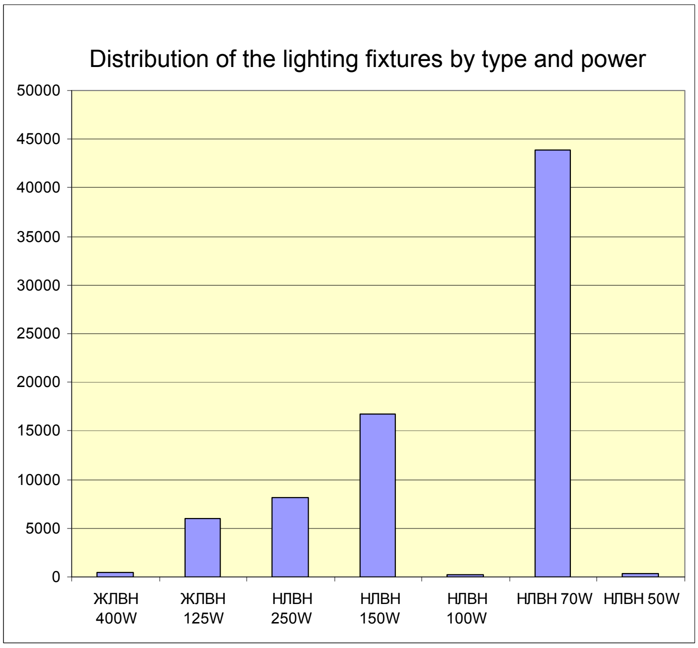
LED lighting fixtures. Objectives, issues and implementation

*Assoc. Prof. Dr. Krasimir Velinov - **http://lighting-bg.eu, candela@mail.bg;***

*Dipl. Eng. Radi Pipev, Sofia-proekt MC – **radi.pipev@gmx.net**,*
PhD Student at St. Ivan Rilski – University of Mining and Geology;

*Poly Velinova – **polyv@abv.bg**,*
Technical University – Sofia – Student

A main part of the modern street lighting systems is implemented with high pressure discharging lamps – sodium or metal – halogen. At present in the street lighting prevails the high-pressure sodium lamp. A typical example for this is the town of Sofia (fig.1). The mostly used lighting fixtures are those employing the high-pressure sodium lamp with power 70W – 44 000 pieces. [1].



Confirmed is the opinion that for the time being the High Pressure Sodium Lamps (HPSL) are the most effective source of light. And this is really so, but for the 400W lamps. At present lamps with such power emit a luminous flux of 55 500 lm. At first glance this means efficacy 139 lm/W. In practice we have losses of active power in the Electronic Regulating Gear (ERG). For example a 400 Watts lamp consumes from the net 450 Watts active power due to losses in the ERG. In this case the efficacy is 122 lm/W. The mostly used lamp in the street lighting is the one with power 70 W (fig.1).

In Table 1 are shown values of the luminous flux of modern sodium lamps with power 50 – 100 W [4, 5].

Table 1

Type of the light source	Power of the lamp		
	50 W	70 W	100 W
SON-T PIA Plus	4400 lm	6600 lm	10500 lm
NAV-T 4Y	3500 lm	5600 lm	
VIALOX NAV (SON) SUPER 4Y	4400 lm	6600 lm	10000 lm

Taking into account that the ERG losses of a 50W lamp are more than 10W, and for a 70W lamp they are 15W, the real efficacy of these sources drops respectively to 58 -73 lm/W and 66 -78 lm/W.

What happens if such lamps are installed in a lighting fixture? It is considered that a good street lighting fixture has an efficiency factor of 70%. And this applies to a lighting fixture with properly designed optical system. This means that additional 30% of the light is lost and is not used by the street lighting. A recalculation of this index in respect of the equivalent efficacy:

$$\eta_e = \frac{\text{Outgoing luminous flux}}{\text{Total consumed power}} \quad (1)$$

Then, the values of Table 1 will correspond to the efficacy shown in Table *2.*

Table 2

Type of the light source	Power of the lamp		
	50 W	70 W	100 W
SON-T PIA Plus	51 lm/W	54 lm/W	64 lm/W
NAV-T 4Y	41 lm/W	46 lm/W	
VIALOX NAV (SON) SUPER 4Y	51 lm/W	54 lm/W	61 lm/W

Hence, the real efficacy of the luminous flux emitted by the lighting fixture is 40 - 55 lm/W. We must not forget that the colour temperature of HPSL is 2000K and its colour rendering index is low [4, 5]. Most optical systems of lighting fixtures that use this source allow only 50% of the light to drop on the road paving.

The other light sources – metal-halogen lamps and compact luminescent lamps have even lower energy indices.

What is the alternative?

Since some ten years LEDs have been considered as a perspective source of light. Only in recent years the development of technologies provided possibility for this to become reality. The big investments in this field said there word and 2009 became a turning point, obtaining high efficacy white light LEDs and achieving considerable reduction of their price, referred to a unit of luminous flux (fig. 2).

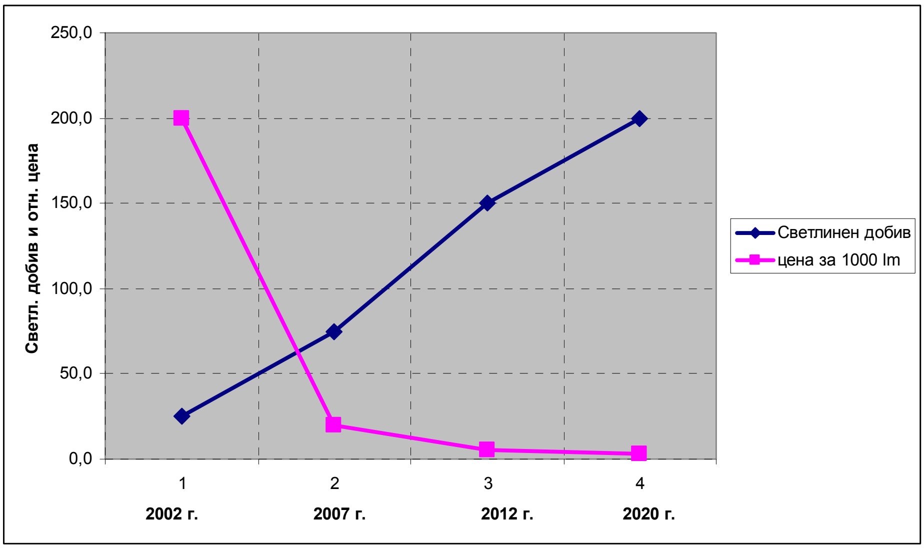


fig.2

The development of technologies in the latest years provided a possibility to produce high efficacy white light LEDs [2].

The main technical parameters of LEDs are working current, voltage, luminous flux and lifetime, or the change of the luminous flux in function of worked hours. All these values strongly depend on the temperature of the semiconductor junction (fig. 3, 4 and 5). Regrettably, direct measurement of the junction temperature is impossible. It may be indirectly read by means of the following formula:

(1) $T_J = T_{SP} + ([R_{th\ j\text{-}sp}] \times [V_F] \times [I_F])$,

where:

T_{SP} is the temperature of the substrate solder;

$R_{th\ j\text{-}sp}$ – the thermal resistance of the substrate;

V_F and I_F are respectively the LED working voltage and current (fig.6)

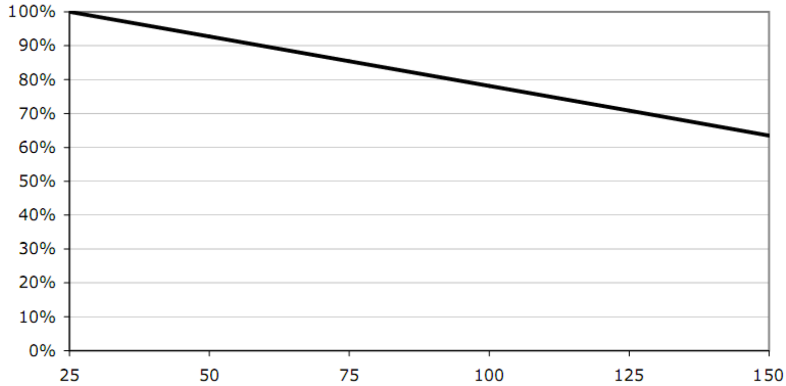


fig. 3. Relative luminous flux depending on the junction temperature

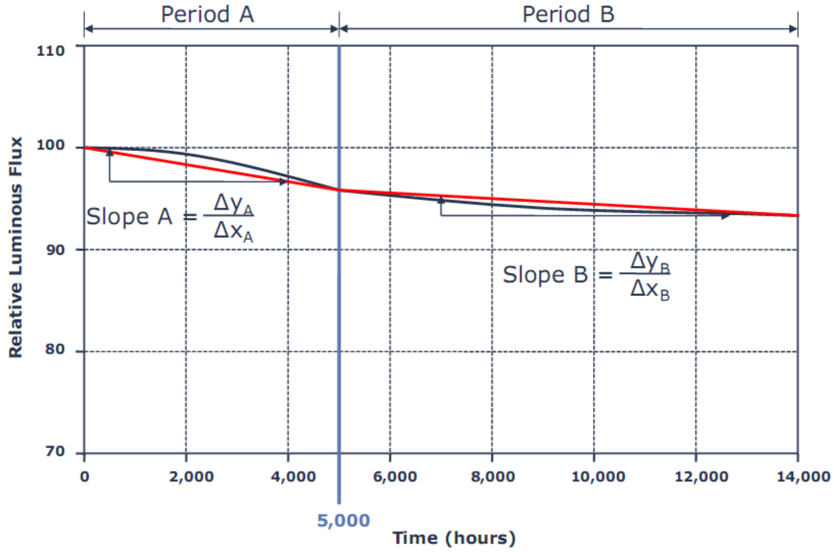


fig. 4. Relative luminous flux depending on the time of lighting

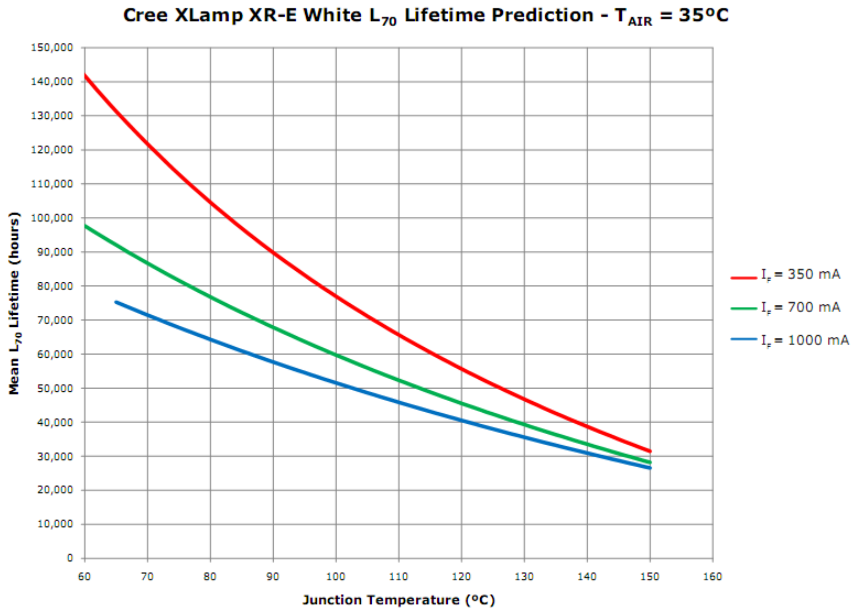


fig. *5.* Lifetime of a white light LED, type XR-E, as function of the junction temperature, the working current being 350 mA, 700 mA and 1000 mA [2].

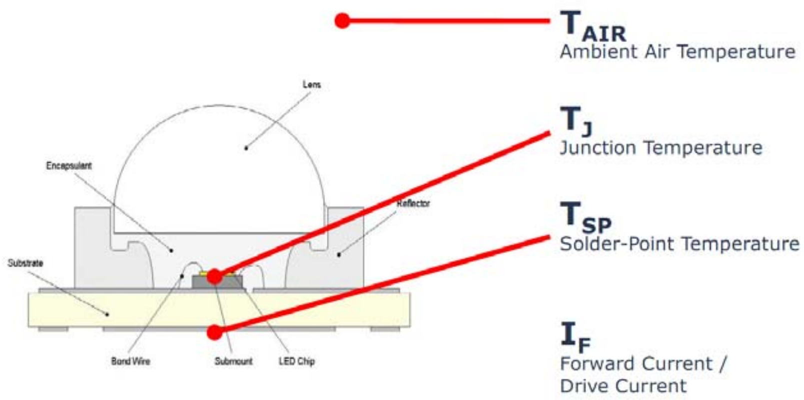


fig.6

Usually the temperature of the junction is assumed to be not above 85^{o}C. In this case one can rely on LED lifetime between 60 -100 thousand hours and luminous flux that will not drop below 85% of the initial value. In order to guarantee this is necessary to provide suitable temperature regime for the lighting fixture, advantageous for the LEDs cooling. This is difficult to accomplish in places with warm climate; in practice this is achieved by an appropriate form of the lighting fixture, which provides good heat output. This determines to some extent the unusual design of the lighting fixture (fig. *7).*

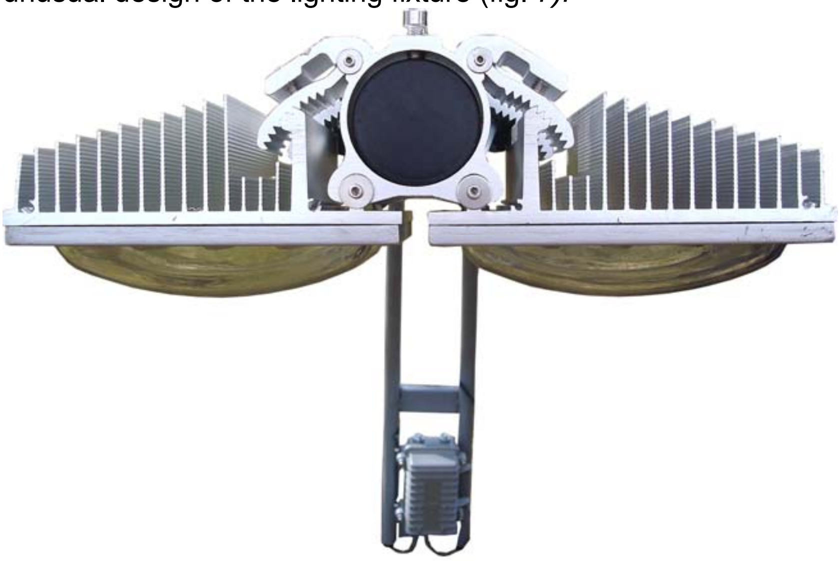


fig. 7. Lighting fixture housing that provides good cooling.

REALIZATION OF APPROPRIATE LIGHT DISTRIBUTION

A typical peculiarity of the road pavement is the existence of a big mirror component. This allows optimize the light distribution of the lighting fixture in such a way that emitting a minimal luminous flux achieves the normative roadway brightness.

The lighting engineering task to find optimal light distribution for a street lighting fixture is formulated in the following way:

- Considered is a Street Lighting System with width B. The lighting fixtures are installed on height H, at a distance L from each other (fig. 8).

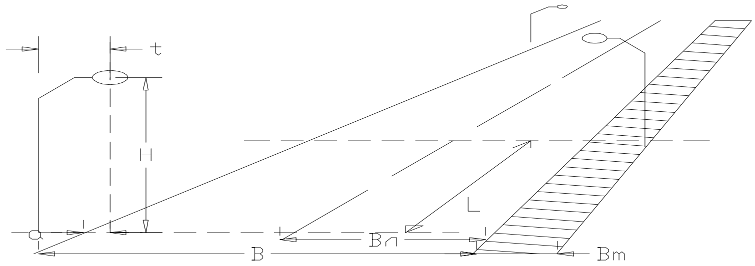


fig. 8

- The reflecting properties of the road pavement at different observation angles are known (corresponding to the permitted movement speeds).

- Required is such light distribution of the lighting fixtures that will guarantee achievement of the normalized quantitative and qualitative indices, having the lowest value of the necessary luminous flux of the source (**Φ_{lamp}** = min).

In order to solve this problem has to be defined and solved an optimization problem under the following restrictive conditions:

$$\Phi_{lamp} = \sum\sum I_{\gamma c} \cdot \Delta\Omega_{\gamma c} = MIN \qquad \gamma=0\text{-}\pi/2,\ C=0\text{-}\pi$$

Under the following restrictive conditions:

$$L_{min} / L_{average} > Go$$

$$E_{min} / E_{average} > Geo$$

$$I\gamma c_{max} \text{ (at } \Phi_{lamp} = 1000 \text{ lm)} < Io$$

$$TI < TI_{assigned}$$

Where:

$L_{average}$ is the average brightness on the roadway,

L_{min} is the minimal brightness on the roadway

Φ_{lapm} is the luminous flux of the lightning fixture

$\Delta\Omega\gamma c$ are the volumetric angles for γ and c

TI – blinding index.

For solving the above optimization problem was used the MATLAB package **fmincon** function. One of the received solutions is shown in fig. 9.

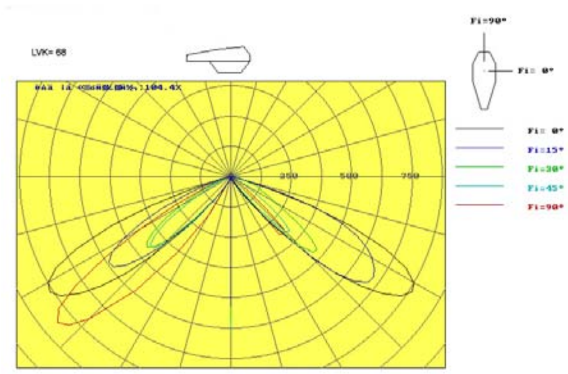


fig. 9 Light distribution achieving the normative brightness with a minimal luminous flux.

The classical way to have the required light distribution employs mirror reflectors. In such a case in the place of the traditional lighting fixture is installed the LED module. The achieved light distribution may be seen in fig. 10. The disadvantage of this method is that cannot be achieved high values of the gain factor.

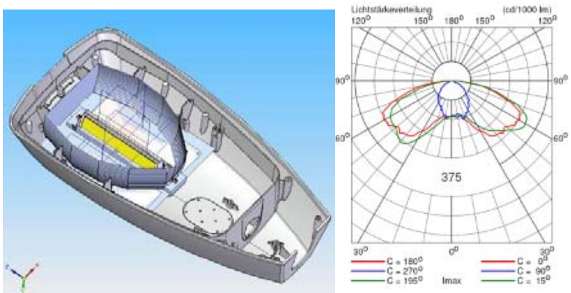
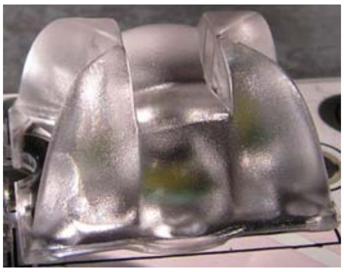


fig. 10. LED lighting fixture with mirror reflector

Regrettably, with a mirror reflector cannot be achieved the optimal light distribution shown in fig. 9.

A possibility to implement this light distribution is to install separate LEDs upon a complex facet surface, which LEDs emit within a very narrow volumetric angle, and then slightly displace their optical axes in a way that the summarized light distribution "fills" the function shown in fig. 5. Such LEDs are produced with an incorporated in the housing optical system – either a reflecting or a refractoring one. The practical execution of such design requires perfect spatial installation of small elements and leads to big amount of hand labour. As a whole the product becomes non-technological and more expensive.



Leading worldwide manufactures of LEDs have taken another way. Designed is a series of lenses, which are installed above the LED, what allows implementing a suitable light distribution. Such lens is shown in fig. 11. The advantage of this approach is the achievement of light distributions with a big gain factor.

fig. 11. Lens for LED

In order to facilitate the assembly process the upper lenses are pressed on a common pad. The group lens is installed on the printed circuit card, which has fixed LEDs, implementing in this way the module shown in fig. 12. Sometimes the module is completed with a cooling radiator.

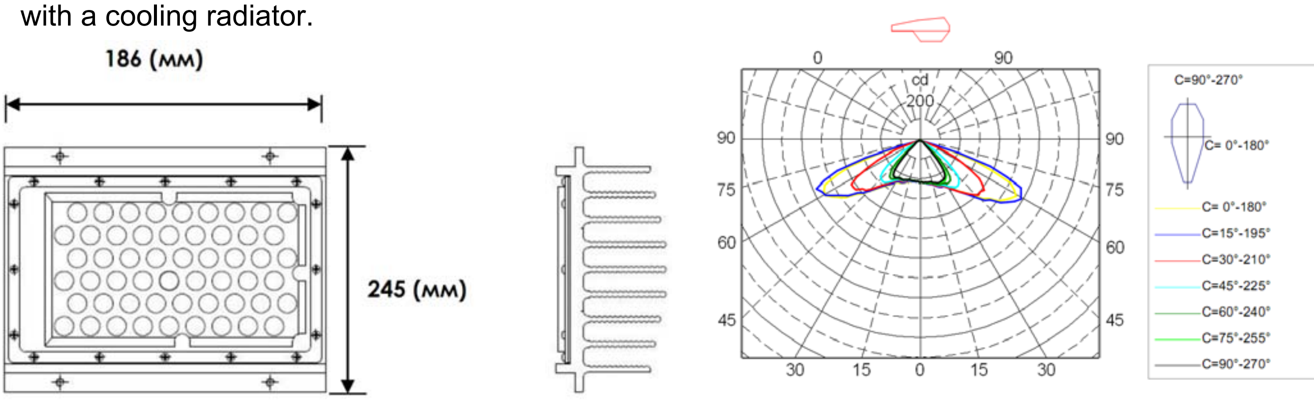


fig. 12. Module with a group lens for LEDs

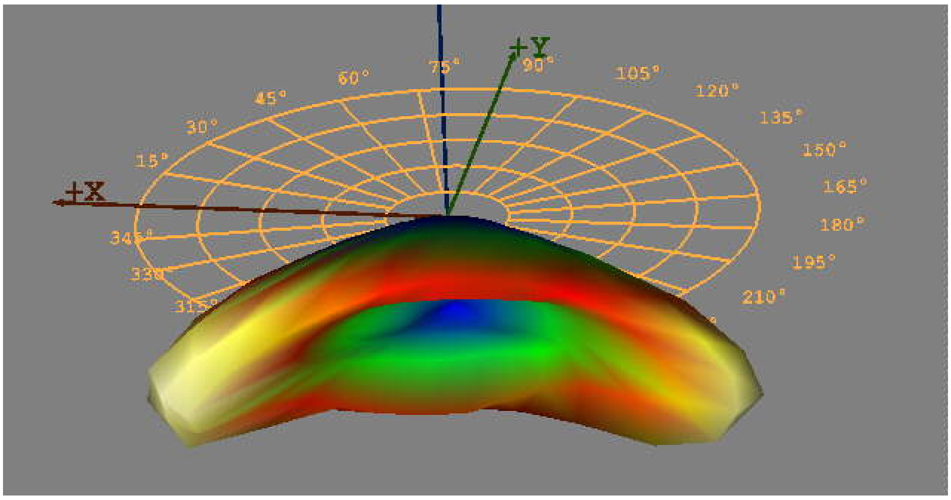


fig. 13. Implemented light distribution of a module with group lens for LEDs (Visualization with ILEXA Ray-Viewer) [5].

The shown partial results of implemented light distributions, provided by real lighting fixtures have been received by measurements in the photometric lab of the Sofia University of Mining and Geology "Sv. Ivan Rilski" – Sofia. For the measurements has been used the newly designed goniophotometer with 39 digital photoreceivers [6].

ASSESSMENT OF EXPLOITATION EXPENSES

In order to determine what is the price of exploitation of different light sources is made the following juxtaposition:

To lighten a street of light class ME5, 9 m wide and with distance between poles 30 m, will be needed a HPSL with 70W power or a LED lighting fixture with total power 60W. The lighting fixture with HPSL, due to losses in the ERG, will consume 85W power. The price of the LED lighting fixture is assumed to be 400 Euro, while the one with HPSL – 120 Euro. The calculations are made for an exploitation period of 50 000 hours, or about 12 years, in average 4200 working hours of the lighting fixture per year. For the whole term of exploitation will be replaced 5 HPSL pieces, considering the lamp parameters with fig. 14. It is assumed that the price of one HPSL is 10 Euro and the replacement price is 35 Euro. The results are shown in fig. 14, the price of the electricity being 10 Eurocents per kWh.

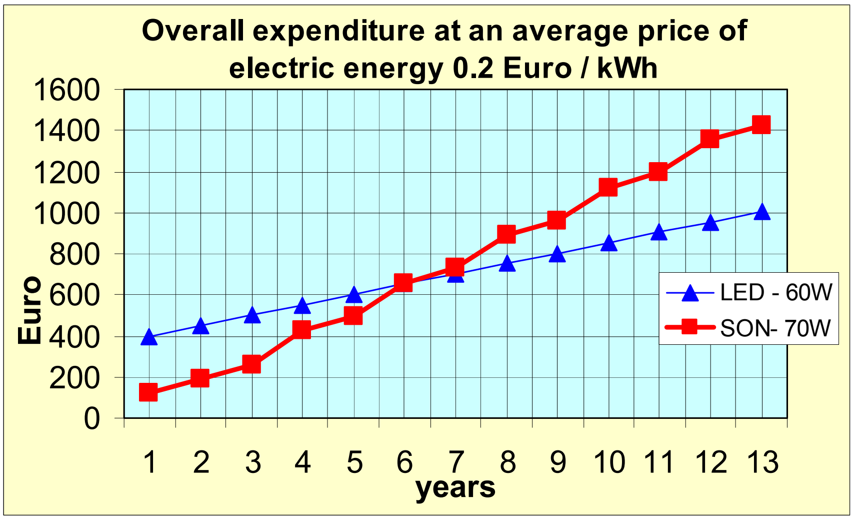


fig. 14. Comparison of total expenses by years

Irrespective of the higher initial price, the LED lighting fixtures have smaller exploitation expenses, because for the entire exploitation period the total price: *capital investments + exploitation expenses* is considerably smaller than the one for a HPSL lighting fixture.

The above prices are typical for Bulgaria. With those correlations, yet in the sixth year the LED lighting fixture will have lower summarized annual expenses. In case of other correlations between the prices of lighting fixtures and energy, the results may be immediately recalculated by means of the programme module designed for this purpose.

ASSESSMENT OF PRODUCTION EXPENSES

In order to assess whether is advantageous to begin production of LED lighting fixtures for a given world region, an investigation has been made to see under which market parameters, production strength and technology will be effective to begin such production. For this purpose is necessary to assess the following parameters:

- Supply price of the LED module – K_m;
- Supply price of the lighting fixture housing that meets the technical requirements – K_l;
- Supply prices of the power supply unit, current restriction unit and the controllers for lighting fixture administration – K _g;
- Price of the labour in assembly works – C_a;
- Monthly use – N_l;
- Warehouse expenses – C_s;
- Transportation expenses – C_t;
- Expenses for administrative services - C_r;
- Taxes and fees due – C_d;
- Formed profit – C_p;

To perform the calculations a programme has been composed, which, with given entry parameters, was determining the final price of the lighting fixture and the monthly profit.

Appearance of the screen is shown in fig. 15.

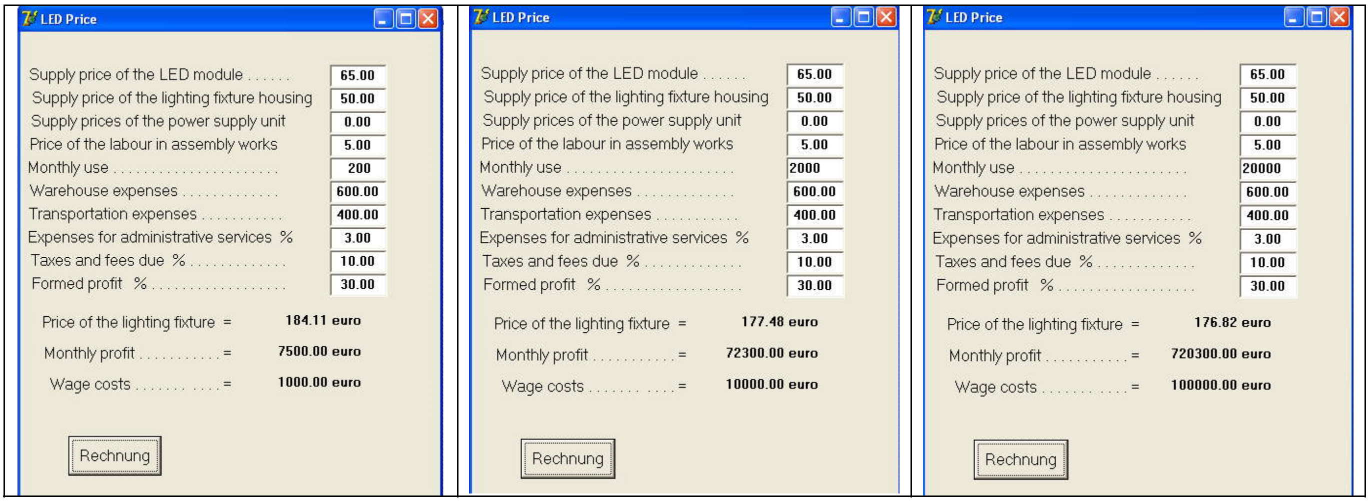


fig. 15. Comparison of the lighting fixture prices for different monthly production volumes.

The monthly salary includes VAT, pension and social security insurance.

Results of the calculations are shown in Table 1.

Table 1

Monthly production	**200 pc**	**2 000 pc**	**20 000 pc**
Price of the lighting fixture	**184.11€**	**177.48€**	**176.82€**
Profit	**7 500€**	**72 300€**	**720 300€**

CONCLUSION

Irrespective of the higher initial price, the LED lighting fixtures have smaller exploitation expenses, because for the entire exploitation period the total price: *capital investments + exploitation expenses*, is considerably smaller than the one for a HPSL lighting fixture.

The application of LED lighting fixtures in the street lighting is an economically effective undertaking. In the first place will be executed LED street lighting in service and in-district streets, road tunnels, parks and recreation zones [7].

When using LED lighting fixtures, big attention has to be paid to the quality of the feeding devices. It is very difficult (more expensive) to produce such an electronic regulating gear, which would have life-time commensurable with that of the LEDs – 50 -100 thousand hours.

Still is not effective to use LEDs in the industrial lighting. There are needed lighting fixtures with big single luminous flux and is more profitable to use a gas vapour discharge lamp – metal-halogen or sodium, with a big single power, for which the efficiency is commensurable with that of the LEDs and the price for 1000 lm is considerably lower.

REFERENCES

[1] К. Велинов, Новости в системите за експлоатация и управление на уличното осветление, Национален семинар “Новости в осветителната техника”, 16 декември 2010 г.

[2] Cree® XLamp® Long-Term Lumen Maintenance, July 2009.

[3] Vassilev Hr., Velinov K., INFLUENCE OF GEOMETRICAL PARAMETERS AND RULE REQUIREMENTS ON THE OPTIMUM LIGHT DISTRIBUTION OF THE STREET LUMINAIRES, Conferinta internationala Iluminat 2007, 06.2007, Clush-Napoka, Romania.

[4] Velinov K., Is it expensive LED lighting? XIV Национална конференция с международно участие BulLight / България Светлина 2010, 10 – 12 Юни 2010, Варна, България

[5] Jordanow W., ILEXA Ray-Analysator and Ray-Viewer - http://www.ilexa.de/

[6] Velinov K. GONIOPHOTOMETER FOR EXPRESS MEASUREMENT OF LED LUMINAIRES, XIV Национална конференция с международно участие BulLight / България Светлина 2010,10 – 12 Юни 2010, Варна, България.
[7] Velinov K, G. Vuchov, SAMEL-90 LED luminaires in the night city. Problems in LED luminaires design. Romanian Lighting Convention - 18-20th May 2011, JW Marriott Bucharest Grand Hotel, Bucharest, Romania, p.141-147