european
council for an
energy efficient
economy

B Class Halogens and Beyond

Design Approaches to Complying with Proposed EU Eco-design Domestic Lighting Requirements: A Technological and Economic Analysis

Commissioned and published by
The European Council for an Energy Efficient Economy, eceee

with financial support from:

the European Climate Foundation and
Defra's Market Transformation Programme (UK)

Prepared by Ecos Consulting, United States

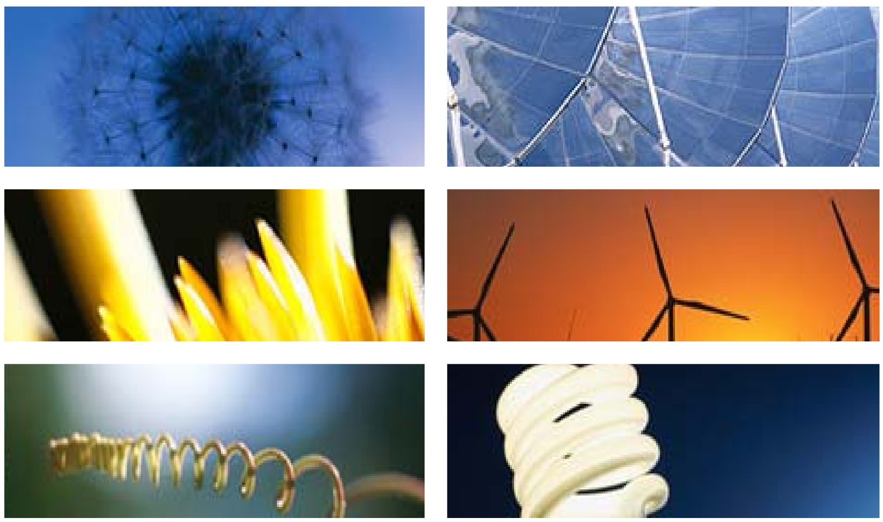
First published 1 December 2008
Revised 12 December 2008

eceee SECRETARIAT
SVEAVÄGEN 98 IV
SE-113 50 STOCKHOLM
SWEDEN

eceee PARIS
27, RUE LOUIS VICAT
FR-75015 PARIS
FRANCE

www.eceee.org
eceee@eceee.org

Making a World of Difference



Portland, OR | San Francisco, CA | Bellevue, WA | Durango, CO

B Class Halogens and Beyond

Design Approaches to Complying with Proposed EU Eco-design Domestic Lighting Requirements: A Technological and Economic Analysis

Commissioned by the:

European Council for an Energy Efficient Economy (eceee)
www.eceee.org

With financial support from the European Climate Foundation and Defra's Market Transformation Programme (UK)

Chris Calwell, Laura Moorefield & Craig Billingsley

Ecos Consulting

1199 Main Avenue, Suite 242

Durango, CO 81310

970 259-6801

December 12, 2008

Table of Contents

List of Figures

List of Tables

Introduction

The European Union has released draft Eco-design requirements for general service lighting that await a final decision on December 8, 2008. These requirements propose a series of mandatory efficiency levels, product definitions, timetables, and exemptions that would correspond to previously proposed mandatory labeling levels. Simply stated, with current commercially available technologies, Class C corresponds to the efficiency achieved by conventional line voltage (230 Volt) halogen lamps. Class B corresponds to the efficiency achieved by halogen lamps employing a low voltage power supply and infrared-reflective coating. Level A corresponds to the efficiency achieved by a relatively well-designed compact fluorescent lamp (CFL).

Ecos Consulting was asked by eceee to answer the following questions:

- Is Class B technically feasible for incandescent lamps?
- Does Class B require proprietary technology only available to one major manufacturer, or could a variety of manufacturers comply with it using different design strategies?
- How do the expected incremental costs of incandescent lamps that comply with Class B compare to the value of the resulting energy savings?
- Can incandescent technologies surpass Class B and deliver additional energy savings?
- Is Class B achievable by 2012 (one year before they would be mandatory according the first proposal the European Commission)?

Background on Incandescent Lamp Design

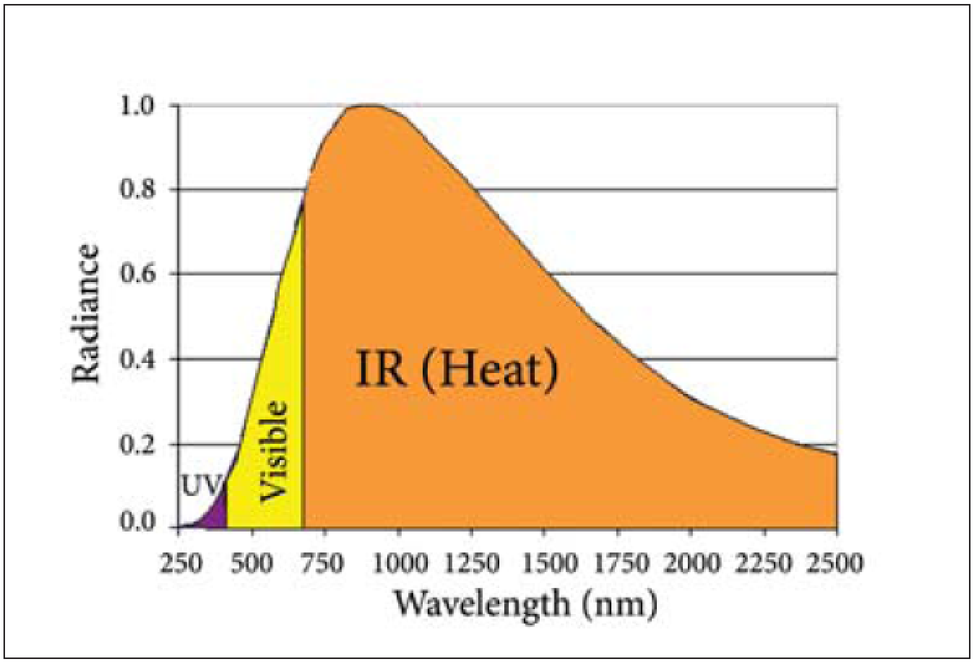


Figure 1. Distribution of Wavelengths Emitted from a Standard Tungsten Halogen Lamp

The greatest challenge in designing incandescent lamps to operate efficiently with a reasonable lifetime is getting the lamp's electromagnetic emissions to occur primarily in the visible spectrum instead of the infrared. Not only do traditional tungsten halogen lamps peak in the infrared, but they emit about 90% of their total energy there, as can be seen in Figure 1.[1]

One of the most promising approaches to shifting emissions from the infrared to the visible spectrum is the selective emitter, high temperature filament technology being pursued by General Electric, Foster-Miller Inc., and Sonsight.[2] Such filaments have a ceramic coating or physical structure that greatly reduces the release of infrared energy from the filament in the first place, and should be capable of achieving efficiencies of 30 lumens/watt or more.[3] Others have investigated photonic lattice nanotechnology to achieve a similar effect – trapping infrared photons within the lattice structure of the filament itself. However, both technologies have not yet been commercialized in consumer products, though Foster-Miller reports it is pursuing selective emitter commercialization with a major lamp manufacturer.

Currently the majority of high efficiency incandescent lamps employ a different design approach: infrared-reflective (IR) coatings applied to the surface of a halogen lamp capsule that reflect heat back onto the filament while allowing the transmission of visible light. Two subsidiaries of Advanced Lighting Technologies—Deposition Sciences (based in California) and Auer Lighting (based in Germany) have developed or co-developed most of the IR coatings in use worldwide on lighting products. They conducted a joint venture with General Electric about 20 years ago to develop the first such coating, and have embarked on later business deals with Philips and Osram to utilize subsequent generations of that coating technology in their halogen lamps.

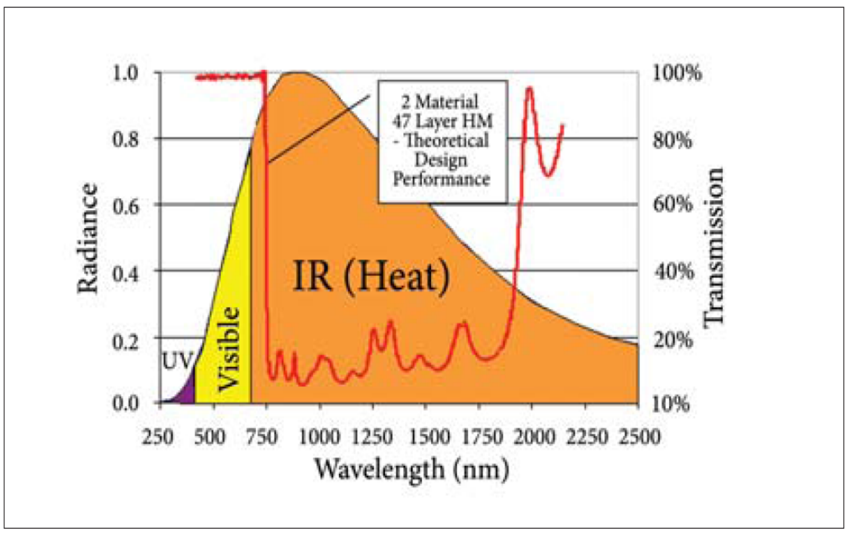


Figure 2. Effectiveness of New IR Coatings at Reflecting Infrared Emissions[4]

Deposition Sciences' most recent "hybrid" coatings typically allow only 20% or less (Figure 2) of the infrared wavelengths between 750 and 1850 nm to pass through. The rest is reflected back on the filament and converted mostly to visible light, greatly increasing efficiency. No such coating is perfectly transparent to visible light or perfectly reflective to infrared, but each subsequent generation of IR coatings has come a little closer to that ideal (note in Figure 2 that the hybrid coating is still largely transparent to infrared emissions above 1850 nm).

---

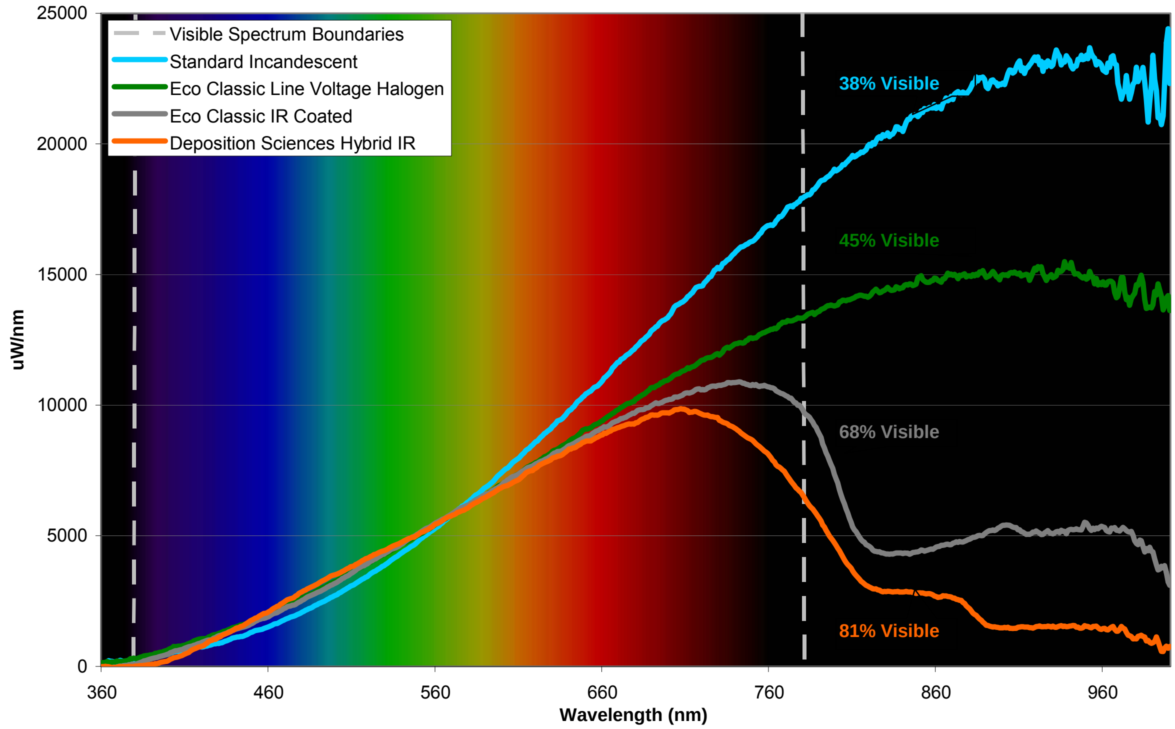
[1] Lee Bartolemei, President, Deposition Sciences, "Advanced Optical Coatings Enable Energy-Efficient Lighting," *The Photonics Solutions Update*, January 29, 2008, http://www.photonicsonline.com/article.mvc/Advanced-Optical-Coatings-Enable-Energy-Effic-0001.

[2] See http://www.freshpatents.com/Light-source-incorporating-a-high-temperature-ceramic-composite-and-gas-phase-for-selective-emission-dt20071011ptan20070236144.php?type=description ; http://www.foster-miller.com/t_advanced_materials.htm ; and http://www.energy.ca.gov/2006publications/CEC-500-2006-047/CEC-500-2006-047.PDF.

[3] See www.businesswire.com/portal/site/ge/?ndmViewId=news_view&newsId=20070223005120&newsLang=en

[4] Lee Bartolemei, "Advanced Optical Coatings Enable Energy-Efficient Lighting," *The Photonics Solutions Update*, January 29, 2008.

Ecos Consulting has tested a variety of incandescent lamps in its laboratory that employ different fill gasses and coatings. All incandescent lamps emit more reddish light than yellow, green or blue. However, the extent to which their emissions are concentrated in the infrared range largely determines their efficiency. Figure 3 illustrates our lab test results for four different incandescent lamps, each scaled to approximately 400 lumens. Note that a conventional incandescent lamp's emissions will continue to rise into the infrared spectrum and not peak until 900 nm or more (blue curve). Only 38% of its emissions between 360 and 1000 nm are visible to the human eye. A line voltage halogen lamp's emissions peak at a slightly lower wavelength, causing 45% of the output to be visible. A low voltage halogen lamp with an IR coating shifts its peak emissions into the visible spectrum at about 740 nm, causing about 68% of its emissions to be visible. The most advanced ("hybrid" or "Hot Mirror") IR coatings shift the peak all the way back to about 700 nm, causing fully 81% of the emissions to be visible.



Note: Orginal values have been scaled to 400 Lumens. Visable spectrum boundaries referenced from The IESNA Lighting Handbook Ninth Edition

Figure 3. Halogen Fill Gas and IR Coatings Increase the Fraction of Light Output in the Visible Spectrum

IR coatings can be added to finished halogen lamp capsules, as depicted in Figure 4, simplifying the manufacturing process and reducing its cost. This is discussed more fully in the cost effectiveness section below.

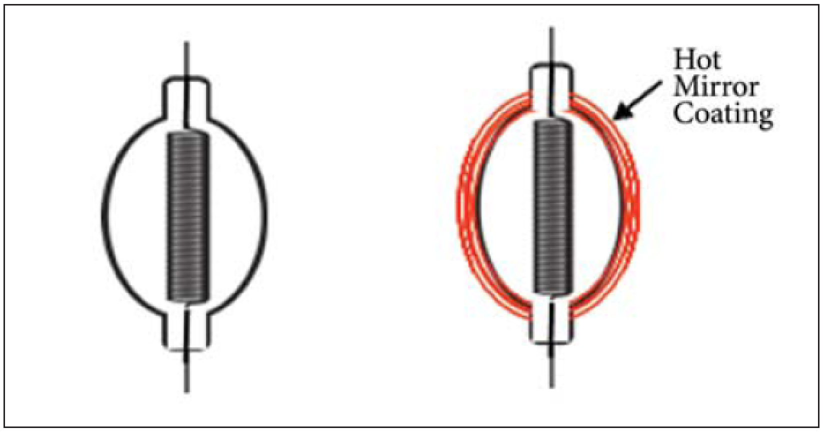


Figure 4: A Double-Ended Halogen Lamp Shown With and Without a Hot Mirror Coating[5]

Voltage and Safety Considerations

There are also differences in lamp performance based on their intended operating voltage. The advantages associated with designing incandescent lamps to operate at low voltage are easy to see in the following table, which illustrates the current flow and filament resistance needed to construct a lamp that will draw 20 watts of power at each of three common input voltages: 230 volts, 115 volts, and 12 volts.

Table 1. Comparison of Filament Resistance as a Function of Voltage

Voltage (Volts)	Power (Watts)	Current (Amps)	Resistance (Ohms)
230	20	0.087	2645
115	20	0.174	661
12	20	1.667	7.2

Note that I^2R is a constant in each case, but the 230 volt lamp's filament must have 378 times the resistance of the 12 volt lamp's filament, leading designers to utilize extremely long, thin tungsten filaments that have been doubly coiled to maximize length and heat retention in a given space. When the filament becomes this thin, it can sag at high temperatures and short circuit, or will experience early lamp failure if enough tungsten evaporates to create a thin spot in one portion of the filament. Such a filament has fewer electrons flowing through it per second and a much greater surface area than a short, thick filament, making it difficult to maintain a high operating temperature at a given wattage. Thus, all other things being equal, incandescent lamps of a given wattage will be brighter (and therefore operate more efficiently) at 12 volts than 115. Similarly 115 volt lamps of a given wattage are brighter and more efficient than comparable 230 volt lamps.

As a general rule, hotter filaments can have shorter lifetimes than cooler filaments of the same size, because tungsten evaporates from them more rapidly. The use of high pressure halogen fill gas in the capsule helps to combat this problem, encouraging the redeposit of evaporated tungsten atoms on the filament. However, this creates a safety risk, since the gas pressure increases inside a very hot halogen capsule, and lamp failure can be explosive.

[5] Lee Bartolemei, "Advanced Optical Coatings Enable Energy-Efficient Lighting," *The Photonics Solutions Update*, January 29, 2008.

Lamp designers traditionally addressed safety by utilizing a very thick, heavy, expensive glass globe around the halogen capsule. More recently, they have found a less expensive solution that is intended to prevent the halogen capsule from rupturing in the first place. The newest pressurized halogen capsule designs increasingly employ simple, low cost fuses that are designed to fail if the capsule begins to draw more power than usual and starts to heat up rapidly. The fuse (small module below the halogen capsule in the photo below) melts and interrupts the circuit before the halogen capsule can ever become hot enough to rupture:

Figure 5. Fuse on Halogen Capsule

This background information enables us to address the specific questions posed by eceee regarding the proposed Eco-design requirements.

Is Class B Technically Feasible?

Class C-compliant line voltage halogen lamps have been introduced by Philips, Osram, and General Electric, and are now widely available.

Figure 6. Osram Line Voltage Halogen Capsule Lamp

Osram's products[6] typically claim 30% energy savings and employ a single-ended halogen capsule (Figure 6). General Electric is introducing a similar line voltage, single-ended halogen product in Europe for which catalog data claim 25% energy savings: a 45 watt model intended to replace a 60 watt conventional incandescent.

We were able to obtain a European sample (referenced below as Sample 3) of the comparable technology from Philips: an Eco Classic 53 watt lamp. It employs a high pressure single-ended halogen capsule without an infrared-reflective coating. The product packaging claims that this 53 watt model can replace a conventional 75 watt incandescent lamp. (Other models offer a 42 watt version replacing a conventional 60 watt incandescent and a 70 watt version replacing a conventional 100 watt incandescent).[7]

We tested the sample in our integrating sphere and confirmed that it operates at 15.8 lumens/watt—essentially identical to the claimed 16 lumens/watt and about 30% more efficient than conventional incandescent lamps of similar to slightly higher brightness. These halogen lamps are currently sold by UK retailers at prices ranging from 1.99 to 2.99 pounds.

Figure 7. Test Sample 3: Philips Eco Classic Line Voltage Halogen Lamp.

[6] http://www.freewebs.com/lamps002/
[7] Philips sells a very similar technology in the United States with a double-ended halogen capsule inside of a smaller, soft white globe. These products are sold under the brand name "Halogena Energy Saver" in two-packs at Home Depot for $10.

The research question before us is whether improvements to the design of these Class C lamps would permit them to comply with the EU's Class B, and how that can be achieved technologically. Philips first released pre-production samples of such a product in the spring of 2007, branded in a variety of ways: "Edore," "Eco Boost," and "MasterClassic" (Figure 8). Our lab testing confirmed the efficiency claims for that product, but only on a single available sample.

Figure 8. 2007 Pre-production Sample of Philips Low Voltage Halogen Lamp with Integrated Power Supply

Ecos Consulting obtained five production samples of the same technology in September 2008 – 20 watt models now bearing the "Eco Classic" brand name. Four of the samples employ a clear globe and one has an ivory globe. These models are being manufactured in a variety of threaded and bayonet bases, and employ an integrated 230 volt to 12 volt ac-ac power supply and a high pressure, single-ended, 12 volt halogen capsule with an advanced infrared-reflective coating. The product packaging claims that this 20 watt model can replace a conventional 40 watt incandescent lamp.

The Eco Classic product achieves its high efficiency through four different, inter-related design approaches:

- Halogen fill gas allows higher temperature filament operation without compromising lamp lifetime, encouraging evaporated tungsten to redeposit on the filament. As filament temperature rises, a greater proportion of total emissions occurs within the visible spectrum instead of the infrared, improving efficiency. This particular design also is intended to operate safely at high fill gas pressures, further increasing efficiency and maintaining lamp lifetime.
- Adding an advanced infrared-reflective coating to the ellipsoid halogen capsule with a carefully aligned and centered filament allows the filament to operate at a higher temperature with lower power input. The coating bounces heat energy back onto the filament. This is likely the single most important efficiency feature in the product.
- The integrated power supply increases current flow for a given level of power consumption. This maximizes filament temperature and efficiency, even when accounting for power conversion losses in the power supply. It also allows the use of a shorter, thicker filament than line voltage halogen products, improving the opportunity to attain good geometries in the infrared-reflection process.

- The integrated power supply is unregulated, meaning that a reduction in input voltage leads directly to a corresponding reduction in output power. As a result, the lamp can be dimmed by the user, allowing further energy savings during periods when full brightness lighting is not necessary.

One other design approach is claimed by Philips to offer additional efficiency and safety benefits. Enclosing the halogen capsule within a second clear globe and evacuating the air in-between allows the halogen capsule to operate at high temperatures while being somewhat insulated from lower room temperatures by the vacuum in-between. However our measurements indicated slightly higher power use and lower light output as a result of the additional globe, so we cannot confirm any efficiency benefits from this design feature.

Regarding the safety claim, the clear globe helps to prevent users from touching the halogen capsule. However, the primary safety feature of this product design is its internal fuse. If the filament within the halogen capsule develops a short circuit or otherwise experiences rapid increases in power draw, temperature, and pressure, the fuse is designed to fail before the halogen capsule would ever explode. This allows the use of a much thinner, more transparent, and less expensive globe around the capsule than has previously been used by most GLS halogen lamp manufacturers.

Conversely, this product *lacks* one key design element that would further improve its efficiency: a double-ended halogen capsule. Philips chose a single-ended design, likely for cost and time-to-manufacture reasons. Unfortunately, it is difficult to achieve the same geometric symmetry and proximity of the infrared reflective coating to the filament in these designs as in double-ended designs, limiting the resulting efficiency of the final product (see further discussion below).

We tested the samples in a SphereOptics integrating sphere in our laboratory and confirmed that the products operate at approximately 17 to 18.5 lumens/watt – roughly twice the efficiency of conventional incandescent lamps of similar to slightly higher brightness. Thus, they consume half the power of the lamps they replace. No retail prices are currently being quoted for these products. Below are data from our laboratory measurements.

Figure 9. Test Sample 1: Philips EcoClassic Lamp with 12 V Halogen IR Capsule

Figure 10. Test Sample 2: Philips EcoClassic Lamp with 12 V Halogen IR Capsule

Figure 11. Test Sample 4: Philips EcoClassic Lamp with 12 V Halogen IR Capsule (Ivory Cover)

Figure 12. Test Sample 5: Philips EcoClassic Lamp with 12 V Halogen IR Capsule and View of 240 to 12 V Power Supply

Samples 1, 2, and 5 are functionally identical 20 watt infrared-reflective halogen lamps operating on the low voltage output of an internal power supply. They are designed to replace conventional 40 watt incandescent lamps. Sample 5 employs a different base type than Samples 1 and 2. Sample 4 is similar to Samples 1 and 2, but with a soft white or “ivory” coating.

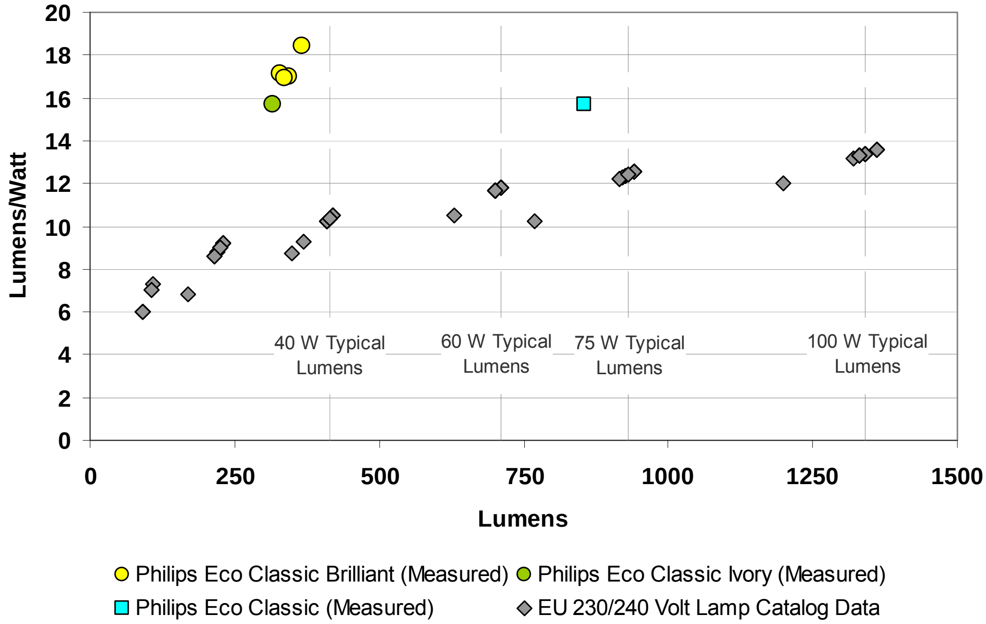


Figure 13. Measured Efficiency Data for Philips Halogen Lamps at 230 Volts

Based on our measurements and associated research, our findings are as follows:

Philips has achieved significant energy savings from its product design relative to the nameplate performance of typical European incandescent lamps. We observed efficiency gains of 75 to 100% relative to conventional 40 watt incandescent lamps operated at 230 volts. Operating wattages were half of what conventional lamps require to provide similar or slightly greater light output. These products exhibit similar behavior to the “energy-saving” incandescent and halogen lamps being sold by Philips and its competitors in the United States, achieving most of their energy savings from technological improvements in efficiency, and some of their savings from operating at slightly lower light output than the lamps they are designed to replace (see Figure 13).

The ivory coating on the Eco Classic lamps reduced light output and efficiency by about 13 to 20%, so the clear lamps would be a better choice in all luminaires where shades or diffusers are available to minimize glare.

Average power consumption and lumen output values were close to the nameplate values on Philips’ packaging, but lumen output variation from sample to sample was somewhat higher than expected. Larger sample sizes would be needed to verify this observation with any statistical rigor.

Overall, the test results confirm that Class B is technologically feasible with clear incandescent sources. An incandescent technology first introduced in a consumer product by Philips in early 2007 is meeting the EU’s proposed efficiency level six to nine years before the EU proposes to make that level mandatory.

Spectral distributions confirm the effectiveness of the infrared reflective coatings at shifting the majority of near-infrared emissions into the visible range. Note in Figure 14 that the line voltage halogen lamp’s output continues to rise in the infrared spectrum, peaking at about 940 nm. By contrast, the IR halogen products peak at 710 to 760 nm, dropping by roughly half at higher wavelengths.

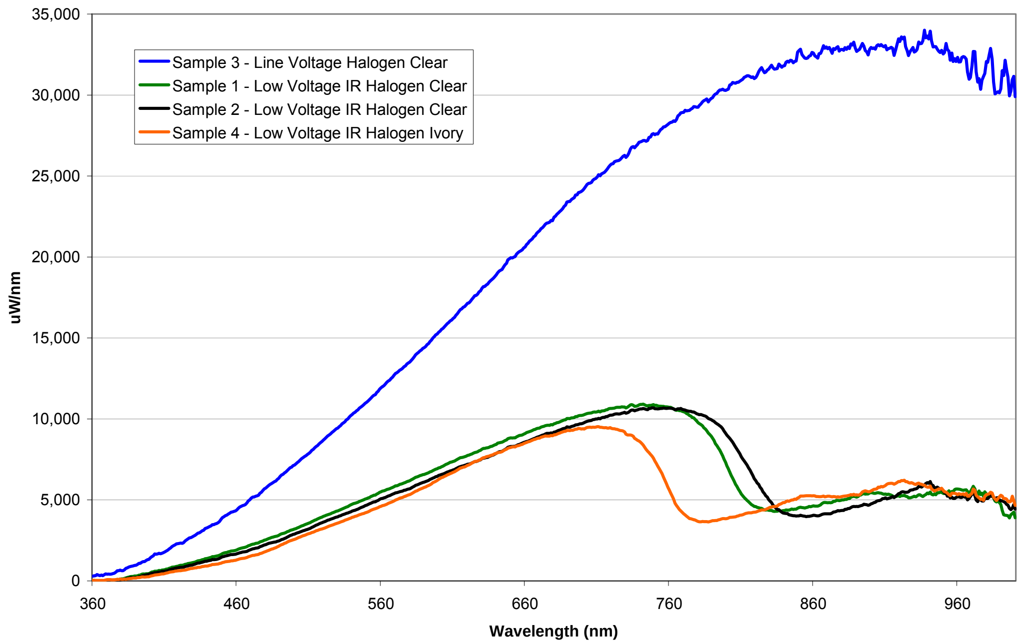


Figure 14. Spectral Distributions of Measured Lamps after 100-Hour Burn In

The potential for further gains in efficiency is evident from the fact that infrared output at 850 to 1000 nm remains roughly half as great as peak visible output, even with the use of an infrared-reflective coating. Thus, significant amounts of energy are still being radiated outside of the visible spectrum. Still, the design is more efficient than Philips' conventional line voltage halogen which, although brighter, consumes nearly three times the power. This confirms that a significant portion of the energy savings in the low voltage Eco Classic result from its IR coating.

It also seems likely that the lamp's operation at 12 volts instead of 230 volts leads to significant efficiency gains. Could that input voltage be more important than the IR coating to achieving energy savings? To test this theory, we compared the Eco Classic's total light output and power consumption when its internal power supply was driving first the included IR halogen capsule and then three other 12 volt incandescent sources: two standard halogen lamps and a xenon lamp. We operated each capsule across a range of input voltages on the Eco Classic's power supply, to test performance when dimmed as well.

Additional Samples Tested

Figure 15. Westinghouse Halogen **GE Halogen** **FEIT Xenon**

Table 2. Nameplate Information for the Tested Halogen and Xenon Capsules

Manufacturer	Philips Eco Classic Brilliant (test sample 5)	Westinghouse	GE	FEIT Electric
Type	IR Halogen	Halogen	Halogen	Xenon
Model	252491	04736	97669	BP18XN-12
Watts	20	20	20	18
Life Hours	3000	No product information	2000	No product information
Lumens	370	No product information	No product information	No product information
Voltage	12	12	12	12

Light output levels varied widely (Table 3). Given the similar nominal lamp wattages, this led to similarly wide variations in efficiency levels (Table 4).

This testing confirmed the absolute importance of the capsule's design itself in achieving overall lamp efficiency. Across a wide range of input voltages, the Philips IR halogen capsule achieved an overall efficiency 90 to 120% higher than the least efficient capsule tested (xenon), and about 25 to 35% higher than the second most efficient halogen capsule tested (GE), largely due to its IR coating.

Table 3. Measured Lumen Output with Various Halogen and Xenon Capsules

Line Voltage	Philips IR Halogen	Westinghouse Halogen	GE Halogen	FEIT Xenon
240	408	257	333	165
230	357	220	286	138
220	302	183	246	114
210	257	151	204	96
200	212	123	166	76
190	172	102	134	56
180	130	79	103	48
170	79	48	63	29
160	49	28	36	16
150	26	14	19	8
140	10	5	7	3

Table 4. Measured Luminous Efficacy (lumens/watt) with Various Halogen and Xenon Capsules

Line Voltage	Philips IR Halogen	Westinghouse Halogen	GE Halogen	FEIT Xenon
240	19.78	13.39	15.94	10.45
230	18.52	12.25	14.66	9.46
220	16.9	11	13.51	8.46
210	15.57	9.92	12.10	7.62
200	13.97	8.82	10.72	6.66
190	12.47	7.88	9.46	5.51
180	10.58	6.79	8.04	4.99
170	7.94	4.96	5.96	3.66
160	5.88	3.59	4.18	2.49
150	4.02	2.26	2.67	1.58
140	2.11	1.14	1.31	0.74

Conversely, even the xenon capsule exhibited a strong efficiency advantage over standard incandescent lamps, due to its highly insulating fill gas and low operating voltage. Its efficiency at an output voltage of approximately 12 volts from the power supply (and including losses in the power supply) was about 9.5 lumens/watt – approximately 40% higher than line voltage incandescent lamps of similar light output. This indicated that input voltage plays a significant but not dominant role in improving incandescent lamp efficiency. It also provided an initial indication that the power supply itself in the Eco Classic operates at high efficiency. We next examined that power supply in greater detail.

Does Meeting Class B Require Proprietary Technology?

Low-Voltage Power Supply

The power supply technology developed by Philips is highly efficient, high power factor, and very compact. It converts line voltage ac input into a nominal 12 volt ac output at a nearly constant efficiency of 91 to 93%. The output voltage was not regulated, but rose and fell in proportion to input voltage, allowing for dimming of the lamp. Power supply efficiency and power factor were well-maintained across the normal dimming range.

Table 5. Detailed Dimming Test Results with Philips Eco Classic

Voltage	240	230	220	210	200	190	180	170	160	150	140
Input Watts	20.62	19.27	17.85	16.49	15.16	13.80	12.32	10.01	8.27	6.59	4.77
PS Output Watts	18.99	17.73	16.48	15.27	14.02	12.80	11.42	9.24	7.64	6.04	4.33
Lumens	408	357	302	257	212	172	130	79	49	26	10
PS Efficiency	92%	92%	92%	93%	92%	93%	93%	92%	92%	92%	91%
Luminous Efficacy	19.79	18.53	16.92	15.59	13.98	12.46	10.55	7.89	5.93	3.95	2.1

The power supply is sealed behind a reflective cap and conductive metal base and completely encased in a dark potting compound. Once that material is removed, it is possible to study the circuitry more closely. Two double-sided circuit boards are used—one mounted perpendicular to the other. They employ a mix of through-hole and surface-mounted parts.

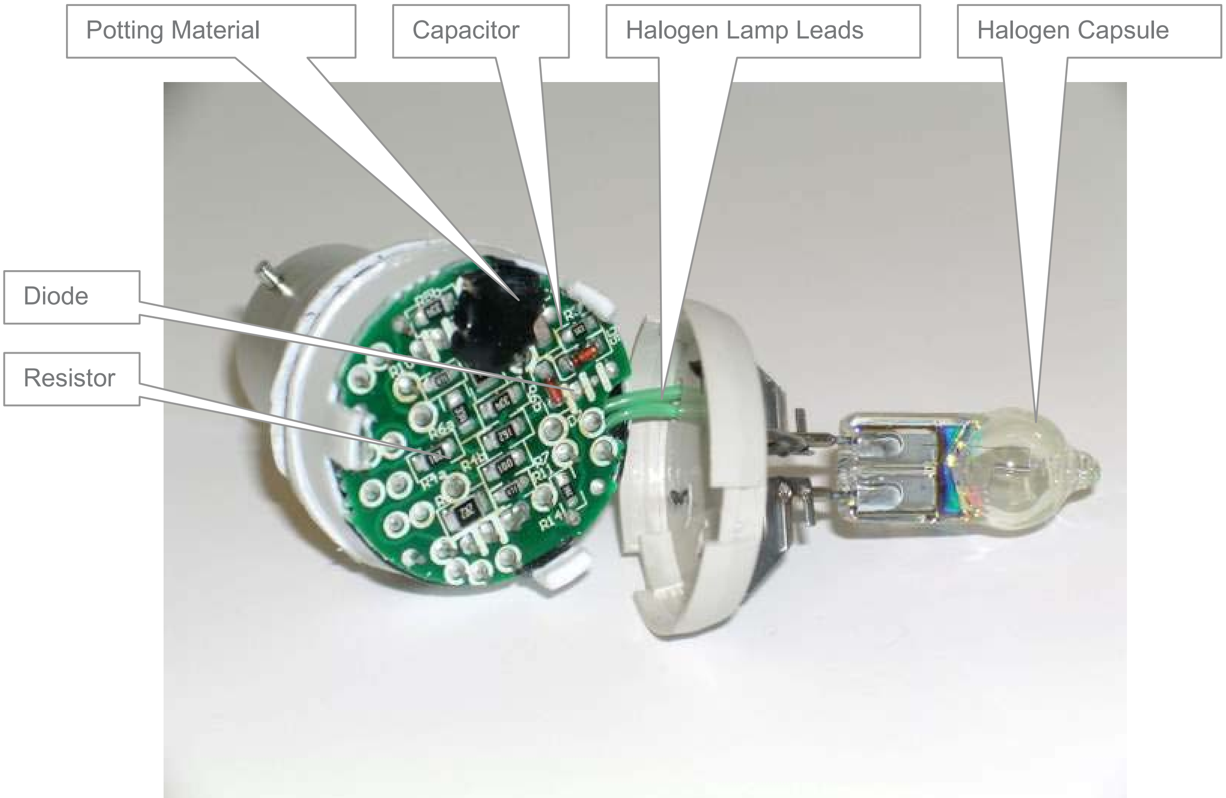


Figure 16. Component Detail Image 1

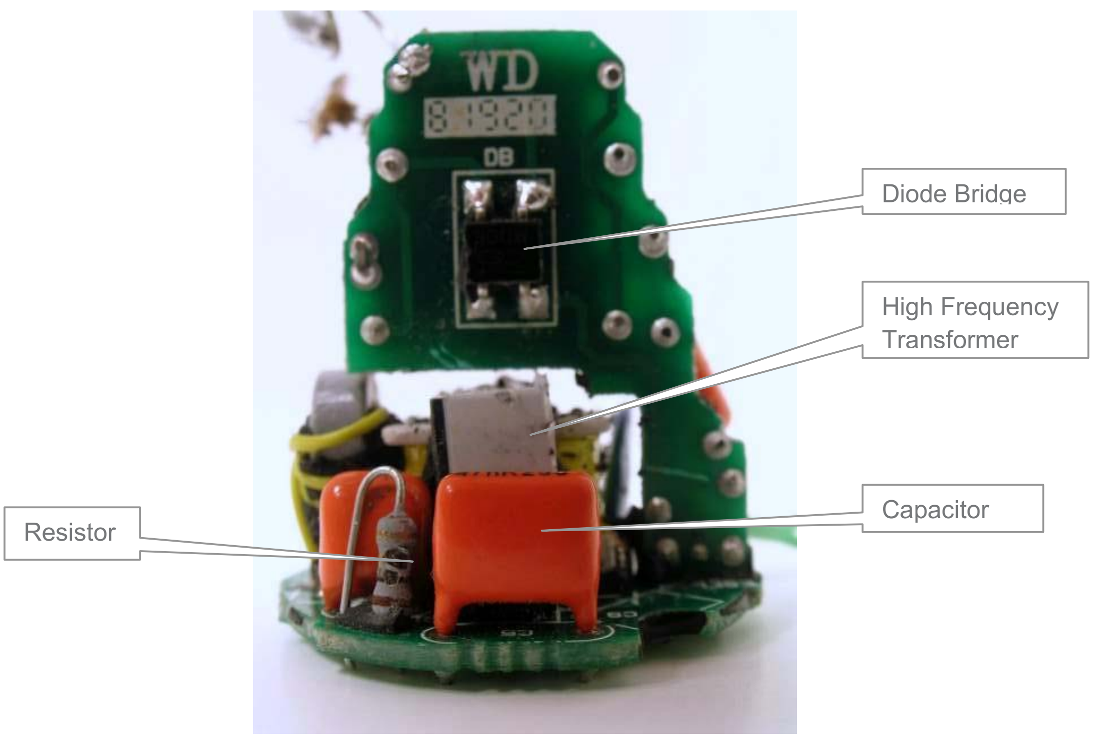


Figure 17. Component Detail Image 2

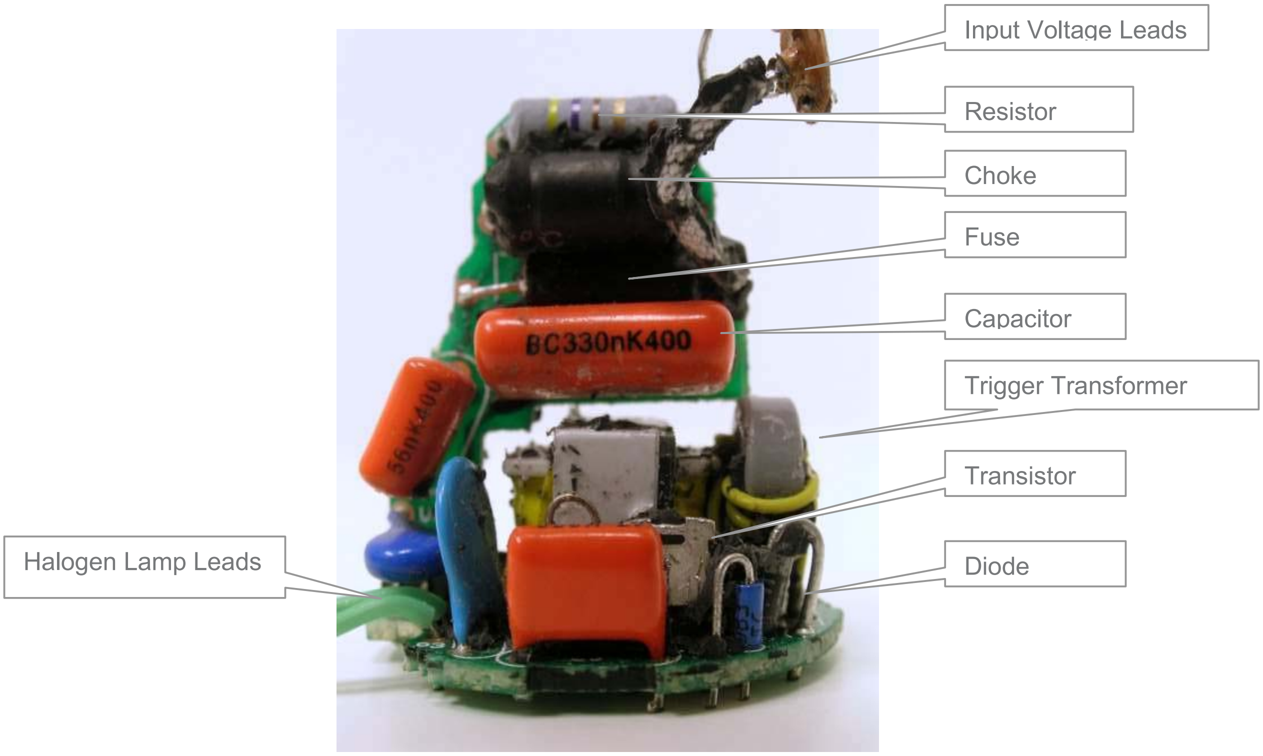


Figure 18. Component Detail Image 3

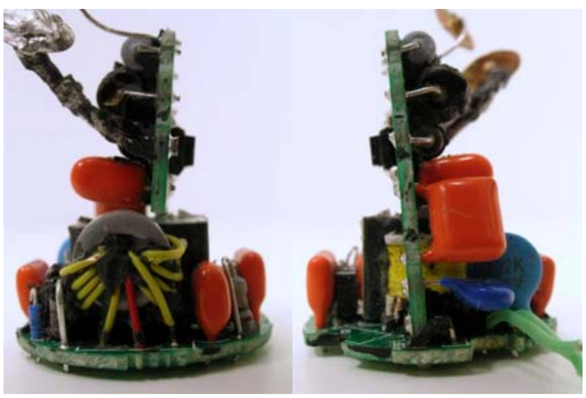


Figure 19. Component Detail Image 4

The power supply design centers around two bipolar DPAK transistors developed by ST Microelectronics: the BULD39D. The basic design of the power supply is spelled out in publicly available application notes for that transistor dating back to 1999, and appears in Figure 20:[8]

[8] P. Fichera and R. Scollo, *Electronic Transformer for a 12V Halogen Lamp*, Application Note, ST Microelectronics, 1999. See http://www.st.com/stonline/products/literature/an/3707.pdf. See also the data sheet for the BULD39D at http://www.stmicroelectronics.com/stonline/products/literature/ds/12333.pdf.

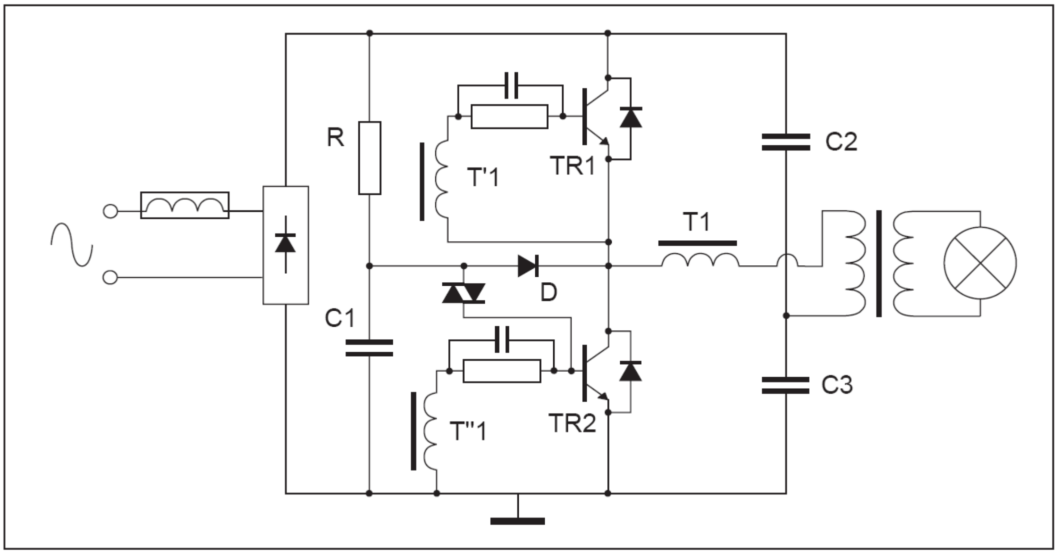


Figure 20. Circuit Diagram for Electronic Transformer for 12V Halogen Lamp

Philips made slight modifications to this circuit, but there are no specialized or proprietary integrated circuits in the power supply. The Philips power supply design is compact but not radical or proprietary in concept. The fundamental design and parts needed to build it have been available for at least nine years. We are aware of no patents on it or other barriers to its replication or modification by Philips' competitors. Moreover, other manufacturers could choose to base their power supply designs around other power transistors or integrated circuits[9] than the STM part depicted. They could also offer higher wattage power supplies embedded in the luminaire itself, remote from the heat output of the associated lamps. This would allow the individual lamps to be higher wattage and brightness without the heat limitations in the Philips power supply design.

Competing small form factor power supply designs exist for compact halogen reflector and desk lamp applications, and are being increasingly developed for low voltage LED applications as well. As a result, the Philips design is replicable by other manufacturers, who may choose to pursue refinements to reduce size and parts count and increase efficiency through greater use of integrated circuitry.

Similarly, the infrared-reflective coating employed is offered in numerous variations around the world by two different subsidiaries of Advanced Lighting Technologies (ADLT) and is manufactured directly by General Electric as well. Figures 21 and 22 illustrate the manufacturing equipment involved in depositing those coatings on halogen capsules, which can be achieved through low pressure chemical vapor deposition or sputtering processes.[10] All three major lamp companies sell halogen capsules coated with this technology.

[9] International Rectifier offers such an IC – the IR2161 – and an accompanying reference power supply design.
[10] Lee Bartolemei, "Advanced Optical Coatings Enable Energy-Efficient Lighting," *The Photonics Solutions Update*, January 29, 2008.

Figure 21. Model 67242 MicroDyn Sputtering Machine Used to Apply the IR-Coating

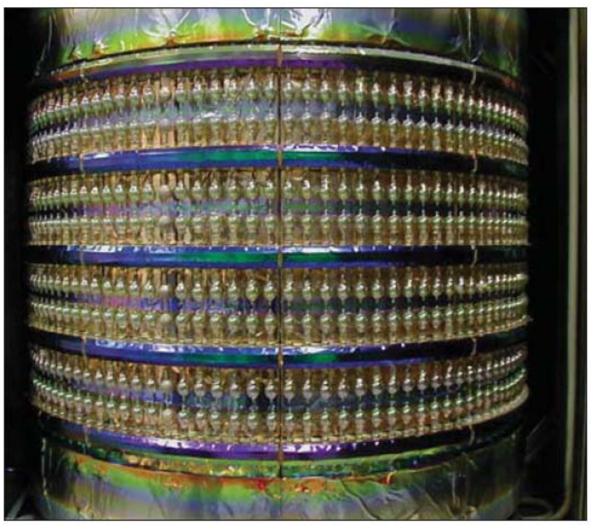


Figure 22. MicroDyn Sputtering Machine Loaded with Halogen Lamps

Based on our own product measurements, a literature review, and conversations with numerous colleagues in the lighting field, we conclude that manufacturers have at least five different technological options (Table 6) for achieving Class B in general service lighting (the second option is discussed more fully in a later section of this report). Among the incandescent options, the Eco Classic products already exist and have been made available in finished retail packaging in limited numbers, but are not yet being widely promoted or offered for sale by Philips in large numbers. These lamps may need to get physically larger to accommodate power supplies capable of handling more than 30 watts and dissipating the resulting heat, but competition among manufacturers to further reduce lamp heat output with better infrared reflective coatings and further reduce power supply heat dissipation through component integration will drive that innovation steadily. Such competition will also help pave the way for widespread availability of affordable, compact, efficient general purpose LED light sources in the future, which can also require small and highly efficient low voltage power supplies.

All of the other options listed are also currently being pursued commercially. Therefore, we conclude that no one proprietary technology is required to achieve Class B. The field is open to intense competition, perhaps more so than ever before, for manufacturers to deliver different mixes of technology, color characteristics, form factor, and lifetime that would meet the new Class B efficiency requirements.

Table 6. Comparison of Class B Qualifying Technologies

Technology	Description	Brand Name / Manufacturer	Currently available in EU	Typical Efficacy at 700 Lumens
IR coated, single-ended halogen capsule	Includes 230 to 12 volt integral power supply	Sold as Philips Eco Classic	In limited quantities	~20 lm/W
Hybrid IR coated, doubled-ended halogen capsule	Bare capsule in prototype form (120 and 12 V)	Deposition Sciences or Auer Lighting coatings applied to other firms' capsules	Prototype only	~29 lm/W
Selective Emitter	Combination of filament coating and fill gas to selectively emit visible light	General Electric, Foster-Miller, Sonsight	No	~30 lm/W
LED	Mostly directional; some general service models emerging	Various	Yes	~11 to 66 lm/W
CFL	Covered and uncovered with integral ballast	All major lamp manufacturers	Yes	~29 to 83 lm/W

Is Class B Cost-Effective?

There are many variables involved in assessing the cost effectiveness of more efficient incandescent lamps. We started with a range of retail prices for conventional 40 watt, 1000-hour incandescent lamps in the UK: €0.20 to €0.60 (according to Defra staff). We then determined the retail price range for line voltage halogen lamps in Europe: €2.33 to €3.50 (converted from publicly quoted prices for these lamps in the UK). Line voltage halogen lamps can last for 2000 to 3000 hours, depending on design (we assumed 3000 hours). Therefore, one halogen lamp replaces three conventional incandescents, but costs more than purchasing those three lamps, yielding an incremental retail cost.

How much more would it cost to upgrade existing line voltage halogen lamps to include a low voltage power supply and Deposition Science's hybrid IR coating on a double-ended capsule? To find out, we disassembled one of the Philips Eco Classic units to determine how its power supply operates and itemize the parts employed in its design. We gathered input from three different industry experts who requested that their identities be kept confidential, due to the sensitive nature of the competitive analysis.

The cost of the parts in this power supply depends greatly on whether the unit is manufactured in small quantities in Eastern Europe with a mix of surface-mount and through-hole parts, or manufactured in large quantities in Asia (product packaging indicates a manufacturing location of China). In production volumes of tens of millions of units or more, we estimate an Asia-price bill of materials (BOM) of €0.69 for the circuit boards, wiring, capacitors, inductor, varistor, fuse, trigger transformer, conventional transformer, diodes, transistors, and resistors found in this power supply. If manufacturing continues at a much smaller scale in Europe, the BOM would be about 50 to 70% higher according to the industry experts we consulted. Standards and labeling programs that greatly increase sales of these products would have the effect of reducing their price toward the lower value by ensuring economies of scale in manufacturing and shipping.

Similarly, the plastic and reflectorized parts found in the Eco Classic appear to represent an incremental cost of approximately €0.05 to €0.15 over conventional line voltage halogens. There may be other modest incremental costs or savings associated with the wiring, globe, and lamp-mounting components themselves, and the associated assembly processes. This is difficult to estimate precisely, since some of the parts needed to mount and secure a single ended or double ended line voltage halogen capsule are not needed in low voltage designs, and there are also differences in fill gas components and amounts.

Deposition Sciences estimates the incremental cost of coating 50 to 100 million halogen capsules per year at approximately €0.20 apiece, including the amortized cost of the sputtering coating systems shown above, the titanium and silicon-based coating materials, and the electricity costs to operate the production equipment.[11]

Manufacturers that plan to produce such lamps in large volumes for worldwide use would find purchasing this equipment and operating it in their own factories the lowest cost approach. Smaller manufacturers can contact Auer Lighting in Germany to request quotes on a per-lamp basis for coating services, avoiding the capital outlay associated with purchasing the sputtering machines.[12] We conservatively estimate a range of incremental costs for that coating process, depending on production volumes, of €0.20 to €0.68, relative to conventional uncoated double-ended halogen capsules.

In total, this yields a range of manufacturing costs for the needed materials and components from €0.94 to €2.00, depending on design approach taken, production volume, exchange rates, and other uncertainties. We then employed a range of manufacturer and retailer markups to those costs, drawing from recently published gross margin estimates for the three largest lighting manufacturers (Philips, General Electric, and Siemens), and three of the world's largest lighting retailers (Wal-Mart, Home Depot, and Lowe's). The cumulative markups ranged from 63% to 101%.[13]

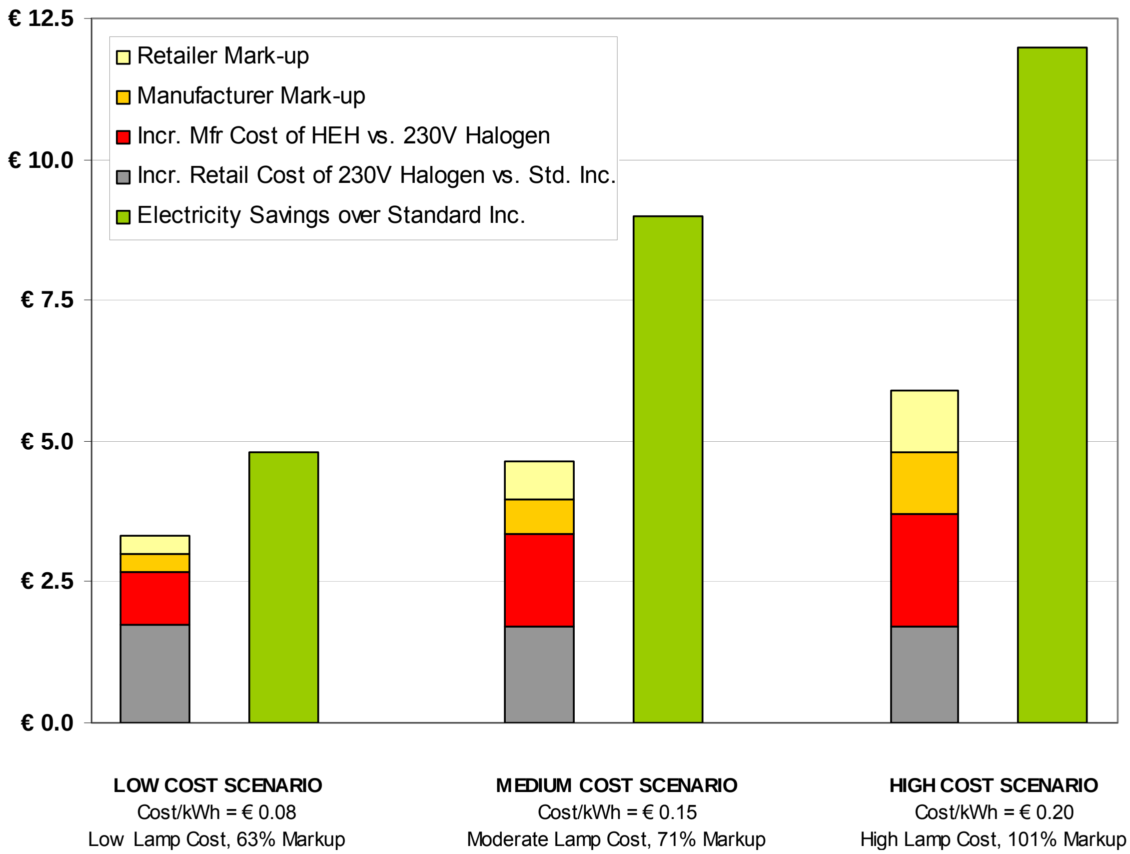
This leads to a retail price range (Figure 23) for the finished product between €3.93 and €7.69, again depending greatly on production volumes. This represents an incremental cost of €3.33 to €5.89. By contrast, the electricity savings relative to conventional incandescents are worth €4.80 to €12.00, depending on the typical electricity price paid in various parts of Europe. This means the electricity savings are much higher than the incremental lamp costs in our low, medium, and high scenarios. In fact, the low range of electricity savings is slightly greater than the medium range of incremental costs, and the medium range of electricity savings is far greater than the high range of incremental costs.

---

[11] Personal communication with Bob Gray, Deposition Sciences, November 6, 2008.

[12] Contact Uwe Fickel, International Sales Manager General Lighting, Auer Lighting, email address: uwe.fickel@auer-lighting.com.

[13] See http://www.marketwatch.com/tools/quotes/profile.asp?symb=SI (or PE or GE), http://www.wallstreet-online.de/diskussion/218439-neustebeitraege/warum-home-depot-trotz-des-kurses-eine-gute-anlage-ist, and http://barelkarsan.com/2008/08/home-depot-vs-lowes.html.



	Low	Medium	High
Cost/kWh	€ 0.08	€ 0.15	€ 0.20
Retail Mark-up	€ 0.34	€ 0.66	€ 1.09
Manufacturer Mark-up	€ 0.33	€ 0.61	€ 1.10
Incremental Manuf. Costs for HEH vs. 230V Halogen	€ 0.94	€ 1.65	€ 2.00
Incremental Retail Cost of 230V Halogen vs. Standard Incandescent	€ 1.73	€ 1.71	€ 1.70
Electricity Savings over Standard Incandescent (3,000 hours)	€ 4.80	€ 9.00	€ 12.00

Figure 23. Comparison of Consumers' Incremental Costs for High-Efficiency Halogen Lamps to the Value of Electricity Savings over 3,000 Hours of Use (all costs and benefits in Euro)

These findings are conservative in three key ways:

- Savings were calculated used a conventional 40 watt incandescent lamp as the base case. Starting with a 60 watt conventional lamp would yield greater energy savings for virtually the same incremental cost.
- Savings were calculated on the basis of single-ended lamp technology and IR coatings, even though double-ended lamp technology with hybrid IR coatings yields greater efficiency gains.
- The medium cost scenario's electricity prices are typical of the weighted average for Europe, yet the low cost scenario's incremental costs are the most likely once the product reaches large production volumes.

As a result, we believe the most likely outcome is one in which the value of the lifetime electricity savings from a Class B-compliant lamp is at least twice its incremental cost.

Can the EU Achieve Savings Beyond Class B with Incandescent Technologies?

As noted in Table 6 above, recent developments with advanced incandescent lamp technologies have made it possible to achieve significantly greater efficiencies than the Philips Eco Classic product. While no samples of the selective emitter technology were yet available for testing in our laboratory, we did have the opportunity to investigate a double-ended halogen capsule with advanced IR coatings.

Next Generation Designs

Deposition Sciences recently began to investigate the additional energy savings that could be obtained by applying its most advanced ("hybrid') infrared-reflective coating not to the single-ended low voltage halogen capsules employed in the Eco Classic, but to a series of 60 watt double-ended halogen capsules intended to operate on 120 volts ac. While double-ended halogen lamps cost slightly more to manufacture than single-ended models, they offer important efficiency advantages. They make it easier to achieve precise geometric centering of the filament relative to the infrared-coating around it, and they can reduce the coating-to-filament distance, increasing effectiveness.[14]

These samples have been sent to the Lighting Research Center and to Ecos Consulting's laboratory for assessment. In Figures 24 (right-hand image) and 25, note the similarity in appearance to the Philips double-ended capsule from the Halogena Energy Saver product currently sold in the U.S. The left-hand image in Figure 24 is a close-up of the halogen capsule used in the Eco Classic 20 watt product.

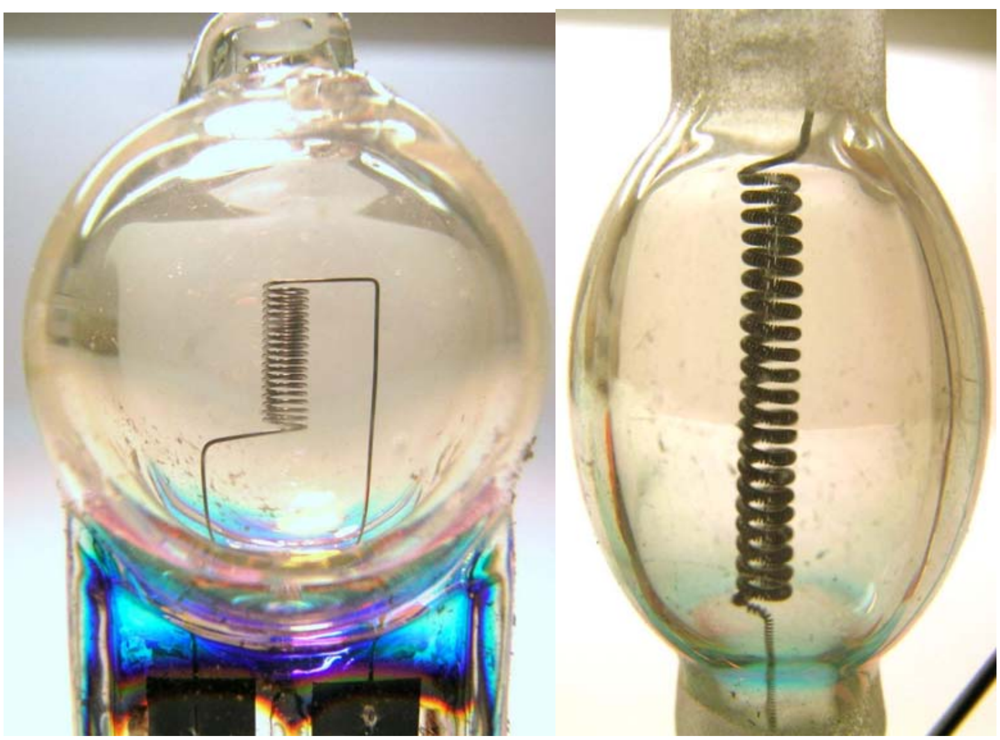


Figure 24. Comparison of Single- and Double-Ended Filaments in Halogen IR Capsules

[14] Note in the photographs that the single ended capsule is roughly spherical, yet its filament is linear, so the geometry does not allow symmetrical reflection of heat. The double ended capsule is elliptical, its support wires are shorter and centered, and the distance from the capsule wall to the filament is shorter. All of these design features help to improve efficiency.

Figure 25. Double-Ended Halogen Capsule from the Philips Halogena Energy Saver

Our laboratory testing confirmed Deposition Sciences' claim of 38 lumens/watt for this product. It achieved 40.2 lumens/watt after warm-up when operated in a vertical orientation and 36.8 lumens/watt after warm-up when operated in a horizontal orientation. Allowing for modest electrical losses in a threaded base and fuse, as well as optical losses through a transparent enclosure, 38 lumens/watt would be a reasonable estimate for the efficiency of a finished 60 watt lamp incorporating this technology when operated vertically. The same technology can be applied to brighter or dimmer configurations, and would be expected to achieve approximately 30 lumens/watt at 800 lumens.[15]

The spectral distributions for this capsule at various input voltages are shown in Figure 26. Note that infrared emissions (>800 nm) are approximately 70% lower than the peak emissions in the visible spectrum, confirming the high effectiveness of this infrared-reflective coating.

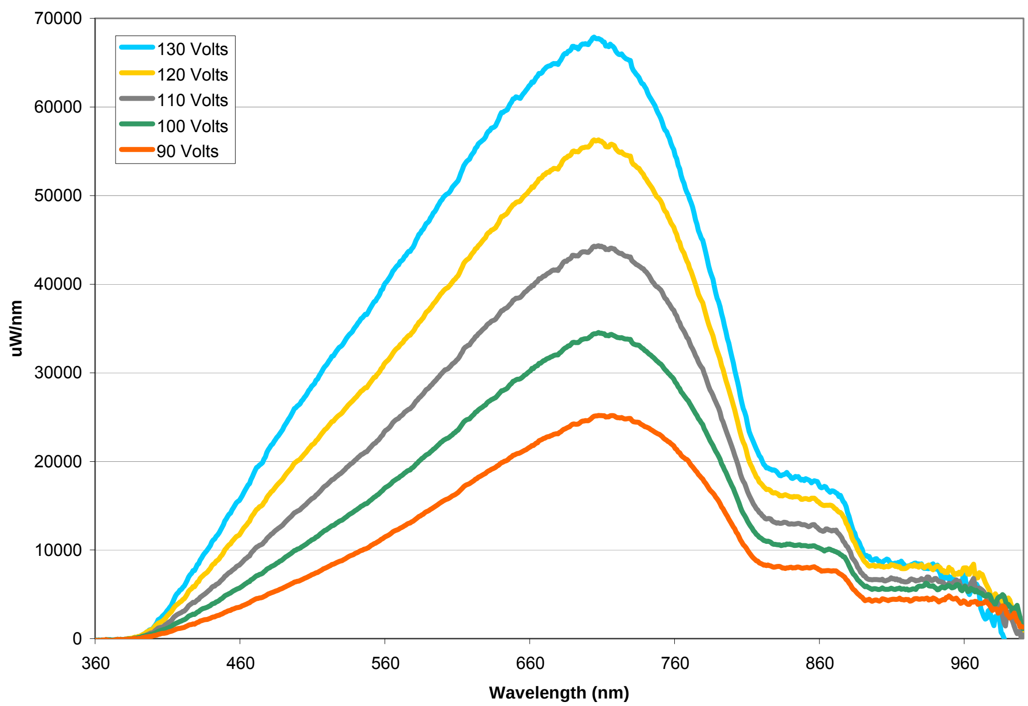


Figure 26. High-Efficiency Hybrid Coated Double-Ended Halogen Capsule (Vertical)

[15] Personal communication with Bob Gray, Deposition Sciences, November 6, 2008.

The challenge of translating these results into 230 volt operation is that the filaments become too long and thin at 230 volts for the infrared-reflective coatings to achieve precise reflections and still maintain sufficiently long lamp lifetimes. Instead, a compact power supply technology similar to that used by Philips in its Eco Classic product would be employed to step the operating voltage down to at most 120 volts and preferably 12 volts ac. This would permit the filament to be shorter and thicker, increasing lamp life and providing a better "target" at which the infrared-reflective coating could direct reflected heat.

The efficiency gains achieved by moving from 120 volts to 12 volts would be roughly comparable to the 8% electrical efficiency losses we have measured in the Philips power supply, causing the two effects to approximately cancel.[16] We have tested the Philips power supply when operating with 20 watts of input power, and understand that a similar version is being developed that can accept up to 30 watts of input power. Apparently, size constraints of the volume beneath the halogen capsule and thermal constraints associated with the power supply's own heat dissipation and the proximity to the heat from the light source prevent the use of power supplies larger than 30 watts of the present design.

However, applying the more efficient coating to a double ended halogen capsule would allow such a 30 watt product to achieve approximately 900 lumens – comparable to the light output of present 75 watt standard incandescents. The hybrid infrared reflective coating greatly reduces heat output as well, allowing sensitive electronics to operate in close proximity without as much risk of early failure as would happen in a less efficient lamp design. Additional heat sinking could be incorporated into the base with the potting compound already employed, if needed, in lieu of the plastic currently used.

As shown in Figure 27, the new Deposition Sciences products are radically more efficient than other incandescent lamp technologies in the market today. Even accounting for losses in the power supplies needed to operate them at lower voltages, we believe these products would perform at far higher efficiencies than the Class B currently proposed in Europe.

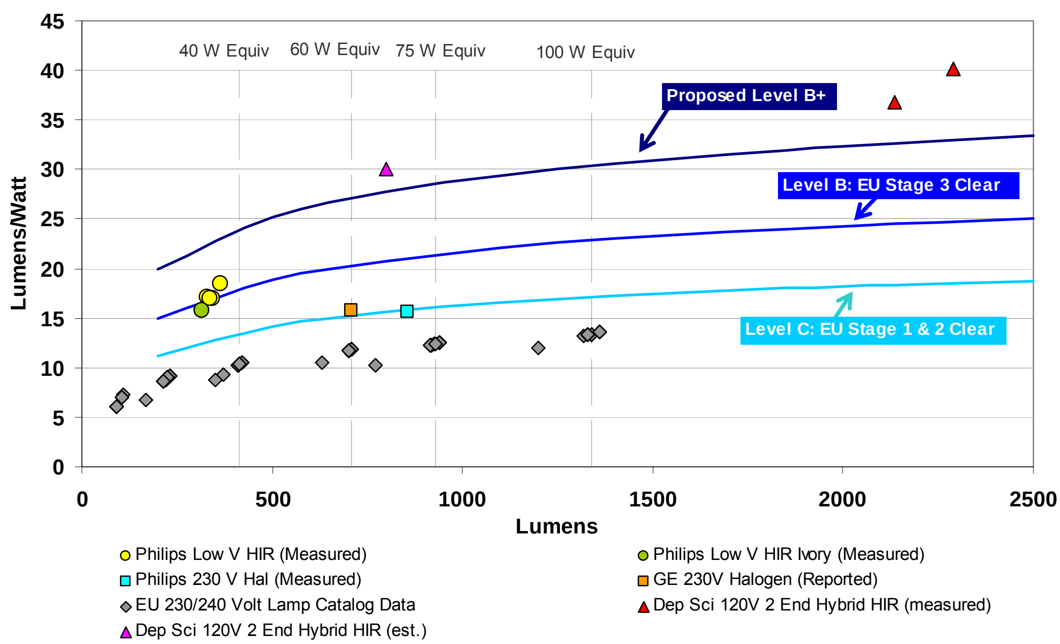


Figure 27. Proposed "Class B+", with Qualifying Prototype Products

[16] This is an estimate which needs to be validated through construction and measurement of prototypes operating at 12 volts and a wide range of lumen output levels.

We propose that the EU consider establishing a new labeling class (called "Class B+" in the figure below)[17] to recognize these highly efficient coated halogen technologies, as well as the selective emitter technology (roughly 30 lumens/watt for 60 watt equivalent lamps) under development at General Electric and other manufacturers. These products deserve a market advantage relative to more conventional Class B incandescents, and bring with them correspondingly higher energy savings at modest incremental cost. Such a "B+ class" would also acknowledge that LED and CFL products not yet able to meet Class A still confer significant energy savings relative to Class B products.

Recent measurements of screw-based LED products in the U.S. and the ENERGY STAR data set of more than 2,000 labeled CFL models indicate the wide range of choices manufacturers have for meeting that "Class B+" as well as Class A.[18] As LED products continue to improve in light output, color quality, efficiency, and cost, they will figure increasingly prominently in future data sets of general purpose light sources, and lead the way toward efficiency levels beyond the current Class A.

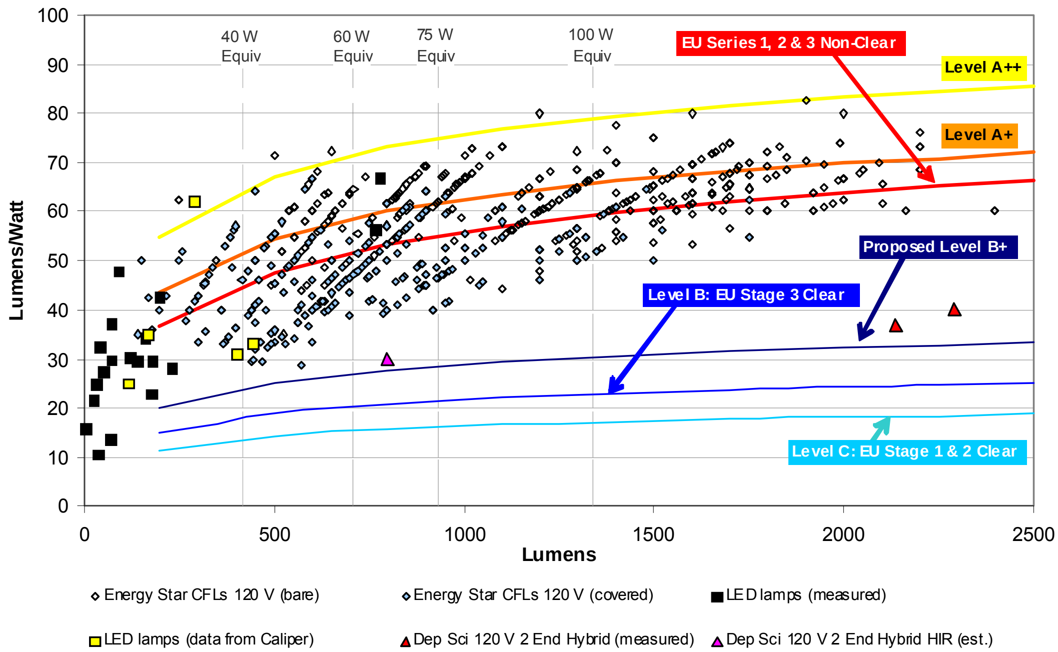


Figure 28. Proposed EU classes "A++" through C and the New Proposed "Class B+" Compared to Existing CFL and LED Products

Can Manufacturers Meet the Proposed Standards already by 2012?

Recent updates to draft Eco-design requirements propose phasing in those requirements over a period of years for various light output levels. This would not require all major incandescent products

[17] The proposed equation for "Class B+" follows the format of the other proposed Eco-design equations, with a different initial coefficient: 0,45 x (0,88√Φ+0,049Φ). The minor adjustments proposed to the Eco-design requirements for the use of a power supply or globe enclosure are not shown.

[18] The LED and CFL data sets are for 115 volt products, but differences in operating efficiencies at that voltage are small for LED and CFL products compared to incandescent products.

to achieve Class B until 2016. The prior draft proposed a date of 2013 for such compliance. Given the widespread availability of compact power supply components and circuit designs, and the fact that such power supplies can be assembled into finished lamps in Asia or shipped to Eastern Europe for final assembly there, the likely increase in demand for power supplies is not by itself a reason to extend lead times for implementing the Eco-design requirements.

Single-ended and double-ended halogen capsules are also widely available and already being manufactured by a host of companies in various sizes, wattages, form factors, and input voltages. Therefore, it is not clear that the need to shift from conventional incandescent lamp manufacturing processes to a halogen capsule-based process would require an additional four years.

What about the infrared-reflective coatings process? Could the principal limitation to achieving an earlier compliance date be the time required to employ infrared-reflective coatings in current halogen lamp designs? Deposition Sciences is currently quoting lead times of less than 12 months between the receipt of orders for coating equipment and its successful installation and commencement of operation in customer factories. Similarly Auer Lighting in Germany is prepared to coat other manufacturers' capsules on a per-piece basis, without the lead times associated with installing new equipment in their existing factories.[19] Thus, if anything, it seems evident that the originally proposed 2013 date is eminently achievable for Class B, and that some manufacturers would use the time between now and then to go beyond Class B to achieve a "Class B+" if such a marketing advantage were offered.

Likewise, while the selective emitter technology developers have not yet committed to a date for commercial introduction, the 2012 deadlines already enshrined in California and Nevada general service lighting efficiency regulations, U.S. federal regulations, and near-final Canadian regulations give them ample incentive to bring such a product to the world market by that time. This technology has the potential to be even less expensive and more energy efficient than the IR halogen technology over the long term, depending on the materials employed, the fill gas chosen, and the final design approach taken. As a result, we recommend that the European Union not delay the implementation date of its Class B requirements beyond the 2013 date originally proposed.

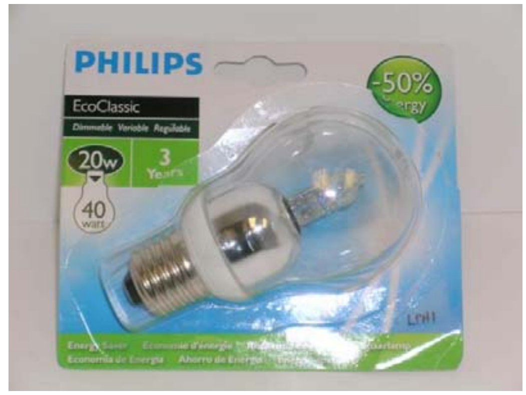
[19] Personal communication with Bob Gray, Deposition Sciences, November 6, 2008.

Appendix: Measurement Data

Test Sample 1

Nameplate Information

Philips Eco Classic Brilliant
Model 250169
20W
3000 Hours
370 Lumens
230V 50Hz



Initial Lumens Data Measurement

Ambient Temperature: 77°F
Voltage used for measurement: 230V / 50Hz

Measured Values
Watts: 19.87
Power Factor: 0.952
Color Rendering Index: *Ra* 98.57

Minutes	1	2	3	4	5	10	15	20	25	30
Kelvins	2851	2846	2842	2841	2843	2847	2849	2851	2851	2852
Lumens	366	365	366	368	370	378	381	382	384	385

Lumens Data Measurements after 100 hour Break-in

Measured Values
Watts: 19.79
Power Factor: 0.956
Color Rendering Index: *Ra* 98.71

Minutes	1	2	3	4	5	10	15	20	25	30
Kelvins	2877	2871	2869	2867	2867	2866	2865	2865	2863	2864
Lumens	402	399	398	398	398	400	400	400	400	400

Test Sample 2

Nameplate Information

Philips Eco Classic Brilliant
Model 250169
20W
3000 Hours
370 Lumens
230V 50Hz

Initial Lumens Data Measurement

Ambient Temperature: 77°F
Voltage used for measurement: 230V / 50Hz

Measured Values
Watts: 20.21
Power Factor: 0.950
Color Rendering Index: *Ra* 98.52

Minutes	1	2	3	4	5	10	15	20	25	30
Kelvins	2809	2804	2804	2805	2806	2808	2808	2807	2808	2809
Lumens	344	342	344	345	346	350	352	353	353	353

Lumens Data Measurements after 100 hour Break-in

Measured Values
Watts: 20.21
Power Factor: 0.953
Color Rendering Index: *Ra* 98.47

Minutes	1	2	3	4	5	10	15	20	25	30
Kelvins	2824	2823	2822	2822	2821	2821	2819	2819	2819	2819
Lumens	370	369	368	368	368	368	369	369	369	369

Test Sample 3

Nameplate Information

Philips Eco Classic
Model 251999
53W
2000 Hours
850 Lumens
230V 50Hz

Initial Lumens Data Measurement

Ambient Temperature: 77°F
Voltage used for measurement: 230V / 50Hz

Measured Values
Watts: 54.57
Power Factor: 1.000
Color Rendering Index: *Ra* 99.62

Minutes		1	2	3	4	5	10	15	20	25	30
Kelvins		2842	2842	2842	2843	2843	2844	2846	2846	2847	2846
Lumens		856	858	859	859	860	864	867	868	872	873

Lumens Data Measurements after 100 hour Break-in

Measured Values
Watts: 54.42
Power Factor: 1.000
Color Rendering Index: *Ra* 99.68

Minutes		1	2	3	4	5	10	15	20	25	30
Kelvins		2847	2846	2846	2845	2846	2845	2847	2848	2848	2849
Lumens		866	867	868	868	870	872	875	875	877	878

Test Sample 4

Nameplate Information

Philips Eco Classic Ivory
Model 250206
20W
3000 Hours
310 Lumens
230V 50Hz

Initial Lumens Data Measurement

Ambient Temperature: 77°F
Voltage used for measurement: 230V / 50Hz

Measured Values
Watts: 20.12
Power Factor: 0.952
Color Rendering Index: *Ra* 99.10

Minutes		1	2	3	4	5	10	15	20	25	30
Kelvins		2582	2579	2578	2578	2578	2579	2583	2585	2584	2588
Lumens		316	315	316	316	317	318	320	321	321	321

Lumens Data Measurements after 100 hour Break-in

Measured Values
Watts: 20.08
Power Factor: 0.954
Color Rendering Index: *Ra* 99.96

Minutes		1	2	3	4	5	10	15	20	25	30
Kelvins		2644	2641	2634	2635	2636	2648	2651	2651	2651	2651
Lumens		333	330	323	323	324	339	342	343	344	345

Test Sample 5

Nameplate Information

Philips Eco Classic Brilliant
Model 252491
20W
3000 Hours
370 Lumens
230V 50Hz

Initial Lumens Data Measurement

Ambient Temperature: 77°F
Voltage used for measurement: 230V / 50Hz

Measured Values
Watts: 19.28
Power Factor: 0.941

Minutes	1	2	3	4	5	10	15	20	25	30
Kelvins:	2763	2764	2765	2765	2769	2774	2776	2776	2777	2778
Lumens:	330	335	337	340	342	351	354	357	359	360

Color Rendering Index: *Ra* 99.64

Lumens Data Measurements after 100 hour Break-in

Measured Values
Watts: 19.27
Power Factor: 0.935

Minutes	1	2	3	4	5	10	15	20	25	30
Kelvins:	2762	2762	2763	2762	2765	2778	2778	2779	2778	2778
Lumens:	340	343	344	348	349	357	360	363	363	364

Color Rendering Index: *Ra* 99.71

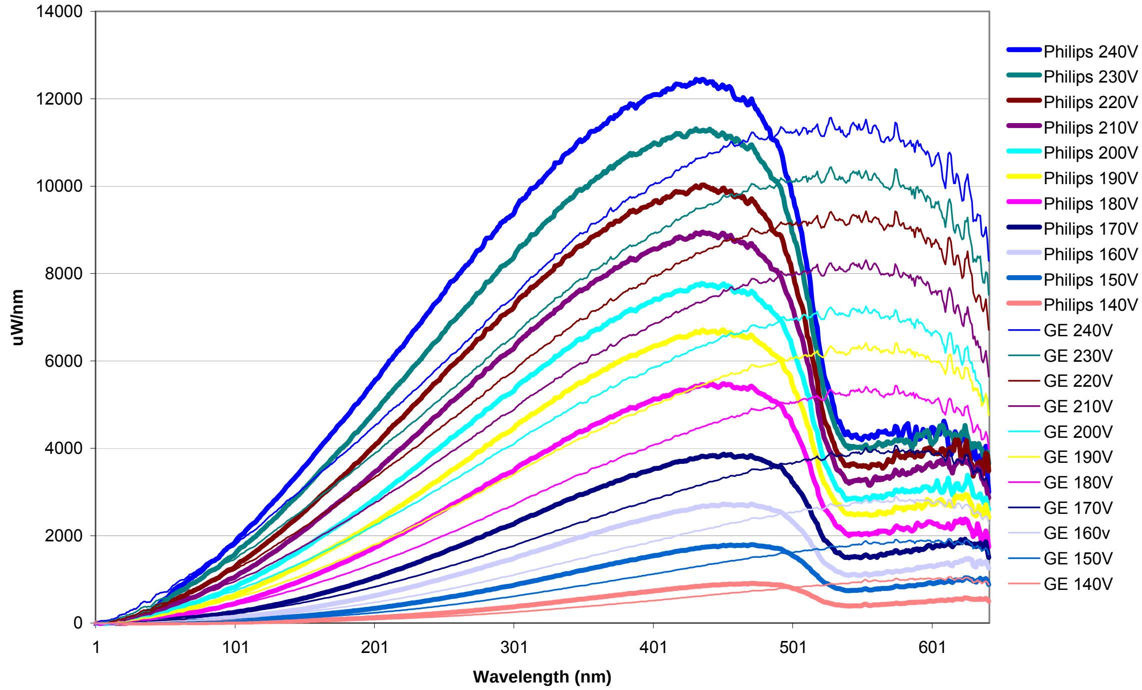


Figure 29. Philips EcoClassic and GE Spectral Scan: Dimming from 240 V to 140 V