Measurements of Lighting and Electrical Parameters of Compact Fluorescent Lamps

Gasparovsky, D. – Krasnan, F. – Pipa, M.
Slovak University of Technology in Bratislava
Ilkovicova 3, 812 19 Bratislava, Slovak Republic

1 Background

Market with energy saving lamps in Slovak Republic and similarly also in Czech Republic offers a crowd of different types and variations, focused to CFLs with E14 and E27 bases as for direct replacement of less efficient incandescent bulbs. Rated power varies usually from 7 W up to 27 watts. Rated average lifetime for cheapest types is only 3 000 hours, high-quality types offer over 9 000 hours (e.g. 12 000 or 15 000), but most types have about 6 000 h. What's the most important when buying a lamp is, of course, it's price. Broad availability of cheap CFL's of eastern production force the competitive companies to push down the price what results in market structure characterized by big deal of lamps with modest lifetime only, also for brand types. The question is, what level of quality is available in general, at such relatively low prices. Because case to case, sometimes more expensive lamps may bring higher economical benefit than cheaper lamps. What is the exact relation between price and lifetime? This and also other questions have been analyzed and investigated. One of the most studied problem was verification of data published on lamp package.

2 Goals of imvestigation

Analysis of properties of CFLs has been focused on measurements of lighting and electrical parameters, followed by evaluation of economical indicators. Particular goals of measurements can be listed as follows:

- Measurement of luminous flux of various types
- Comparison of measured flux with its rated flux
- Comparison of measured flux with luminous flux of equivalent incadescent bulb of this relation is stated by manufacturer
- Measurement of colour temperature
- Measurement of light spectrum emitted by CFL
- Measurement of current and power characterstics
- Measurement of harmonics

Measured data have been consequently processed to obtain following parameters and characteristics:

- Dependance of luminous efficacy on lamp input power
- Energy savings for replacement of incadescent bulb at current electricity prices
- Paybacktime for investments (overall and relative) at current price relations
- Price of the lamp vs its lifetime
- Price of the lamp vs its power

3 Methodology

More than 100 different types of energy saving lamps from 30 manufacturers have been laid under photometrical and electrical tests. From each type, selection of three samples have been performed, i.e. total over 300 lamps have been measured.

Efficacy of lamps has been measured by method of luminous flux measurement in photometric integrator with 1,2 m diameter. All lamps undergo standard ageing time of min. 100 h. Before the measurement, lamps have been stabilized for 20 minutes.

Measurement of spectrum has been performed by optical spectrometer Ocean Optics USB 2000. This instrument has a detector SONY ILX511, what in fact is a 2048-element linear silicon CCD sensor, sensitive in region between 200 to 1 100 nm, suitable for UV, visible and IR ranges. Optical resolution is 0,3 – 10 nm depending on the range and sensitivity is 86 photons to one integrating unit. Signal/noise ratio is 250:1.

Luminous flux has been measured by callibrated illuminance meter L-02. Colour temperature has been measured by MINOLTA Color Meter II, which has a range 1 600 – 40 000 K and accuracy ± 20 K at 3 200 K.

Electrical parameters have been measured by network analyzer Eurotest 61557. This instrument is capable to evaluate harmonics of both voltage and current up to 21. Result is displayed in per cents of total value. Voltage is for harmonic analysis measured with resolution 1 V and accuracy ± (5 % of measured value + 3D). Current is measured by means of clamps, in given ranges the resolution is 1 mA and accuracy is ± 5 % of measured value. Total Harmonic Distortion THD is measured with resolution 0,1 % and accuracy ± (5 % of measured value + 5D). Following electrical parameters have also been measured: P (W), Q (VAr), S (VA) and also the power factor (PF) cos φ. Within given ranges, the resolution is 0,1 W/VAr/VA or below measured 10 W/VAr/VA the resolution is 0,01.

Measured values have been assembled to table sheets in MS Excel. Energy savings, i.e. savings of costs for electricity during rated average lifetime of CFL at replacement of common bulb with its equivalent luminous flux have been calculated by formula according to [1]

$$U = \frac{C_I L_C}{L_I} - C_C + \frac{C_E L_C}{1000}\left(P_I - P_C\right) \tag{1}$$

where C_I, C_C - costs (price) for incandescent lamp (index I) and for CFL (index C)
L_I, L_C - average lifetime for incandescent lamp (index I) and for CFL (index C)
P_I, P_C - input power of incandescent lamp (index I) and CFL (index C)
C_E - current electricity price

Input power and average lifetime of lamps are published by manufacturer on their package. Input power of corresponding incandescent lamp is taken from packaging leaflet as well, rather than measured value. Lifetime of incandescent lamp can be set as standard 1000 h. For electricity price, current value of 3,85 Sk/kWh for most frequently used tariff in households has been applied.

4 Results and discussion

Compact fluorescent lamps are sorted according to manufacturers, however, for usual reasons exact types are not published, rather labeled by symbols in alphabetical order (A to Z, then AA to AD). Knowledge of exact types or manufacturers is not crucial for building up an overall picture of market situation, what's important, is variety of available types and their parameters. Lamps under test can be divided into three groups depending on their quality:

- „brand“ types, manufactured by four major light source producers (A-D)
- less known brands, products having similar quality of parameters as for traditional producers (E-R)
- lamps of less known brands or noname lamps, properties of which lie significantly below usual standards defined by previous categories (S-AD)

Tab. 1 Overview of luminous efficacy η (lm/W) of compact fluorescent lamps

Type	Power (W)															
	3	**5**	**7**	**9**	**11**	**13**	**15**	**16**	**17**	**18**	**20**	**21**	**23**	**24**	**25**	**27**
A						55,7		52,6								
B				54,7	54,4		63,7				58,5					
C	17,8	21,7	59,1	54,3	52,7		63,7				66,4		68,0			
E			58,7		53,5	61,6			54,2			52,9				
F			66,7		55,4	60,0				16,0	59,3					
G			47,7	51,8	54,8	51,4	52,0			55,6						
H					61,5						52,9					
I						49,6		56,5								
J							52,6									
K				53,1	52,6		49,8				55,7					
L						58,6										
M				55,6	39,1		56,2				52,0					52,8
N							56,7									
O					55,5											
P					46,8								55,9			
Q						51,4			57,3			52,0				
R			54,2	55,6	60,8		65,6				61,8					
S					34,0	31,5					24,1				24,6	
T							45,7									
U											37,0					
V					39,1						34,1		36,6			
W					48,9											
X														35,2		
Y				49,0		44,8										
Z					31,4		32,2							30,5		
AA				35,1	30,1					32,7						
AB				37,9	55,6					42,3						
AC					43,7	49,7				49,9	47,3			57,1		
AD				31,6	31,4		30,6							29,9		
average 1	17,8	21,7	59,1	54,5	53,6	55,7	63,7	52,6			62,5		68,0			
average 2			56,8	54,0	53,3	55,4	55,5	56,5	55,8	35,8	56,3	52,5	55,9			52,8
average 3				38,4	39,3	42,0	36,2			41,6	35,6		36,6	38,2	24,6	

Criterion for selection of lamps into groups has been selected the luminous efficacy η (lm/W), lamps with efficacy between 50 – 60 lm/W have been categorized to group no. 2, while the rest of lamps belong to the group 3.

4.1 *Luminous flux and efficacy*

Efficacy is a measure of lamp efficiency and depends on input power of the lamp. Tab.1 shows the values of measured luminous efficacy, average values are depicted on Fig. 1.

From table it can be seen that most of compact fluorescent lamps have efficacy more than 50 lm/W, therefore these lamps are 5 times more efficient than incandescent lamps of the same (virtual) wattage. For many lamps the efficacy even exceeds 60 lm/W. On the other hand, lamps put into third group achieve only 30 lm/W average, what is about a half in comparison to common types. For example, the S type as a worst case had only 24 lm/W. 3W and 5W cannot be compared this way because such types are intended for decoration purposes and not for illumination.

One of the results that can be entitled „interesting“ is that measurements did not confirm expected raise of efficacy for high-power lamps. E.g. columns of average values on Fig. 1 are too flat but also in individual cases there is no clear dependande of efficacy on input power. Such a dependance should only be clear for a series of only one lamp family (e.g. 2U, 3U, globe etc.).

It is also useful to know how measured luminous flux is in compliance with data given on package, i.e. how seriously manufacturers informe their customers. Results are composed to Tab. 2 as percentual values (measured/rated), results of verification for equivalent incandescent lamps in similar way are also given here. Due to limited space, only selected types are shown in the table.

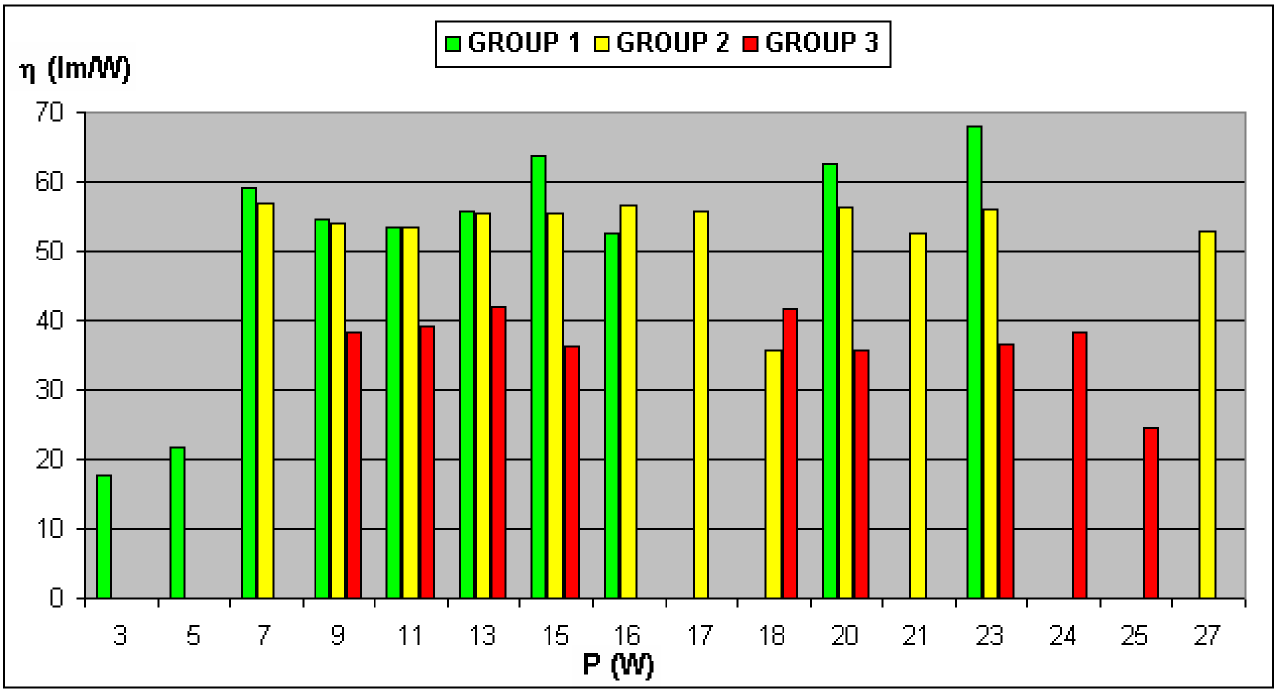

Fig. 1 Average values of luminous efficacy vs input power

Tab. 2 Percentage of measured luminous flux to rated luminous flux and the flux of equivalent incandescent lamp

Type	% of rated luminous flux								% of luminous flux of equivalent incandescent							
	7 W	9 W	11 W	13 W	15 W	18 W	20 W	24 W	7 W	9 W	11 W	13 W	15 W	18 W	20 W	24 W
A				93,6								87,8				
B		100,5	99,8		106,1		101,8			114,5	82,0		99,5		84,9	
C	118,2	99,8	92,1		106,1		110,6		188,0	113,7	107,1		99,5		96,2	
E	108,2			108,2					95,6			109,7				
F									124,6		91,0	98,8		23,7	85,9	
G	98,3	97,1	98,8	87,9		88,5			89,1	96,1	89,9	84,5	81,1	80,7		
H			123,0				88,1				92,7				76,6	
J													82,2			
K		106,1	105,1		99,6		101,3			111,1	79,2		98,6		80,7	
L								67,8								44,2
M		96,2	71,7		93,7		79,1			103,1	59,0		87,8		75,4	
O			101,7								83,6					
P			85,8								70,5					
Q				85,6								91,5				
R	90,4		94,1				117,8		88,3	103,3	91,7		102,4		89,6	
S			61,7	63,0			43,8				51,2	45,5			35,7	
T													71,4			
U															53,6	
V			71,7				62,0				59,0				50,7	
W											73,7					
X																51,0
Y		95,8								100,1						
Z			76,7		71,6			67,8			47,3		44,3			44,2
AA		114,7	100,3			98,3										
AB			101,9							70,3	83,7			61,4		
AC			87,3	99,4		89,8	86,1	122,3			71,7	81,8		72,4	68,6	
AD		70,2	76,8		68,1			66,5		58,6	47,4		42,1			43,3

From Tab. 2 it follows that CFL’s of first class are in very good compliance to rated luminous flux and in fact also the equivalence to incandescent bulb is well expressed. It was interesting to know that for CFL’s enlabelled as B their manufacturer claimed not only power equivalency between CFLs and incandescents, but also luminous fluxes for these incandescent lamps; however, these data (fluxes) quite much differ from those given in catalogue of lamps of this manufacturer, so CFL are overrated, indeed.

For groups 2 and 3 both the rated and measured luminous fluxes are in good accordance. But equivalence to incandescent lamps is a real problem. Manufacturers deliberately give higher luminous fluxes for equivalent incandescent lamps what may dissapoint customers by unexpected low illuminance levels, accented by the fact that CFL’s have different spatial distribution of light, with a bottom gap (operated in a base-up position). For example the S type’s claimed equivalent lamp had two times the flux really measured.

4.2 Colour temperature and spectrum

All types of CFL’s available have rated colour temperature as much as 2 700 K – warm white light colour similar to the light colour of incandescent lamp to be replaced. By measurments it was found out that the range for chromacity is wider, most of lamps belog to average 3 000 K but higher values are also not rare. Results for some lamp types are composed to Tab. 3.

Colour temperature is in a close relation to spectrum of lamps. Example for one type is depicted on Fig. 2 but other lamps do not differ much from this picture, mainly about 600 nm, eventually there is a higher peak in blue part of the spectrum (comparable to two peaks on Fig. 2).

Tab. 3 Measured values of colour temperature Tc (K)

Type	Power (W)															
	3	5	7	9	11	13	15	16	17	18	20	21	23	24	25	27
B				2780	3050		2880				3130					
F			2770		3000	2940					3050					
G			3170	3030	3030	3030	3050			3030	3470					
I					2990			2900								
K				3030	3030		3030				3350					
M				2950	3060		2830				3030					3050
P					2970								3060			
Q									2930							
R					2950						3000					
V					3480						3440		3550			
W					2990											
Y				2890	3100											
Z					3090		3150							3150		
AC					2980	3100				3130	3190					
AD				3800	3580		3550							3330		

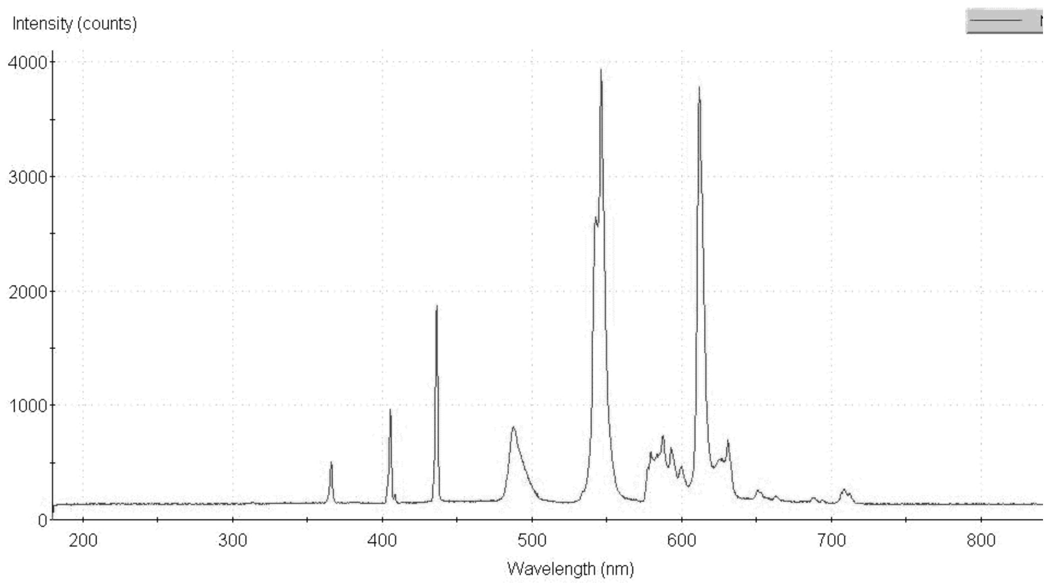

Fig. 2 Spectrum of the M type CFL, 11 W

4.3 Current and input power

Tab. 4 show results of measured current versus rated values given per cents. It can be seen that many lamps have current higher than rated what results, of course, to higher input power of lamps. More detailed analyzes will follow in further works. Power factor cos φ in most of cases varies between 0,5 and 0,6.

Tab.4 Differences in measured and rated current per cents

Type	Power (W)															
	3	5	7	9	11	13	15	16	17	18	20	21	23	24	25	27
A						168,3		120,7								
B				81,3	97,9		110,8				195,4					
F			70,3		65,8	66,5				245,0	140,6					
G			112,6	49,1	51,3	59,9				129,3						
H					200,3						327,0					
I					129,1			138,5								
J							114,1									
K				62,4	142,5		82,4				123,4					
L						51,5										
O					121,6											
P					226,8								180,0			
Q						91,0			147,3							
R					95,2						125,0					
S					56,0						73,8				82,7	
U											219,4					
V					74,0						101,4		202,4			
X														137,5		
Y				124,3	188,5											
AA				141,5	104,0					142,4						
AB				76,4	106,5					107,6						

4.4 Harmonics

More detailed discussion on harmonics requires a broader space. Here only the most important parameter THD is briefly mentioned. THD for most of measured CFLs was 110 – 140 %, only few types have this parameter under 110 % (A, E, I, P, T) and rarely is higher (F, R). Average value is 122 %. Third harmonic is about 60 % with just small dispersion, similarly the fifth harmonic is 45 % average.

4.5 Economical indicators

Payback time is the most important economical parameter and can be calculated using the formula (1) over rated lifetime. Payback time has been calculated in absolute values (hours), but it is more illustrative to express it as a relative paybacktime for particular lifetime of the lamp. Such data are given in Tab. 5. Although according to this table the best times are achieved for i.e. „cheap“ CFL’s of group 3, their low efficacy and worse technical parameters could prevail their low price benefit. But also here further works should be yet performed.

Problems occured also with premature mortality of lamps. Higher failure rates are typical for F, S, C and AC brands.

Tab.5 Relative payback time in per cents of rated lifetime

Type	Power (W)															
	3	5	7	9	11	13	15	16	17	18	20	21	23	24	25	27
A								15								
B					20		11				10					
C				49	182		28				26		8-12			
F			24-39		16-25	9-15				21	8-19					
G			26	29	24	10-21	8			15						
K				31			18									
L						16										
Q						16										
R				25			20									
S					5						4				3	
W					8											
X														6		
Y				36												
AC					15	13	12			13	14					

5 Conclusions

This paper brings some first results from analyses of properties of compact fluorescent lamps, the lamps widely sold throughout Europe in variety of brands, types and properties. Analyses are focused on lighting, electrical and economic properties, according to current project goals (see footnote) with strong emphasize on harmonics and mutual CFL-network influences.

Results given in this paper can be generalized such a way that also lamps of renowned major manufacturers do not necessarily hav always the best parameters – either luminous, electrical but in first order lifetime related. It is specifically tailored for the CEE markets that few years ago there were mainly lamps with lifetime 10 000 h (12 000 or 15 000 h as standard) available, recently most of lamps are offered with decreased lifetime (6 000 h or 3 000 h) because of their price.

Situation is actually influenced by many EU related legislation. Let us pick up two of them:

1. Duties applied for CFL imports from asian countries, mainly from China, what may lead to unbalanced market structure (since April 2005)
2. Directive on the WEEE, obligation for manufacturers in disposal of lamps is expected to raise prices of CFLs approx. in 60 %, what is particularly unfavourable for customers, who may prefer again less efficient incandescent bulbs (legally since August 2005)

References

[1] Gasparovsky, D., Smola, A. Energy saving lighting systems. Projects of houses 2001, No.1, pp. 240 -243, ISSN 1335-3527 (in Slovak)

Acknowledgments
This work was supported by Science and Technology Assistance Agency under the contract No. APVT-20-002004.