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ON THE SUBSTITUTION OF INCANDESCENT LAMPS BY COMPACT FLUORESCENT LAMPS: SWITCH ON BEHAVIOUR AND PHOTOMETRIC DISTRIBUTION

B. Roisin[a], M. Bodart[b], A. Deneyer[c], P. D'Herdt[c]

[a]Université Catholique de Louvain (UCL), Unité d'Architecture, Place du Levant, 1, B-1348 Louvain-La-Neuve, Belgium.
[b]Fond National de la Recherche Scientifique (FNRS), Université Catholique de Louvain (UCL), Unité d'Architecture, Place du Levant, 1, B-1348 Louvain-La-Neuve, Belgium.
[c]Belgian Building Research Institute (BBRI), Division of Energy and Climate, Avenue Pierre Holoffe, 21, 1342 Limelette, Belgium.

Abstract

When considering the replacement of incandescent lamps by screwbase integrated compact fluorescent lamps (CFLs), we must ensure that the CFL will provide satisfaction to the users in order to avoid the hark-back to the inefficient technology of incandescent lamps. One of the possible reasons of the users' disappointment is the perception of the quantity of the luminous flux of these lamps. The first cause of this bad perception is the lamp photometric distribution which can affect the illuminance of the task areas and the background environment. The second is the time it takes before the nominal flux of the lamp is reached.

The first objective of this paper is to analyze the time required for different CFL to reach their nominal flux. While some lamps start rapidly (1.5 minutes to reach 90% of the nominal flux), others require a very long delay to reach their nominal flux and to stabilize (more than 15 minutes to reach 90% of the nominal flux). This delay is difficult to foresee and differences appears even for same type of lamp (model and brand), for different powers.

The second objective of this paper is to determine the photometric distribution of various types of CFLs. While quad and three tubes lamps have very different photometric curves (radiating more horizontally than vertically) compared to incandescent bulbs, the photometry of CFL with bulbs is very similar to the photometry of incandescent lamps. Simulations of these lamps placed in a room were carried out and they did not show great variations of the room illuminance, for the different lamps.

Keywords: Compact fluorescent lamp; Photometric distribution, Warm-up time, Energy savings.

INTRODUCTION

The use of screwbase Compact Fluorescent Lamps (CFLs) can reduce drastically the lighting consumption of dwellings. The replacement of standard incandescent bulbs (GLS) by CFLs can enhance the luminous efficacy by about 75%, resulting in a reduction of the lighting installed power and, therefore, of the consumption. But beside all the advantages of CFLs (high efficacy, longer lamp life time), some barriers have impeded their spreading. These barriers were flashing and flickering, noise, warm-up time, cost, lifetime, size, colour and light output equivalent [1]. These last years, lots of improvements have been made to reduce the size and by now, nearly all CFLs are using electronic ballasts reducing thus flickering and noise [2]. The cost is not a really relevant problem because, as CFLs have a lifetime much higher and consume less than traditional incandescent lamps, the return of investments on CFL is quite short [3]. The resulting mains barriers are thus lifetime, colour, warm-up time and light output equivalent.

Some studies focus on these points. In [4], Serres analysed the stabilisation time of integrated CFLs. He concluded that some CFLs should be operated for more than 2 hours to reach their nominal flux. However, his study is quite old and evolution on CFLs these last 10 years are huge. The study on the distribution of different CFLs for a table lamp is performed in [5]. The conclusions are that the lamp position and geometry can have a significant effect on the light output, distribution and shade losses. In [1], the colour and the warm-up time of different CFLs were measured. For the colour, results show that colour temperature and chromaticity coordinates can vary widely. These variations have been found between manufacturers but also within manufacturers' own CFL product line.

Concerning the warm-up time, all the tested lamps needed less than 23 seconds to reach 80% of their nominal flux.

The objective of this paper is to analyse two of these four barriers; the warm-up time and the photometric distribution of different kinds of compact fluorescent lamps.

In the first part, the measurement method and material are presented, ass well as the tested lamps. The second part presents the results of these measurements. Analysis of these results leads to some advices to replace incandescent lamps by CFLs.

MATERIALS AND METHODS

This section presents the tested lamps and the methodology to measure their photometric distribution and their warm-up time.

Lamps tested

During this study, 12 lamps (10 CFLs and 2 incandescent lamps also called General Lighting Services - GLS) were analyzed. These lamps can be sorted according to their shape and power. Table 1 presents the different sorts of lamps tested.

Table 1: Descriptions of the tested lamps

Acronym	Name	Shape	Power	Warm-up
MCE	Megaman Cat's Eye	Globe with Phosphores-cent coating	11W	/
MCR	Megaman Compact Reflector	Reflector	7W	/
OF	Osram Facility	Triple tubes	14W	Quick start
PG	Philips Genie	Triple tubes	11W 15W	/
PS	Philips Softone	Globe	12W 20W	/
PT	Philips Tornado	Twisted tubes	20W	/
SBS	Incandescent Sylvania Brilliant Satin	GLS frosted bulb	60W	/
SCC	Incandescent Sylvania Classic Clear	GLS clear bulb	60W	/
SML	Sylvania Mini-Lynx	Quad	11W	Fast start
SML	Sylvania Mini Lynx	Triple tubes	15W	Fast start

Photometric bench

Measurements were carried out on a test bench in a black room (see Fig. 1). The bench consists of an illuminance meter (Hagner EC1-X) placed on a mobile carriage; a lamp socket on a stand with 2 orthogonal axes of rotation and of shielding screens to avoid external reflections.

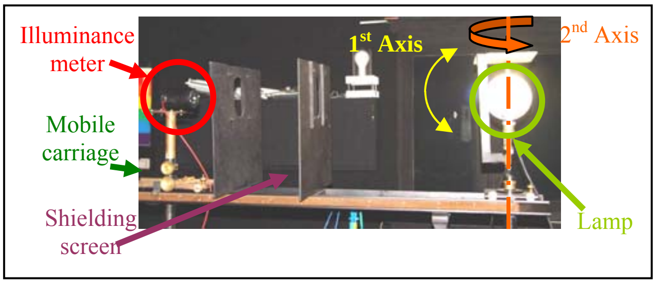

Fig. 1: The photometric bench

The relation between the measured illuminance and the lamp intensity is given by the following relation:

$$E = \frac{I\cos(\theta)}{d^2} \qquad (1)$$

where E is the illuminance, I the intensity, d the distance between the lamp and the receiving surface and θ the angle between the normal of the receiving surface and the direction of emission. In our case, *d* was fixed to 1m and $\cos(\theta) = 1$.

Warm-up time measurement

Before testing, the lamps were seasoned 100h in vertical base-down position [6].

Illuminance measurements are taken every 10s after switching on the lamp. The measurement stops when there were no significant changes in the values within 1 minute. The values of illuminance during the warm-up can be divided by the nominal value (value after warm-up) in order to get the relative flux.

Photometric measurement

To obtain the photometric distribution of the lamps, values of intensities were obtained for different angles following the two axes of rotation of the lamp (see Fig.1). Elevation (θ) was varied by steps of 10° from 0 to 180°. Azimuth (φ), was varied by steps of 45° from 0 to 360°. Fig. 2 shows the two angles for the lamp *"Sylvania Classic Clear"*.

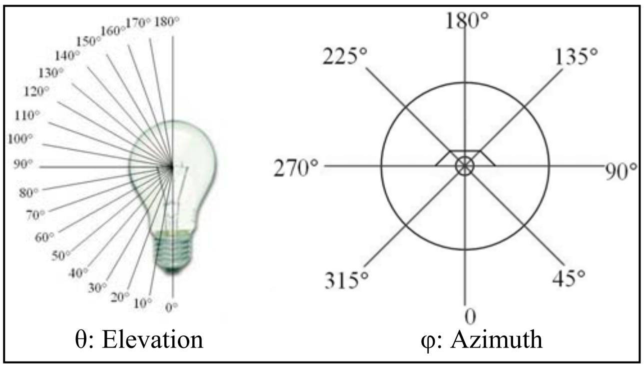

Fig. 2: Elevation and Azimuth angle for the "Sylvania Classic Clear" lamp

With these values, the 3D photometric distribution is represented by 138 points and the photometric curves can be traced for the C0-C180, C45-C225, C90-C270 and C135-C315 planes.

Values of intensities can also lead to the calculation of the luminous flux of the lamps. This calculation is made by spherical integration. The relation between flux and intensities is:

$$\Phi = \iint_{4\pi} I d\omega \qquad (2)$$

where Φ is the luminous flux and I the intensity. Eq. 2 can be written using the Azimuth and Elevation:

$$\Phi = \int_{\theta=0}^{\pi} \int_{\varphi=0}^{2\pi} I(\varphi,\theta) d\varphi \sin\theta \, d\theta \qquad (3)$$

Top-Side-Bottom contributions

Another representation of the photometric distribution of the lamps can be made. For each lamp, the intensity diagram can be divided in three areas: the top section, the bottom section and the side section (see Fig. 3). The top section is the area delimited by elevation angles from -60° to +60°. The side section is the area delimited by angles of elevation from 60° to 120° and from 240° to 300°. The bottom section is the area between 120° and 240° of elevations.

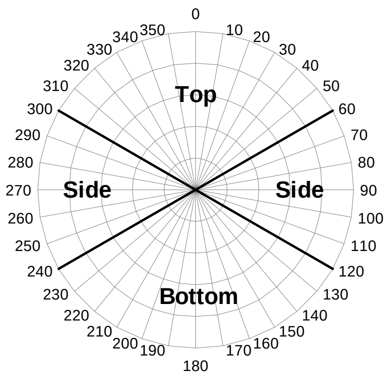

Fig. 3: Top-Side-Bottom representation

The light contribution can be calculated for each of these sections. This contribution is computed by calculating the area of the photometric curve comprised in each section relatively to the total area of the curve. This representation, which we called Top-Side-Bottom (TSB) gives an idea of the type of lamp distribution; an isotropic source has a TSB of 33-33-33 while an ideal narrow reflector lamp will have a TSB of 0-0-100.

RESULTS

Warm-up time

The following figures (Fig. 4 and Fig. 5) present the relative output flux after switching on the lamps.

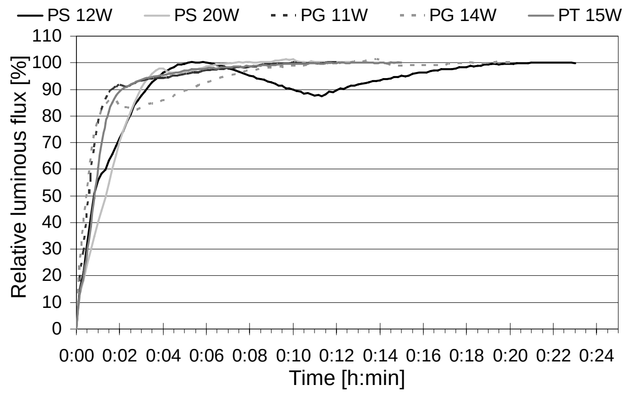

Fig. 4: Warm-up time for the Philips lamps

In the Fig. 4, we can observe that for two lamps of a same model (PS) but of different powers (12W and 20W), the starting behaviour is very different.

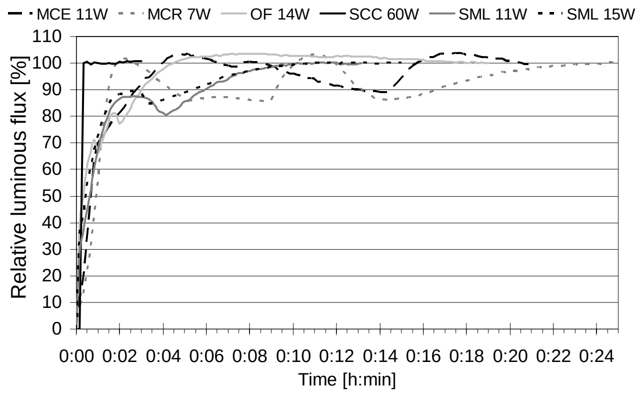

Fig. 5: Warm-up time for the other lamps

In Fig. 5, we see that the incandescent lamp (SCC) has an instant start and is thus different from the CFLs. The relative flux of some CFLs (MCE and MCR) fluctuates heavily while the stabilisation of other (OF, PG, PT) is clearly faster.

Photometric distribution

After analysis of the photometric distribution, it appeared that all the lamps of a same shape have the same distribution. So, in order to present clear and comprehensible results, photometric distributions are presented only for the different shapes of lamps and not for all the tested lamps. Fig. 6 shows the photometric curves for the different lamp shapes, for 1000 lm incident flux. These curves can be very different depending on the shape of the lamp. Frosted incandescent lamps are quite isotropic except from the base side of the lamp.

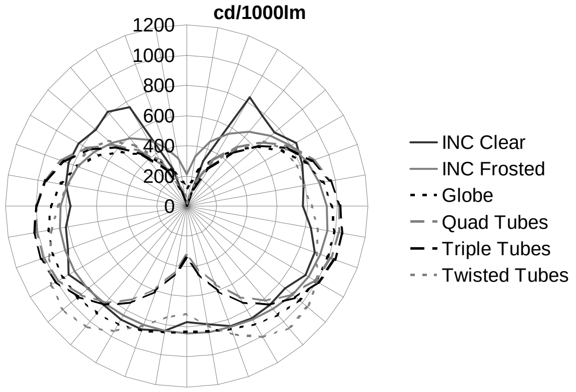

Fig. 6: Photometric curves for different shapes of lamps

Clear incandescent lamps are even more isotropic but the curve is not so smooth due to the sight of the filament and its reflection in the bulb of the lamp. The curve for CFLs with globe is quite the same as for frosted incandescent lamps. The distribution of the CFLs with quad or triple tubes is rather different compared to the incandescent lamps. These CFLs radiate more horizontally at the expense of the vertical intensity. The photometric distribution of twisted tubes CFL is very similar to the distribution of incandescent lamps. The Reflector CFL has a very different distribution. Its photometric curve is presented at Fig. 7.

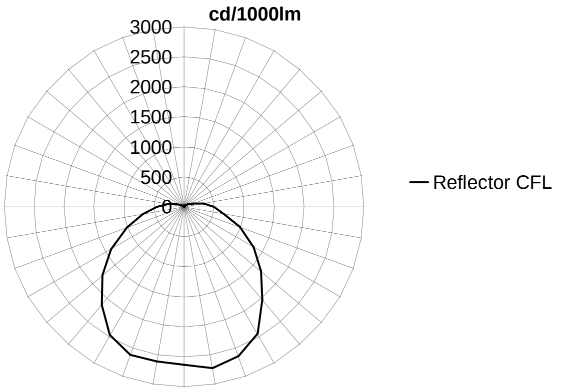

Fig. 7: Photometric curve for the Reflector CFL lamp (MCR)

TSB contributions

Fig. 8 presents the Top-Side-Bottom contribution for the different shapes of lamps. We can see that CFLs with globe show nearly the same results as GLS. Quad and Triple Tubes CFLs radiate more to the sides and less to the top and the bottom, as already observed on the photometric curves. Twisted CFLs are almost the same as GLS but the side and the bottom distribution is more equilibrated. Reflector CFLs, as already mentioned, directs their flux only to the bottom.

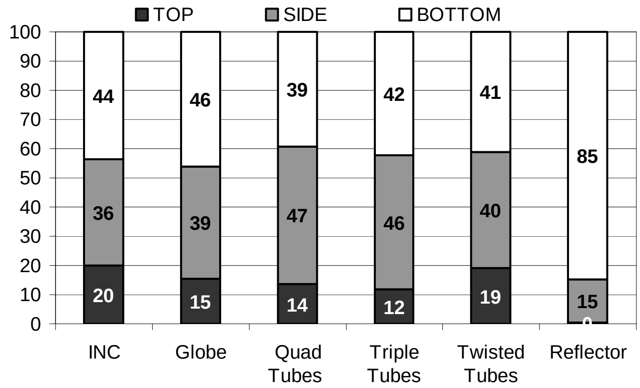

Fig. 8: Mean TSB for each shape of lamp

Luminous flux

Most European lamp manufacturers advise to calculate the power of the substitution compact fluorescent lamp by dividing the power of the previously used incandescent lamp by 5. The total nominal flux of the CFL should be at least equal to the nominal flux of the previously used incandescent lamp.

Fig. 9 presents value for the luminous flux as provided by the manufacturer and the measured value of the luminous flux.

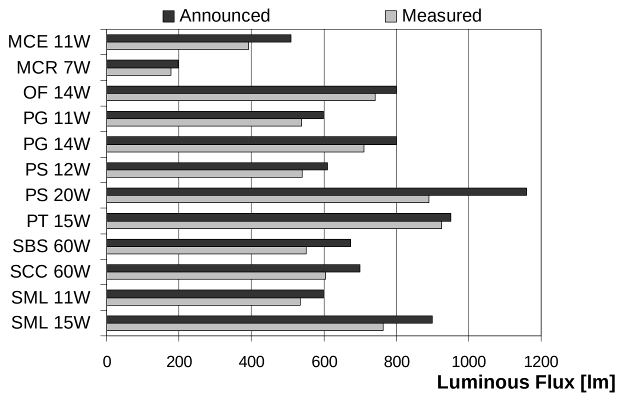

Fig. 9: Measured luminous flux and announced luminous flux

We see that the differences between announced and measured luminous flux can be quite large. Nevertheless, we see that for CFLs of power less or equal to 12W, the luminous flux (announced or measured) is less than the flux of a 60W GLS.

Effect of the shape when using the lamps in a room

The results show that the lamp shapes can affect the photometric distribution. The aim of this part is to study if this difference in the distributions can have an impact of the light distribution in a room.

From the measured lamp distributions, Eulumdat files were created. Then these files were integrated in the software DIALux to make illuminance simulations on a room. The room sizes are 5 m long and 4 m wide with a height of 2.8 m. The reflection coefficients are 0.7 for the walls and the ceiling and 0.2 for the floor. The maintenance factor has been fixed to 0.7. Two lamps (without luminaires) are positioned in the room with respective coordinate (1.25,2) and (3.75,2) at 10 cm of the ceiling. The flux of the lamps has been fixed to 1000 lm. So, only the photometric distributions of lamps change between two different simulations. Fig. 10 gives a representation of the room.

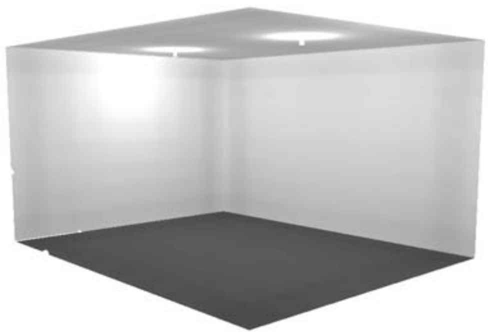

Fig. 10: Representation of the room

For each simulation, mean illuminances were taken respectively for the workplane (at a height of 0.8 m), the roof, the ceiling, and the walls.

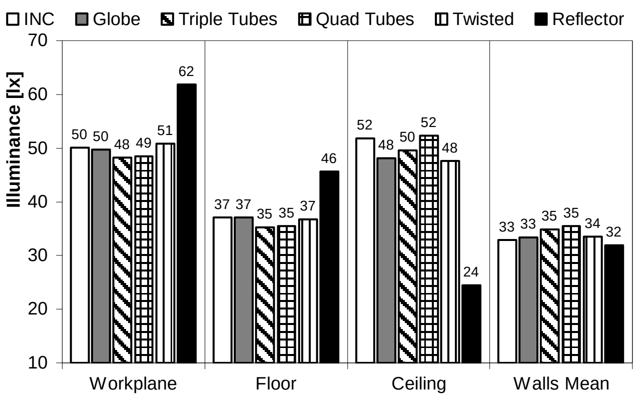

Fig. 11: Mean illuminances on the workplane, the floor, the ceiling and the walls

We can see in Fig. 11 that, except for the reflector lamp, the differences in mean illuminances on the different parts of the room are very small.

DISCUSSION

This section discusses the results of the measurements and is divided in three parts: the warm-up time, the photometric distribution and the consequences of these results.

Warm-up time

As observed in Fig. 4 and Fig. 5, the warm-up time of CFLs can be very different. All the lamps have approximately the same comportment to reach 80% of their flux (within 1 to 2.5 minutes). Once this level is reached, most of the lamps present a decrease of the flux before increasing again to finally reach 100%. The time it takes for the lamp to stabilize from ~80% to 100% depends heavily on the lamp. Some of the lamps also present one or two fluctuations between these values. They take thus quite a long time to reach their full flux.

The differences between the warm-up time of the lamps can not easily be foreseen because it seems to be unpredictable. Indeed, even in a same type of lamp of a same brand but of different power, the warm-up behaviour can be very different (PS12W and PS20W).

Photometric distribution

The lamp shape has a great influence on its photometry. The CFLs with a globe present nearly the same photometric distribution as incandescent lamps. As these lamps look like incandescent bulbs, they are good replacement lamps, when visible (not hidden by the luminaries). Naked quad or triple tube CFLs present a great difference in their photometric distribution, compared to traditional incandescent lamps. Most of their flux is emitted horizontally while GLS bulbs emit preferably vertically. However, very small differences were found in the light distribution of the room. The major problem of these lamps is thus not their photometric distribution but their aesthetic aspect. These lamps should be preferably used in closed luminaires or luminaries hiding the lamp. The same interpretation can be done for the twisted tube CFLs. The reflector CFLs are not expected to replace standard GLS bulb but small incandescent reflectors. So the analysis of these lamps is purely informative and no advice can be made. The replacement of GLS bulbs by this kind of lamps is not appropriate because of their difference in their application fields.

Power, luminous flux and warm-up time

Most of the European manufacturers announce that an incandescent bulb can be replaced equivalently by a CFL having a power equal to the incandescent lamp power divided by five. Luminous flux of the lamps was thus measured. The analysis of the differences between measured and announced flux leads to the conclusions that the method used (integration of measured intensities) is not very precise. However, the manufacturers data's leads to affirm that the division by five is not really correct and that the flux is lower for the CFLs with power of one fifth of the power of GLS. It should be preferable to consider a division of the power by four. In this way, the luminous flux is slightly higher than the one of the incandescent bulb. This higher flux can lead to different advantages. Firstly, it will compensate the differences in the Life Lumen Maintenance Factor (LLMF) between the two kinds of lamps. Indeed, GLSs have a LLMF of 0.93 while CFLs have a LLMF of 0.85 [7]. If, at the end of the life of each lamp, we want to reach the same flux, we must install a CFL with a higher flux. The flux of the CFL must be higher by a factor of $1-\frac{0.93}{0.85}\approx 10\%$ [8].

The second advantageous effect of having a higher flux for the CFLs is that it will compensate the warm-up time. Indeed, let's consider a CFL giving 800 lm (14W CFLs) compared to GLS giving 700 lm (60W). The 700 lm flux is reached for the CFLs when 88% of the full flux is reached. So, the output of the CFL is equivalent to the output of the GLS within approximately 2 minutes. If the CFL had a flux of 700 lm, it would take more than 10 minutes to reach the same flux.

Beside photometry and warm-up time, other parameters could influence the luminous flux of the CFLs and have an impact on the user's perception. These parameters are the lamp position and the temperature but they have not been tested in our study.

CONCLUSION

This paper proposed to analyze two barriers affecting the use of integrated compact fluorescent lamps in domestic applications. The first one concerns the warm-up time of these lamps. The second one focuses on the photometric distribution of the CFLs.

If we look at the warm-up time of the CFLs, we found out that they do not reach their full flux immediately. The time needed to reach their full flux can be quite long and varies between the lamps. Some of them can be "fast", reaching 90% of their nominal flux within 1.5 min. Others take more than 17 min to reach 90% of their nominal flux. The time it takes to the lamps is quite difficult to foresee when buying them because some lamps have written "fast start" on their packaging but are in fact not faster than others. Without testing them, the warm-up time cannot be predicted.

Concerning the photometric distribution of the different lamps, large difference can be found. The major differences concern CFLs with naked quad or triple tubes which radiate more horizontally. However, these differences do not lead to significant differences for the light distribution in a room. So the conclusions are that the photometric distribution is not a real problem for the use of CFLs.

At last, looking at the equivalent power of CFLs, the conclusions are that most of the European manufacturers give wrong advice on the equivalent power of their CFLs. Generally, users which follow their advice will not be happy with the quantity of light they receive from the lamp. It is preferable to divide the power of incandescent lamps by 4 (instead of 5) to obtain the power of the equivalent CFLs. In this way, CFLs would give more light filling in their inferior life lumen maintenance factor and longer warm-up time.

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REFERENCES

[1] Figueiro, Mariana, Jennifer Fullam, Conan O'Rourke, Martin Overington, Mark Rea, and Jennifer Taylor, *Increasing Market Acceptance of Compact Fluorescent Lamps (CFLs)*, Lighting Research Center, Rensselaer Polytechnic Institute, Troy, NY, Prepared for US Environmental Protection Agency, September 30, 2003.

[2] J. Palmer and B. Boardman, DELight – Domestic Efficient Lighting. Environmental Change Unit, University of Oxford, 1998.

[3] International Energy Agency, *Light Labour's Lost: Policies for Energy-Efficient Lighting, OECD/IEA 2006*

[4] A.W. Serres, On the photometry of Integrated Compact Fluorescent Lamps. Journal of the Illuminating Engineering Society 24(1), 1995, pp. 58-62

[5] E. Page, C. Praul and M. Siminovitch, Comparative Candelpower Distribution Analysis for the Compact Fluorescent Table Lamp Systems. Journal of the Illuminating Engineering Society 26(1), 1997, pp. 3-9

[6] European Standard EN13032-1:2004. Light and lighting. Measurement and presentation of photometric data of lamps and luminaires. Measurement and file format.

[7] CIE Standard CIE97:2005: Maintenance of indoor electric lighting systems.

[8] FV Topalis, MB Kostic and ZR Radakovic, Advantages and disadvantages of the use of compact fluorescent lamps with electronic control gear. Lighting Research & Technologies 34(4), 2002, pp. 279-288.