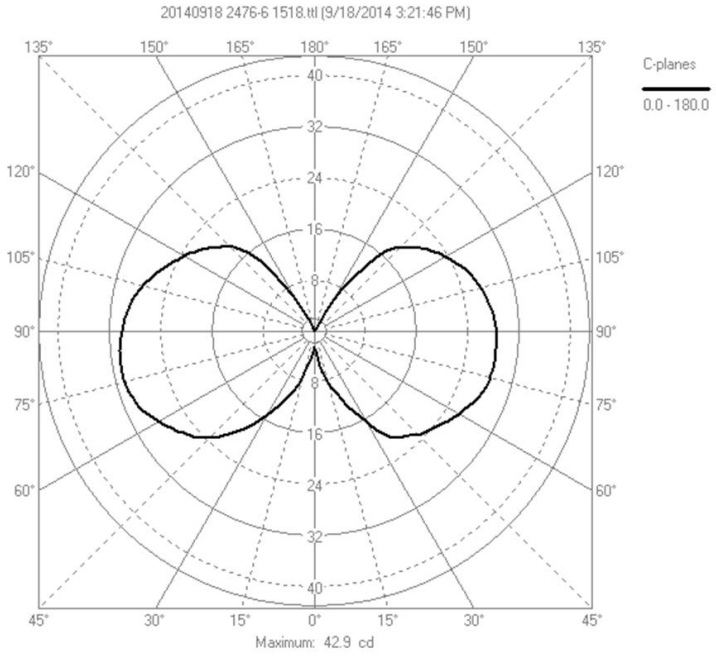


Table B5. Test Results for LED Connection "Classic LED bulb"

Manufacturer	LED Connection (importer)		**Parameter**	**Average Value**
Retailer	LED Connection		MacAdam centre x	0.4445
Model	Classic LED Bulb		MacAdam centre y	0.3952
Parameter	*Units*	**Average Value**	Within MacAdam 6	Yes
Efficacy	*(lm/Watt)*	67.5	Max ellipses**	1.69
Light output	*(lumens)*	426	CRI01	80.0
CCT	*(K)*	2830	CRI02	94.1
CRI	*(Ra)*	80.4	CRI03	90.6
Voltage	*(VAC)*	230.3	CRI04	74.3
Current	*(I mA)*	29.1	CRI05	80.2
Wattage	*(Watts)*	6.31	CRI06	91.9
Power Factor	*(pF)*	0.94	CRI07	77.7
Length	*(mm)*	118	CRI08	54.4
Width	*(mm)*	67	CRI09	5.2
Weight	*(grams)*	49	CRI10	85.9
Max Op Temp	*(C)*	60.4	CRI11	71.3
Dimmer - Leading	*(yes/no)*	No	CRI12	74.7
Dimmer - Trailing	*(yes/no)*	Yes	CRI13	83.7
Min Duv	*(+ / -)**	-0.0046	CRI14	95.7
Max Duv	*(+ / -)**	-0.0034	CRI15	73.8
x		0.4430	CRI16	70.3
y		0.3956	Gamut Point	0.40

* A negative number for the Duv means that the lamp tested is below the Planckian Locus.

** Max ellipses are the number of MacAdam ellipses necessary to contain all test points.

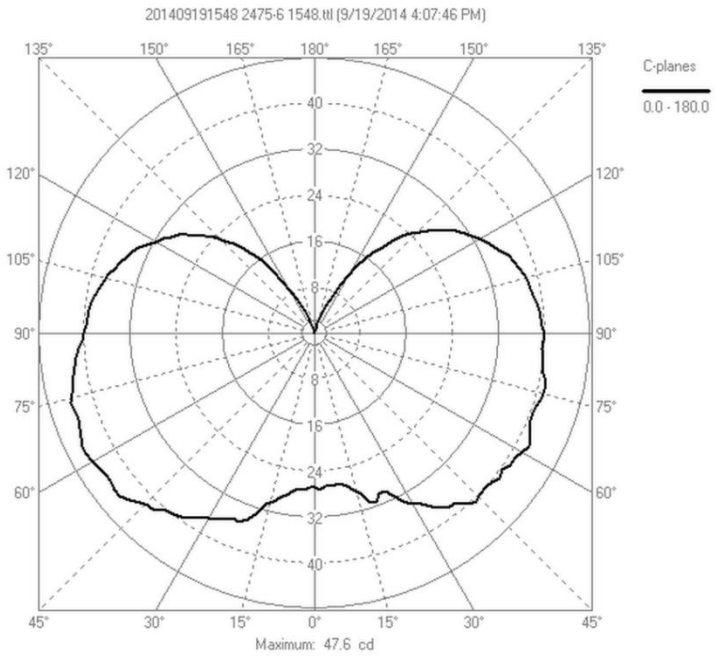


Table B6. Test Results for IKEA "LEDARE" / 602.553.62

Manufacturer	IKEA		**Parameter**	**Average Value**
Retailer	IKEA		MacAdam centre x	0.4639
Model	LEDARE / 602.553.62		MacAdam centre y	0.4083
Parameter	*Units*	**Average Value**	Within MacAdam 6	Yes
Efficacy	*(lm/Watt)*	62.7	Max ellipses**	4.65
Light output	*(lumens)*	596	CRI01	90.0
CCT	*(K)*	2673	CRI02	94.0
CRI	*(Ra)*	90.1	CRI03	96.3
Voltage	*(VAC)*	230.3	CRI04	89.9
Current	*(I mA)*	44.2	CRI05	89.4
Wattage	*(Watts)*	9.50	CRI06	92.7
Power Factor	*(pF)*	0.93	CRI07	90.5
Length	*(mm)*	120	CRI08	78.1
Width	*(mm)*	60	CRI09	52.2
Weight	*(grams)*	116	CRI10	85.1
Max Op Temp	*(C)*	83.8	CRI11	89.8
Dimmer - Leading	*(yes/no)*	Yes	CRI12	81.6
Dimmer - Trailing	*(yes/no)*	Yes	CRI13	90.8
Min Duv	*(+ / -)**	-0.0021	CRI14	97.2
Max Duv	*(+ / -)**	0.0009	CRI15	86.0
x		0.4609	CRI16	85.9
y		0.4090	Gamut Point	0.41

* A negative number for the Duv means that the lamp tested is below the Planckian Locus.

** Max ellipses are the number of MacAdam ellipses necessary to contain all test points.

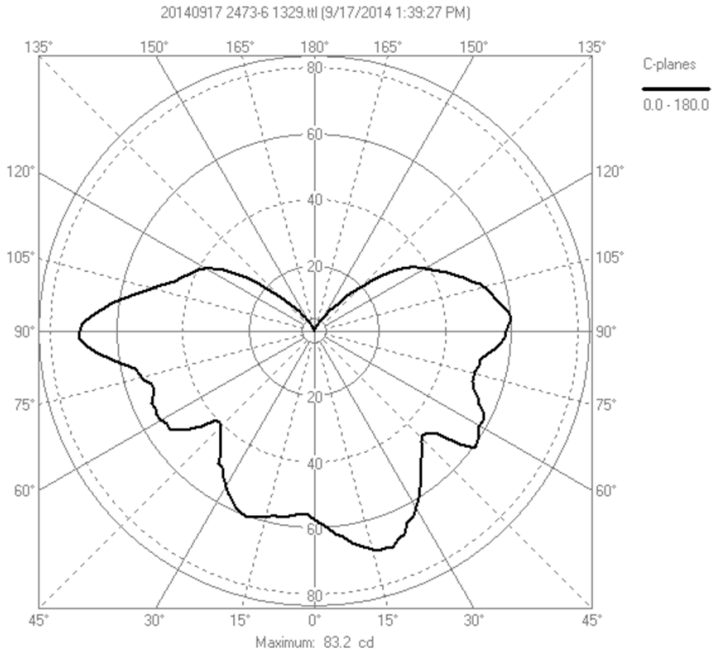


Table B7. Test Results for Vosla GmbH (DE) "vosLED-light bulb clear, 5.5W"

Manufacturer	VOSLA		**Parameter**	**Average Value**
Retailer	VOSLA (Germany)		MacAdam centre x	0.4619
Model	LED Bulb Clear, 5.5W		MacAdam centre y	0.4112
Parameter	*Units*	**Average Value**	Within MacAdam 6	Yes
Efficacy	*(lm/Watt)*	109.8	Max ellipses**	4.55
Light output	*(lumens)*	607	CRI01	90.6
CCT	*(K)*	2761	CRI02	96.4
CRI	*(Ra)*	91.0	CRI03	98.1
Voltage	*(VAC)*	230.3	CRI04	87.7
Current	*(I mA)*	36.1	CRI05	89.8
Wattage	*(Watts)*	5.53	CRI06	94.7
Power Factor	*(pF)*	0.66	CRI07	90.3
Length	*(mm)*	110	CRI08	80.8
Width	*(mm)*	60	CRI09	60.1
Weight	*(grams)*	39	CRI10	89.5
Max Op Temp	*(C)*	48.4	CRI11	86.5
Dimmer - Leading	*(yes/no)*	n/a	CRI12	78.1
Dimmer - Trailing	*(yes/no)*	n/a	CRI13	92.0
Min Duv	*(+ / -)**	-0.0021	CRI14	98.7
Max Duv	*(+ / -)**	0.0024	CRI15	87.9
x		0.4537	CRI16	87.2
y		0.4070	Gamut Point	0.41

* A negative number for the Duv means that the lamp tested is below the Planckian Locus.

** Max ellipses are the number of MacAdam ellipses necessary to contain all test points.

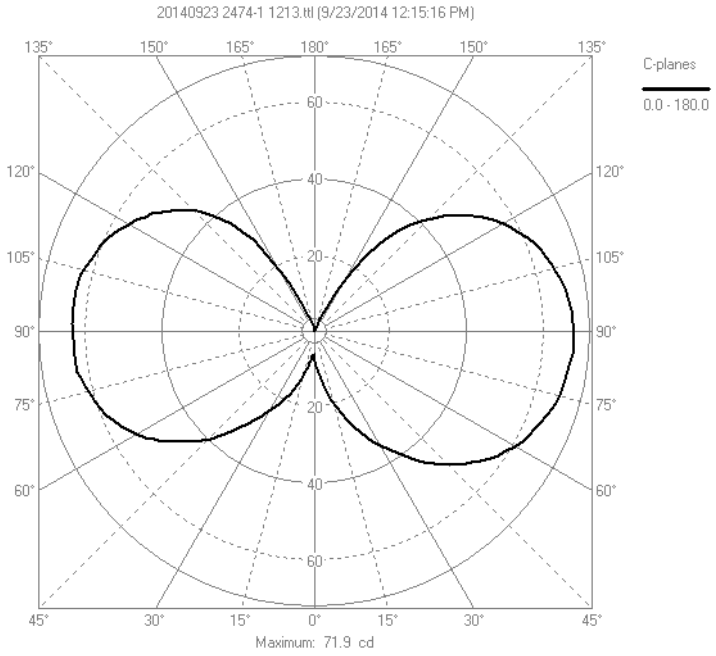


Table B8. Test Results for LED Connection 8W LED Filament

Manufacturer	LED Connection		**Parameter**	**Average Value**
Retailer	LED Connection		MacAdam centre x	0.4461
Model	8W LED Filament		MacAdam centre y	0.4055
Parameter	*Units*	**Average Value**	Within MacAdam 6	Yes
Efficacy	*(lm/Watt)*	102.8	Max ellipses**	5.63
Light output	*(lumens)*	782	CRI01	81.0
CCT	*(K)*	2889	CRI02	91.6
CRI	*(Ra)*	82.6	CRI03	96.4
Voltage	*(VAC)*	230.3	CRI04	76.9
Current	*(I mA)*	67.1	CRI05	79.6
Wattage	*(Watts)*	7.61	CRI06	87.9
Power Factor	*(pF)*	0.49	CRI07	84.1
Length	*(mm)*	112	CRI08	63.0
Width	*(mm)*	59	CRI09	18.8
Weight	*(grams)*	42	CRI10	78.6
Max Op Temp	*(C)*	53.8	CRI11	72.3
Dimmer - Leading	*(yes/no)*	n/a	CRI12	68.5
Dimmer - Trailing	*(yes/no)*	n/a	CRI13	83.4
Min Duv	*(+ / -)**	-0.0032	CRI14	98.5
Max Duv	*(+ / -)**	0.003	CRI15	76.2
x		0.4449	CRI16	74.6
y		0.4064	Gamut Point	0.41

* A negative number for the Duv means that the lamp tested is below the Planckian Locus.

** Max ellipses are the number of MacAdam ellipses necessary to contain all test points.

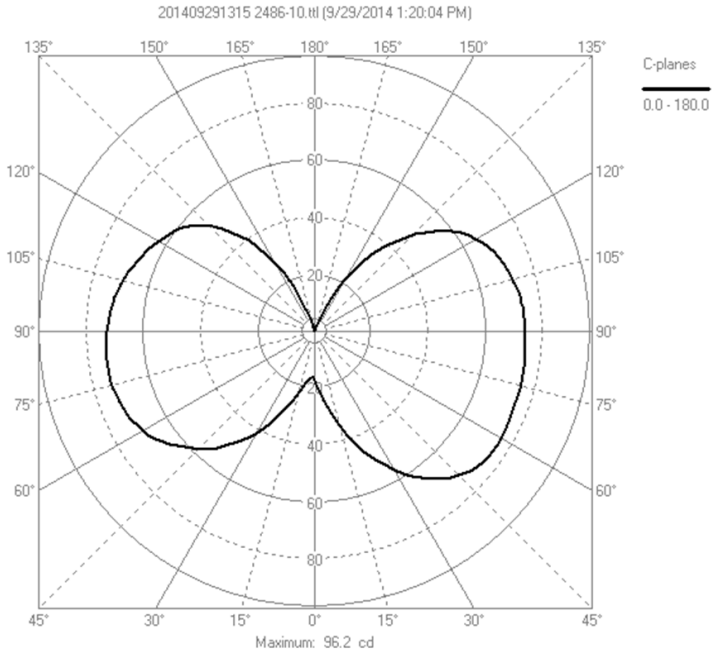


Table B9. Test Results for Panasonic "Nostalgic Clear"

Manufacturer	Panasonic		**Parameter**	**Average Value**
Retailer	shop.panasonic.fr		MacAdam centre x	0.4079
Model	Nostalgic Clear		MacAdam centre y	0.3496
Parameter	Units	**Average Value**	Within MacAdam 6	No
Efficacy	*(lm/Watt)*	82.3	Max ellipses**	33.82
Light output	*(lumens)*	792	CRI01	78.3
CCT	*(K)*	2717	CRI02	92.1
CRI	*(Ra)*	79.5	CRI03	91.7
Voltage	*(VAC)*	230.3	CRI04	75.3
Current	*(I mA)*	70.6	CRI05	78.8
Wattage	*(Watts)*	9.64	CRI06	91.5
Power Factor	*(pF)*	0.59	CRI07	77.7
Length	*(mm)*	126	CRI08	50.7
Width	*(mm)*	59	CRI09	-4.7
Weight	*(grams)*	92	CRI10	82.7
Max Op Temp	*(C)*	77.6	CRI11	74.2
Dimmer - Leading	*(yes/no)*	n/a	CRI12	74.3
Dimmer - Trailing	*(yes/no)*	n/a	CRI13	81.7
Min Duv	*(+ / -)**	-0.0441	CRI14	96.0
Max Duv	*(+ / -)**	0.0032	CRI15	69.4
x		0.4580	CRI16	65.8
y		0.4095	Gamut Point	0.41

* A negative number for the Duv means that the lamp tested is below the Planckian Locus.

** Max ellipses are the number of MacAdam ellipses necessary to contain all test points.

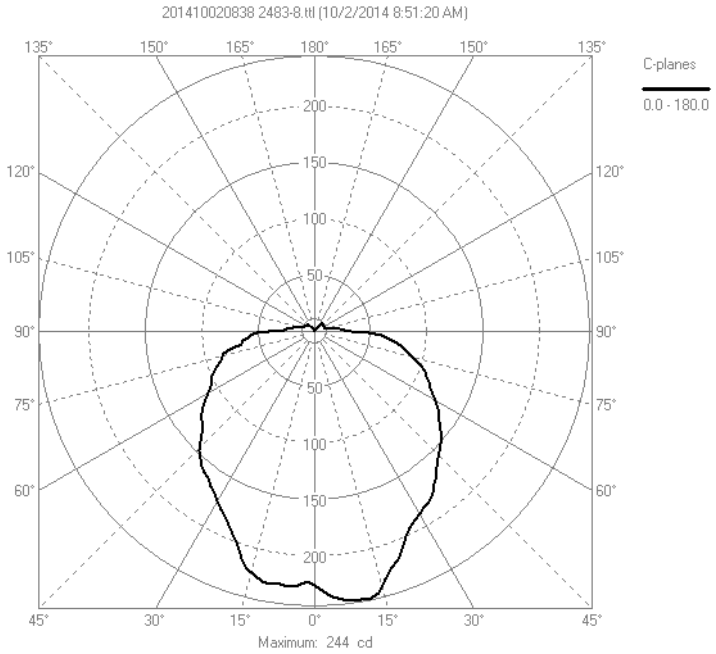


Table B10. Test Results for NCC-Licht / LED Filament Glühbirne 6W = 60W E27 Glühlampe Glühfaden warmweiß 2700K 360° A++

Manufacturer	Shada Bv LED's Light		**Parameter**	**Average Value**
Retailer	www.amazon.de		MacAdam centre x	0.4757
Model	LED Filament Glühbirne 6W		MacAdam centre y	0.4156
Parameter	Units	**Average Value**	Within MacAdam 6	Within tolerance
Efficacy	*(lm/Watt)*	104.1	Max ellipses**	6.36
Light output	*(lumens)*	707	CRI01	77.2
CCT	*(K)*	2587	CRI02	91.0
CRI	*(Ra)*	79.1	CRI03	93.3
Voltage	*(VAC)*	230.3	CRI04	73.5
Current	*(I mA)*	56.1	CRI05	76.9
Wattage	*(Watts)*	6.77	CRI06	89.1
Power Factor	*(pF)*	0.52	CRI07	79.2
Length	*(mm)*	104	CRI08	52.8
Width	*(mm)*	60	CRI09	1.8
Weight	*(grams)*	34	CRI10	79.8
Max Op Temp	*(C)*	66.7	CRI11	70.3
Dimmer - Leading	*(yes/no)*	n/a	CRI12	72.2
Dimmer - Trailing	*(yes/no)*	n/a	CRI13	80.2
Min Duv	*(+ / -)**	-0.0008	CRI14	97.0
Max Duv	*(+ / -)**	0.0034	CRI15	70.0
x		0.4702	CRI16	67.4
y		0.4139	Gamut Point	0.41

* A negative number for the Duv means that the lamp tested is below the Planckian Locus.
** Max ellipses are the number of MacAdam ellipses necessary to contain all test points.

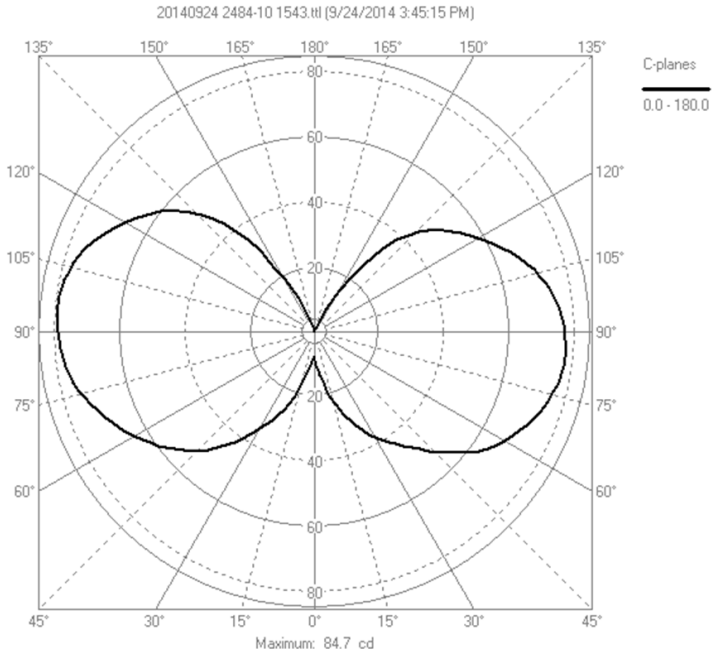


Table B11. Test Results for LED24.cc / E27 LED Glühfaden Birne 8w

Manufacturer	LED24cc		**Parameter**	**Average Value**
Retailer	www.amazon.de		MacAdam centre x	0.4503
Model	LED Glühfaden Birne 8w		MacAdam centre y	0.4119
Parameter	Units	**Average Value**	Within MacAdam 6	Yes
Efficacy	*(lm/Watt)*	98.4	Max ellipses**	5.43
Light output	*(lumens)*	663	CRI01	80.6
CCT	*(K)*	2909	CRI02	91.8
CRI	*(Ra)*	82.2	CRI03	96.0
Voltage	*(VAC)*	230.4	CRI04	76.1
Current	*(I mA)*	66.4	CRI05	79.3
Wattage	*(Watts)*	7.53	CRI06	88.0
Power Factor	*(pF)*	0.49	CRI07	83.5
Length	*(mm)*	112	CRI08	62.2
Width	*(mm)*	59	CRI09	17.3
Weight	*(grams)*	40	CRI10	78.9
Max Op Temp	*(C)*	54.4	CRI11	71.3
Dimmer - Leading	*(yes/no)*	n/a	CRI12	70.1
Dimmer - Trailing	*(yes/no)*	n/a	CRI13	83.2
Min Duv	*(+ / -)**	-0.0018	CRI14	98.5
Max Duv	*(+ / -)**	0.004	CRI15	75.8
x		0.4427	CRI16	74.3
y		0.4044	Gamut Point	0.40

* A negative number for the Duv means that the lamp tested is below the Planckian Locus.

** Max ellipses are the number of MacAdam ellipses necessary to contain all test points.

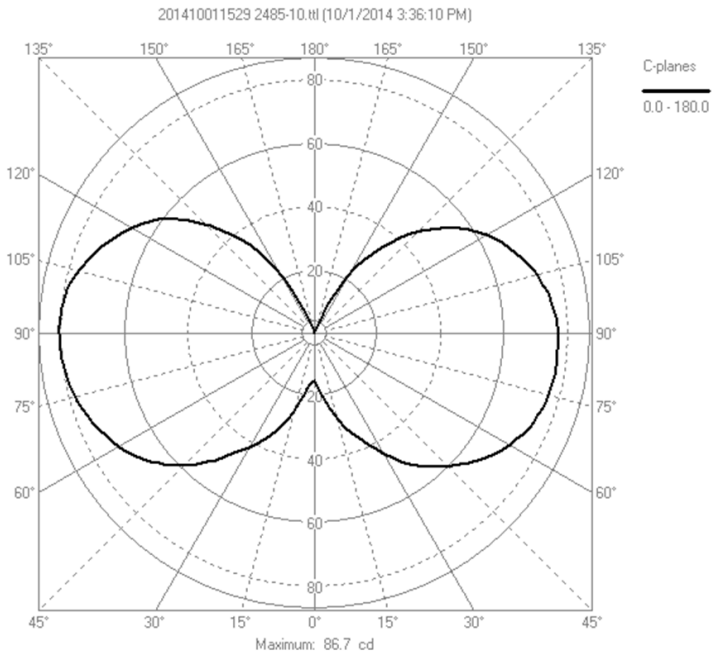


Table B12. Test Results for Star Trading (SE) LED filament lampa E27 Nr. 338-71

Manufacturer	StarTrading PromoLED 440 lm		**Parameter**	**Average Value**
Retailer	Sweden Star Trading		MacAdam centre x	0.4586
Model	LED filament lampa, 338-71		MacAdam centre y	0.4097
Parameter	Units	**Average Value**	Within MacAdam 6	Yes
Efficacy	*(lm/Watt)*	111.9	Max ellipses**	3.38
Light output	*(lumens)*	459	CRI01	79.8
CCT	*(K)*	2731	CRI02	88.2
CRI	*(Ra)*	81.1	CRI03	93.5
Voltage	*(VAC)*	230.3	CRI04	77.7
Current	*(I mA)*	38.1	CRI05	77.6
Wattage	*(Watts)*	4.12	CRI06	82.5
Power Factor	*(pF)*	0.47	CRI07	85.6
Length	*(mm)*	111	CRI08	64.3
Width	*(mm)*	60	CRI09	19.8
Weight	*(grams)*	38	CRI10	70.3
Max Op Temp	*(C)*	44.1	CRI11	72.7
Dimmer - Leading	*(yes/no)*	n/a	CRI12	59.9
Dimmer - Trailing	*(yes/no)*	n/a	CRI13	81.2
Min Duv	*(+ / -)**	-0.0025	CRI14	95.6
Max Duv	*(+ / -)**	0.0016	CRI15	76.0
x		0.4555	CRI16	75.9
y		0.4067	Gamut Point	0.41

* A negative number for the Duv means that the lamp tested is below the Planckian Locus.

** Max ellipses are the number of MacAdam ellipses necessary to contain all test points.

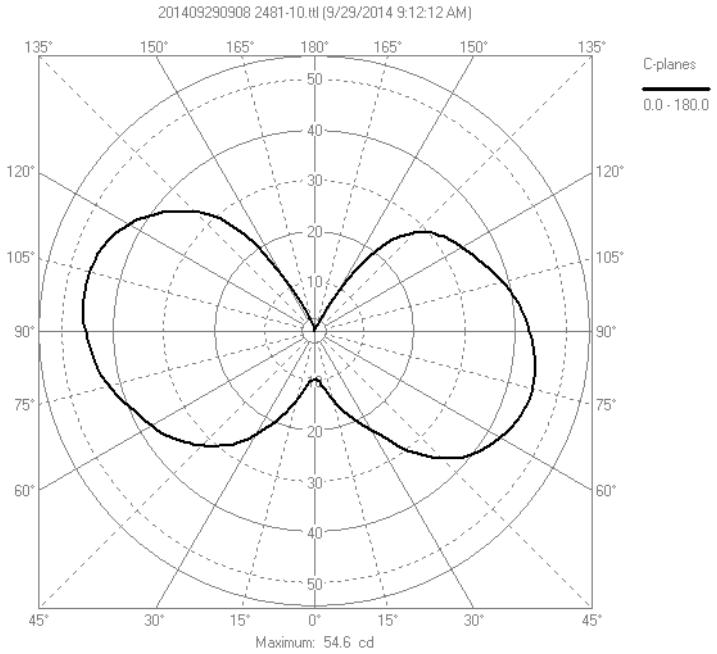


Table B13. Test Results for Star Trading (SE) LED filament lampa E27 Nr. 338-09 (candelabra)

Manufacturer	StarTrading Illumination LED		**Parameter**	**Average Value**
Retailer	Sweden Star Trading		MacAdam centre x	0.4519
Model	LED filament lampa, 338-09		MacAdam centre y	0.4087
Parameter	Units	**Average Value**	Within MacAdam 6	Yes
Efficacy	*(lm/Watt)*	66.2	Max ellipses**	3.3
Light output	*(lumens)*	285	CRI01	80.9
CCT	*(K)*	2825	CRI02	89.3
CRI	*(Ra)*	82.6	CRI03	95.7
Voltage	*(VAC)*	230.3	CRI04	79.8
Current	*(I mA)*	27.9	CRI05	79.6
Wattage	*(Watts)*	4.31	CRI06	85.0
Power Factor	*(pF)*	0.67	CRI07	85.7
Length	*(mm)*	137	CRI08	64.9
Width	*(mm)*	45	CRI09	21.3
Weight	*(grams)*	49	CRI10	74.4
Max Op Temp	*(C)*	64.2	CRI11	76.7
Dimmer - Leading	*(yes/no)*	Yes	CRI12	67.8
Dimmer - Trailing	*(yes/no)*	Yes	CRI13	82.4
Min Duv	*(+ / -)**	-0.0012	CRI14	97.2
Max Duv	*(+ / -)**	0.0017	CRI15	76.0
x		0.4497	CRI16	75.9
y		0.4077	Gamut Point	0.41

* A negative number for the Duv means that the lamp tested is below the Planckian Locus.

** Max ellipses are the number of MacAdam ellipses necessary to contain all test points.

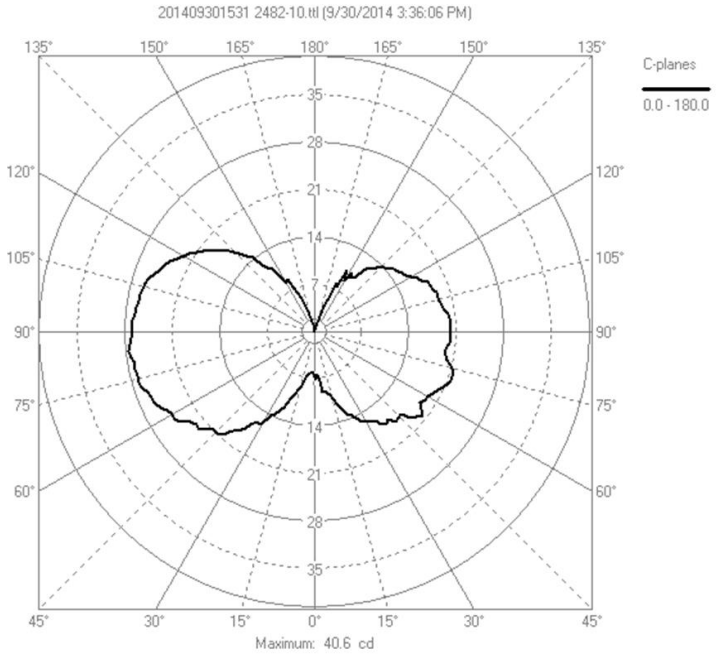


Table B14. Test Results for Osram PARATHOM Classic A ADV 10W 827

Manufacturer	OSRAM Parathom Classic A		**Parameter**	**Average Value**
Retailer	www.ledlightbulbs.co.uk		MacAdam centre x	0.4715
Model	PARATHOM Classic A 10W 827		MacAdam centre y	0.4190
Parameter	Units	**Average Value**	Within MacAdam 6	Yes
Efficacy	*(lm/Watt)*	89.5	Max ellipses**	3.33
Light output	*(lumens)*	863	CRI01	77.3
CCT	*(K)*	2739	CRI02	88.0
CRI	*(Ra)*	79.9	CRI03	96.8
Voltage	*(VAC)*	230.3	CRI04	77.0
Current	*(I mA)*	44.1	CRI05	76.8
Wattage	*(Watts)*	9.65	CRI06	84.5
Power Factor	*(pF)*	0.95	CRI07	82.4
Length	*(mm)*	109	CRI08	56.5
Width	*(mm)*	60	CRI09	3.4
Weight	*(grams)*	153	CRI10	72.9
Max Op Temp	*(C)*	86.5	CRI11	74.4
Dimmer - Leading	*(yes/no)*	Yes	CRI12	68.0
Dimmer - Trailing	*(yes/no)*	No	CRI13	79.3
Min Duv	*(+ / -)**	0.0017	CRI14	98.3
Max Duv	*(+ / -)**	0.003	CRI15	70.5
x		0.4582	CRI16	69.5
y		0.4122	Gamut Point	0.41

* A negative number for the Duv means that the lamp tested is below the Planckian Locus.

** Max ellipses are the number of MacAdam ellipses necessary to contain all test points.

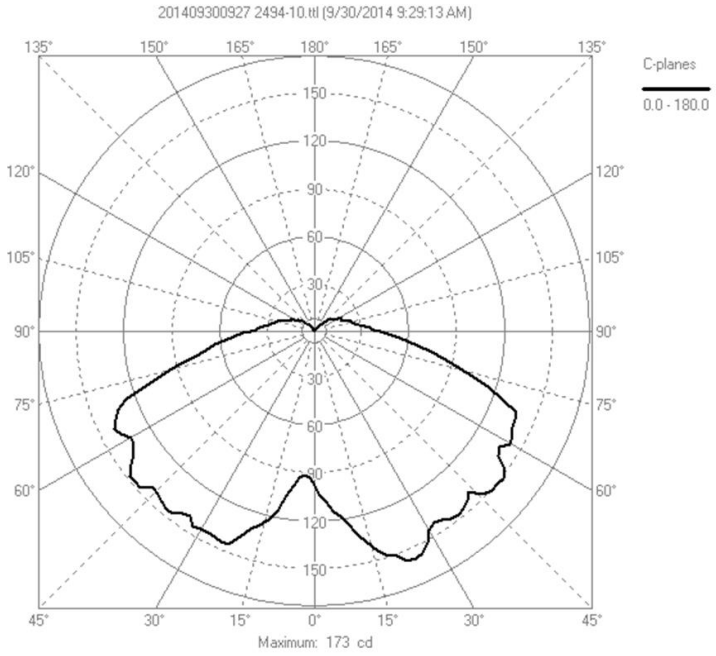


Table B15. Test Results for Philips "Clear LED bulb" - GLS 6W A60 E27 Very Warm White 827 Clear

Manufacturer	Philips Clear LED bulb		**Parameter**	**Average Value**
Retailer	www.ledlightbulbs.co.uk		MacAdam centre x	0.4629
Model	GLS 6W A60 E27 827		MacAdam centre y	0.4065
Parameter	Units	**Average Value**	Within MacAdam 6	Within tolerance
Efficacy	*(lm/Watt)*	84.7	Max ellipses**	6.19
Light output	*(lumens)*	501	CRI01	80.5
CCT	*(K)*	2705	CRI02	91.0
CRI	*(Ra)*	82.1	CRI03	96.1
Voltage	*(VAC)*	230.3	CRI04	77.7
Current	*(I mA)*	42.8	CRI05	79.9
Wattage	*(Watts)*	5.92	CRI06	88.0
Power Factor	*(pF)*	0.60	CRI07	82.6
Length	*(mm)*	109	CRI08	61.1
Width	*(mm)*	58	CRI09	17.3
Weight	*(grams)*	80	CRI10	78.7
Max Op Temp	*(C)*	77.5	CRI11	74.6
Dimmer - Leading	*(yes/no)*	Yes	CRI12	70.9
Dimmer - Trailing	*(yes/no)*	No	CRI13	82.8
Min Duv	*(+ / -)**	-0.0032	CRI14	98.5
Max Duv	*(+ / -)**	-0.0004	CRI15	75.6
x		0.4547	CRI16	74.3
y		0.4021	Gamut Point	0.40

* A negative number for the Duv means that the lamp tested is below the Planckian Locus.

** Max ellipses are the number of MacAdam ellipses necessary to contain all test points.

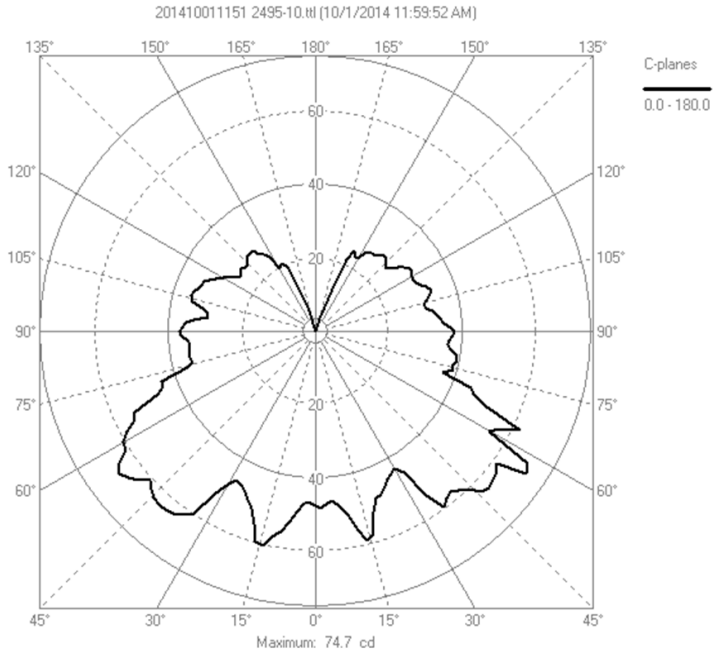


Table B16. Test Results for Led lampen direct (NL) / "Polaris 4 Watt"

Manufacturer	YPHIX 4W 450lm		**Parameter**	**Average Value**
Retailer	www.ledlampendirect.nl		MacAdam centre x	0.4724
Model	Polaris 4 Watt		MacAdam centre y	0.4180
Parameter	Units	**Average Value**	Within MacAdam 6	yes
Efficacy	*(lm/Watt)*	115.2	Max ellipses**	2.86
Light output	*(lumens)*	462	CRI01	76.8
CCT	*(K)*	2637	CRI02	89.9
CRI	*(Ra)*	79.2	CRI03	94.2
Voltage	*(VAC)*	230.3	CRI04	75.6
Current	*(I mA)*	32.8	CRI05	77.2
Wattage	*(Watts)*	4.02	CRI06	88.9
Power Factor	*(pF)*	0.53	CRI07	79.5
Length	*(mm)*	110	CRI08	51.3
Width	*(mm)*	49	CRI09	-5.2
Weight	*(grams)*	42	CRI10	78.3
Max Op Temp	*(C)*	43.3	CRI11	73.9
Dimmer - Leading	*(yes/no)*	n/a	CRI12	73.5
Dimmer - Trailing	*(yes/no)*	n/a	CRI13	79.6
Min Duv	*(+ / -)**	0.0006	CRI14	97.3
Max Duv	*(+ / -)**	0.0036	CRI15	68.2
x		0.4686	CRI16	65.5
y		0.4178	Gamut Point	0.42

* A negative number for the Duv means that the lamp tested is below the Planckian Locus.

** Max ellipses are the number of MacAdam ellipses necessary to contain all test points.

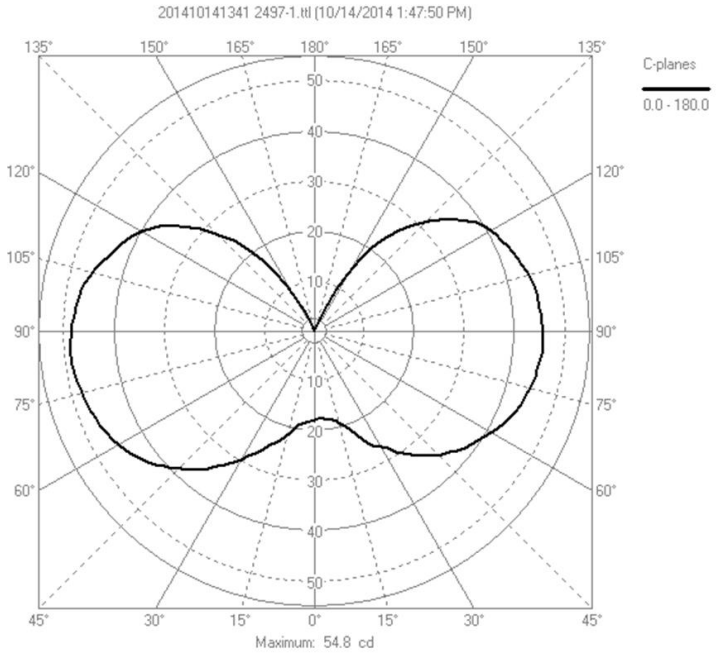


Table B17. Test Results for Calex (NL) "LED Filament GLS" / 474732

Manufacturer	Calex		**Parameter**	**Average Value**
Retailer	Electrocirkel n.v. (BE)		MacAdam centre x	0.4667
Model	LED Filament GLS / 474732		MacAdam centre y	0.4116
Parameter	Units	**Average Value**	Within MacAdam 6	No
Efficacy	*(lm/Watt)*	84.5	Max ellipses**	9.48
Light output	*(lumens)*	573	CRI01	88.1
CCT	*(K)*	2671	CRI02	97.0
CRI	*(Ra)*	87.9	CRI03	94.0
Voltage	*(VAC)*	230.4	CRI04	84.4
Current	*(I mA)*	56.2	CRI05	88.3
Wattage	*(Watts)*	6.78	CRI06	96.5
Power Factor	*(pF)*	0.52	CRI07	85.0
Length	*(mm)*	104	CRI08	70.0
Width	*(mm)*	60	CRI09	38.9
Weight	*(grams)*	38	CRI10	92.6
Max Op Temp	*(C)*	51.9	CRI11	83.9
Dimmer - Leading	*(yes/no)*	n/a	CRI12	82.5
Dimmer - Trailing	*(yes/no)*	n/a	CRI13	90.5
Min Duv	*(+ / -)**	-0.0027	CRI14	97.6
Max Duv	*(+ / -)**	0.0048	CRI15	82.7
x		0.4619	CRI16	80.2
y		0.4104	Gamut Point	0.41

* A negative number for the Duv means that the lamp tested is below the Planckian Locus.

** Max ellipses are the number of MacAdam ellipses necessary to contain all test points.

Table B18. Test Results for Segula

Manufacturer	Segula		**Parameter**	**Average Value**
Retailer	LEDitLight.net (NL)		MacAdam centre x	0.4740
Model	Model #: 474732		MacAdam centre y	0.4156
Parameter	Units	**Average Value**	Within MacAdam 6	Yes
Efficacy	*(lm/Watt)*	117.8	Max ellipses**	5.11
Light output	*(lumens)*	655	CRI01	79.4
CCT	*(K)*	2558	CRI02	90.4
CRI	*(Ra)*	81.4	CRI03	97.1
Voltage	*(VAC)*	230.4	CRI04	77.1
Current	*(I mA)*	50.4	CRI05	78.3
Wattage	*(Watts)*	5.56	CRI06	87.9
Power Factor	*(pF)*	0.51	CRI07	82.8
Length	*(mm)*	106	CRI08	58.4
Width	*(mm)*	60	CRI09	10.5
Weight	*(grams)*	35	CRI10	77.4
Max Op Temp	*(C)*	45.7	CRI11	74.0
Dimmer - Leading	*(yes/no)*	n/a	CRI12	69.5
Dimmer - Trailing	*(yes/no)*	n/a	CRI13	81.6
Min Duv	*(+ / -)**	-0.001	CRI14	99.0
Max Duv	*(+ / -)**	0.003	CRI15	72.6
x		0.4755	CRI16	70.8
y		0.4190	Gamut Point	0.42

* A negative number for the Duv means that the lamp tested is below the Planckian Locus.

** Max ellipses are the number of MacAdam ellipses necessary to contain all test points.