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Petko MASHKOV, Berkant GYOCH, Rosen IVANOV*
University of Ruse
8, Studentska, 7017 Ruse, Bulgaria
**Corresponding author*. E-mail: rossen@uni-ruse.bg

INVESTIGATION OF CHARACTERISTICS AND THERMAL LOADING OF LED BULBS FOR AUTOMOTIVE HEADLIGHTS

Summary. The aim of the study is related to obtain real data for the LEDs' thermal load and characteristics of several LED lamps types H4 and H7 for automotive headlights with different cooling system.

Power consumption, temperature regimes of the LEDs' operation, lamps' radiation spectral distribution, and luminous flux of lamps for automobile headlights with active and passive cooling system at different ambient temperatures have been investigated. The obtained data under real conditions of operation in several cars have been verified. The results are compared with the data in promotional materials and the requirements of Regulations of the United Nations Economic Commission for Europe. Studies enable to evaluate the feasibility, advantages and disadvantages of LED lamps of this type when replacing standard halogen lamps in headlights.

1. INTRODUCTION

The use of LEDs as lighting and indicator elements in cars has been widespread for many years [1–11]. Their use as light sources in car headlights has entered in the last few years after light efficacy of LED headlamps began to compete with that of xenon and the best halogen headlamps.

The positive trends in the development of white LEDs make them increasingly suited to meeting the high demands of auto headlamps as well as fog lamps. A major advantage is the life of the LEDs and the associated light source exploitation resource.

The service life and associated replacement and warranty costs for various vehicle components are becoming increasingly important. The average vehicle life is estimated at about 5000 hours; the LEDs' life at proper thermal management exceeds this value significantly. Due to an increased warranty period for car manufacturers, the average lamp life of the car headlights is becoming increasingly important.

Another major advantage in the use of LEDs for car headlights is the possibility of multivariate design solutions with one or more LED modules, sectioning the light source, creating adaptive lighting, etc.

In the last few years, LED technology has begun to accelerate the production of car headlights. Almost all new cars are powered by LEDs for low beam, high beam, and fog lights.

The approach to car lighting requirements has also changed. Emphasis is placed not only on the light flux directed to the road, but also on the adaptability and intelligent lighting control systems—Fig. 1.

Despite the glamorous trends for the development of LED lighting systems in the world of cars, several important facts have to be noted. These systems are still embedded in top-class cars that are far from the general public. It will probably take many years before this technique becomes widely used (similar to ABS and stabilizing electronic systems in cars).

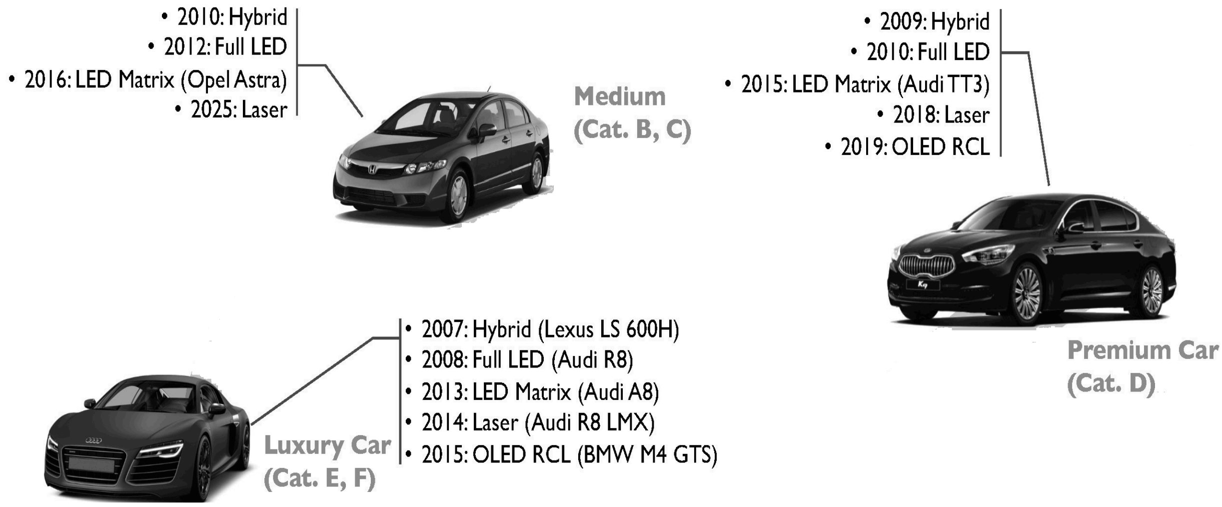


Fig. 1. Trends in car lighting to improve security, convenience, functionality, and adaptability [12]

2. PROBLEM STATEMENT

There are a lot of LED bulbs for replacement, the mostly used halogen car lamps, mainly made by Chinese manufacturers. The suggestions are very tempting—the prices are acceptable, the lamps should be eternal compared to the car's life, and the light flux of LED headlamps are better than the xenon lamps (which have not become widely used because of their high price) – Fig. 2.

a) b)

Fig. 2. LED headlamps of the type: a) H4 - 1 type and H7 - 1 type; b) H4 - 2 type and H7 - 2 type

The problem is that there is often a significant difference between advertising and the actual product characteristics under real operating conditions. Our view is that serious deficiencies are inadmissible in this area – they can cost material damage and health or the lives of consumers or others.

It is important to bear in mind that the main advantages of LED light sources can only be realized when the thermal load of the LEDs is properly controlled during operation. The rise in the p-n junction temperature results in a decrease in the light efficency of the LEDs, a significant reduction in their life and the reliability of the LED light sources.

Most LED manufacturers at nominal regime of operation usually indicate a p-n junction temperature of 85°C; which should not exceed 150°C [1–7].

Figure 3 shows the thermal resistance model: p-n junction (temperature T_j) – solder point ($R_{th\ j\text{-}sp}$); solder point–heat sink ($R_{thsp\text{-}h}$); heat sink–ambient for one LED ($R_{th\ h\text{-}a}$) [2].

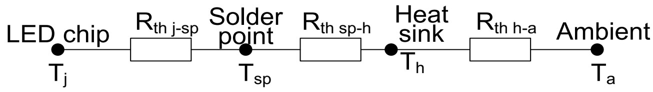


Fig. 3. Thermal resistance model

Tj–p-n junction temperature; Tsp–solder point temperature; Th–heat sink temperature; Ta–ambient temperature.

For each measured solder point temperature, Tsp the corresponding p-n junction temperature is calculated using equation (1):

$$T_j = T_{sp} + R_{th\ j\text{-}sp} * P_{LED} \quad (1)$$

The purpose of this work is to study and obtain real data on the light and power characteristics of some of the most-spread light sources for car headlamps based on powerful LEDs and LED modules and to estimate the real LEDs' thermal loads at different modes of operation.

3. EXPERIMENTAL INVESTIGATIONS

The investigations were carried out in the laboratory of light measurements of the Physics Department–Angel Kanchev University.

The used equipment includes a 1m-diameter integrating sphere (according to the United Nations Economic Commission for Europe –Regulation 112) and Stellar Net equipment, the ThermaCam E300-FLIR Systems, thermometers, etc.

The characteristics of three types of LED headlamps—H4-1 type (Fig.2a), H4-2 type (Fig. 2b), H7-1 type (Fig. 2a), and H7-2 type (Fig. 2 (b) have been tested. Patterns were selected for which the features in the promotional materials are very good and the LED modules used are of reputable manufacturers. Tests of three samples of each type of lamps have been made, and the results obtained for the samples of one kind are practically the same.

Using the same measuring equipment, comparison tests of standard H4 and H7 halogen lamps were performed.

The design and method of LEDs' cooling in the lamps H4-1 type, H7-1 type, and H4-2 type are similar—the heat pipes are used, the cooling is passive, the radiators are made of copper braid—Fig. 4. The cooling for the H7-2 type lamp is active with a fan.

Experimental studies were performed in a thermal chamber. The LED lamps are powered by drivers and the tests have been carried out at supply voltages ranging from 9 to 15V [4, 5].

The temperature load of the LEDs in car lamps have been investigated by conventional temperature measurements (using thermocouples) and using the Therma Cam E300-FLIR Systems infrared camera.

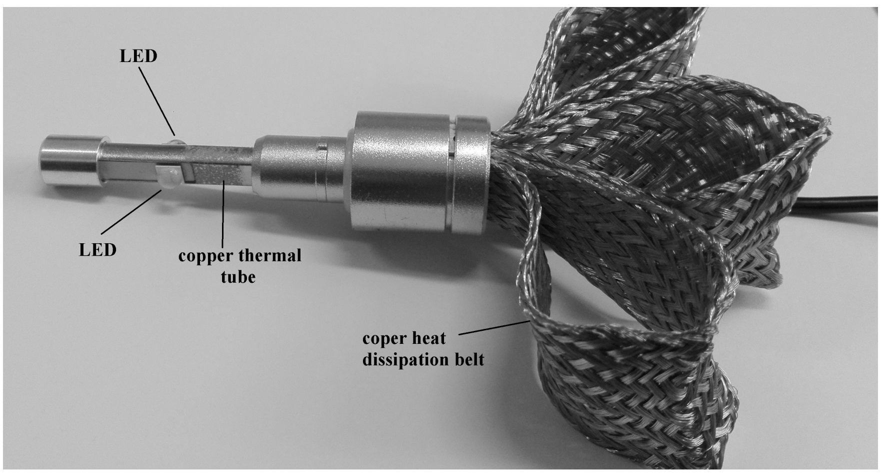


Fig. 4. Design and method of cooling for LED automobile lamps

3.1. RESULTS. Tests of LED H7 lamps

Typical results for electrical characteristics of the H7 type lamps are shown in Table 1.

Table 1
Supply voltage, current consumption, and power of an H7 LED lamp

U,V	I,A	P,W
9	2,77	24,93
9,5	2,62	24,89
10	2,48	24,80
10,5	2,37	24,89
11	2,26	24,86
11,5	2,16	24,84
12	2,07	24,84
12,5	1,99	24,88
13	1,91	24,83
13,5	1,84	24,84
14	1,78	24,92
14,5	1,71	24,80

As can be seen from the presented results, the power consumption of the lamp is practically constant – about 25W and does not depend on the supply voltage. The tests showed that the light output of the lamp decreased after switching on (about 10%–15%), after about 7–8 minutes it stabilized, and then remained constant.

According to the requirements of the United Nations Economic Commission for Europe (UNECE), the photometric tests for headlamp lamps are carried out at a supply voltage of 13,2 ± 0.1V. In Table 2, the results obtained for LED H7 and compared with the characteristics of a standard halogen lamp H7 obtained at the same measuring equipment are presented.

Table 2
Current, power, and light output current at a supply voltage of 13.2 V per H7 type LED lamp and standard H7 halogen lamp

LED lamp type H7		Standard H7 halogen lamp
U,V	13,2	13,2
I,A	1,88	4,23
P,W	24,82	55,84
F,lm	1370	1060

The comparison of the presented results shows that the LED lamp's luminous flux is about 30% greater, while the power consumption is about 2.2 times less.

The compliance of the color characteristics of the lamp light (according to the UNECE Regulations - Rules 112, 113) is also examined–Fig. 5. The color coordinates of the samples tested are within the permissible area of the color space (CIE 1931).

LEDs' thermal load investigations of H7-1 type LED lamps

Temperature dependences of the LED module's solder point temperature T_{sp} from the ambient air temperature T_a are presented in Fig. 6a. In the sets of supplied auto headlamps, there is no information regarding what exactly the LED modules are embedded in.

If the LED module is actually XHP50, CREE Corp., which is one of the promotional materials, the resistance between the soldering point and the p-n junction is $R_{th\ jsp}$= 1,2° C / W and the temperature difference between them is:

$$T_j - T_{sp} = R_{th\ j\text{-}sp} * P_{LED} \approx 12°C \tag{2}$$

The analysis of the obtained results shows that at ambient temperatures above 60° C, the LED modules will operate at temperatures close to the maximum allowable temperature.

Lamps of this type are also subjected to long-term tests in real operating conditions in Opel car. Experimental studies were performed during the summer at ambient temperatures above 30° C.

The results show that in real operating conditions, the LED modules operate at much lighter heat load. When the car is moving, the solder point temperatures T_{sp} do not exceed 90°C.

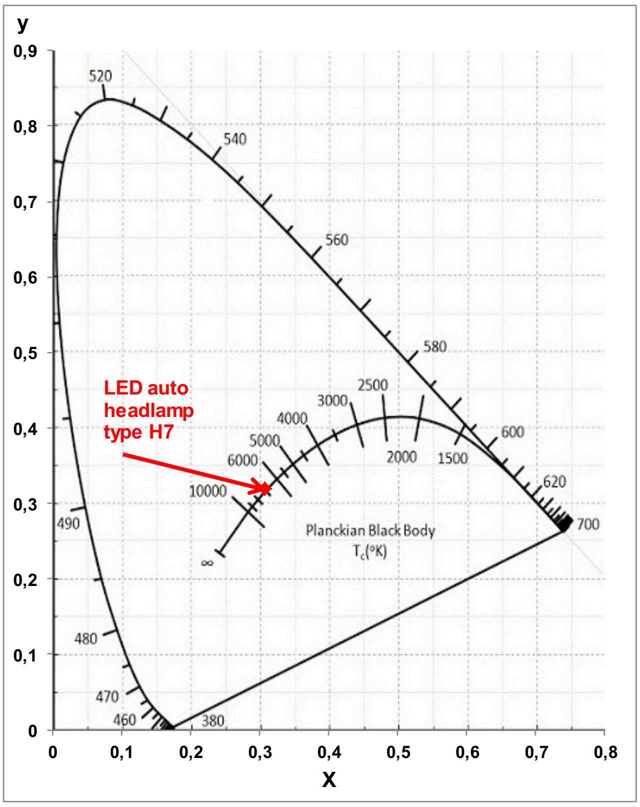
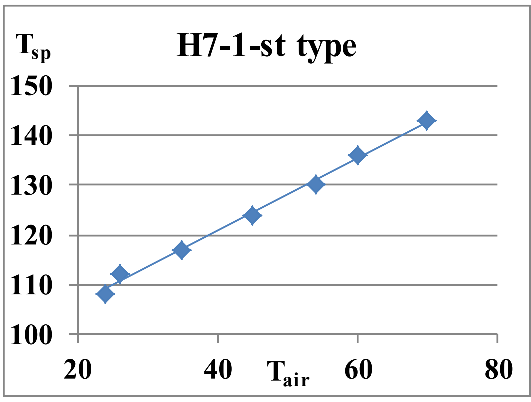
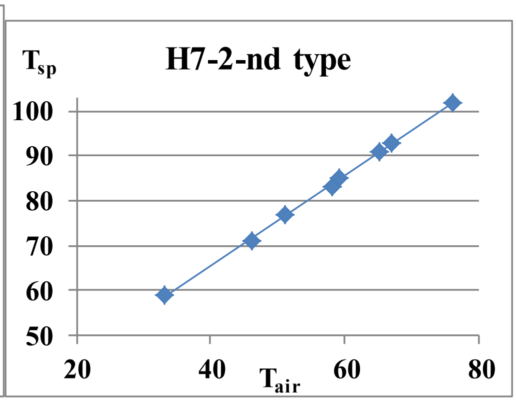


Fig. 5. Measured color characteristics of LED auto headlamp type H7





a) b)

Fig. 6. Temperature dependences of the LEDs' solder point temperatures T_{sp} on the ambient air temperature T_{air} f or lamp: a) H7 - 1 type, b) H7 - 2 type

When the heat load of the LEDs is maximum for a standstill and a running engine—then T_{sp} reaches 105 ° C. These modes of operation are fully acceptable, which means that this passive cooling is sufficient, and a long and reliable operation of LED lamps of this type can be expected. A major advantage of this construction is the lack of moving parts (fans), which makes it reliable in harsh conditions of operation—vibrations, dirt, and heat

LEDs' thermal load investigations of H7-2 type LED lamps

The lamps of this type are with an active cooling system—with fan-—Fig. 2b. The power consumption of the lamp is about 16W and does not depend on the voltage supply. The luminous flux is practically the same as that of a standard halogen lamp H7; the power consumption is 3.5 times less.

Figure. 6b shows the dependence of the solder point temperature T_{sp} on the ambient air temperature T_{air} for the H7-2 type lamp. Thanks to active cooling, the thermal load of LEDs does not exceed the maximum allowable temperature at ambient temperatures up to 80°C.

The problem with this type of cooling is related to the heavy operating conditions. If the fan fails, the passive cooling is insufficient and the temperature load on the LEDs is unacceptable.

3.2. RESULTS. Tests of LED H4 lamps – 1 type

LED lamps H4 - 1 type (low beam)

In Table 3, the results for power consumption of these type of headlamps (at low-beam operation) are shown. Practically, it does not depend on the voltage supply. Tests have shown that lamp stabilization occurs about 5–7 minutes after switching on.

Table 3

Voltage supply, current, and power of
a LED headlamp H4 - 1 type (low beam)

U,V	I,A	P,W
9	1,81	16,29
9,5	1,71	16,25
10	1,63	16,25
10,5	1,55	16,28
11	1,48	16,28
11,5	1,41	16,24
12	1,35	16,24
12,5	1,30	16,25
13	1,25	16,25
13,5	1,20	16,24
14	1,17	16,38
14,5	1,12	16,24

Table 4

Current, power, and light flux at 13.2 V voltage supply for
LED headlamp H4 - 1 type and for standard halogen lamp (low beam)

LED headlamp H4 - 1 type (low beam)		Standard halogen lamp H4 (low beam)
U,V	13,2	13,2
I,A	1,21	4,7
P,W	15,972	62,04
F,lm	997	848

The characteristics' comparison of the tested LED H4 - 1 type with those of standard halogen lamps (for low beam)—Table 4. This shows that the light flux of the LED lamp is about 10%-15% higher at power consumption about 3.9 times smaller.

The color characteristics of the samples tested meet the requirements of the UNECE Regulations.

(B) LED lamps H4-1 type (high beam)

As can be seen from Table 5, the average power consumption is about 24 W, and it is independent of the supply voltage. The stabilization time of the photometric characteristics of the lamp is less than 10 minutes

The results show that the light output of the LED headlamp H4-1 type high beam is practically like a standard halogen lamp, but the power consumption is almost 3 times lower.

The color characteristics of the samples of the LED headlamps H4-1 high beam meet the requirements of the UNECE Regulations.

Table 5
Voltage supply, current consumption, and power of an LED lamp H4-type 1 high beam

U,V	I,A	P,W
9,00	2,65	23,89
9,50	2,52	23,89
10,00	2,39	23,90
10,50	2,28	23,94
11,00	2,17	23,89
11,50	2,08	23,89
12,00	1,99	23,89
12,50	1,91	23,89
13,00	1,84	23,89
13,50	1,77	23,90
14,00	1,71	23,90
14,50	1,65	23,93

Table 6
Current, power, and light flux at 13.2 V voltage supply for LED headlamp H4-1 type and for standard halogen lamp (high beam)

LED headlamp H4 - 1 type (high beam)		Standard halogen lamp H4 (low beam)
U,V	13,2	13,2
I,A	1,82	5,4
P,W	24	71,28
F,lm	1400	1445

3.3. RESULTS. Tests of LED H4 lamps – 2 type

A) LED lamps H4-2 type (low beam)

The average power consumption for an LED lamp of this type is about 20 W and does not depend on the supply voltage—Table 7. The luminous flux of LED headlamp of this type is about 5% greater than that of halogen lamps, with the power consumption being about 3 times smaller.

Table 7
Voltage supply, current, and power of a LED headlamp H4-2 type (low beam)

U,V	I,A	P,W
9	2,31	20,79
9,5	2,18	20,71
10	2,05	20,50
10,5	1,94	20,37
11	1,85	20,35
11,5	1,76	20,24
12	1,68	20,16
12,5	1,61	20,13
13	1,54	20,02
13,5	1,48	19,98
14	1,44	20,16
14,5	1,4	20,30

Table 8
Current, power, and light flux at 13.2 V voltage supply for LED headlamp H4-2 type and for standard halogen lamp (low beam)

LED headlamp H4 - 2 type (low beam)		Standard halogen lamp H4 (low beam)
U,V	13,2	13,2
I,A	1,52	5,4
P,W	20,064	71,28
F,lm	900	1445

The spectral performance characteristics of this type of LED lamps meet the requirements of the UNECE Regulations.

(B) LED lamps H4-2 type (high beam)

The average electrical power of this type of lamp is around 20W, not dependent on the supply voltage.

The luminous flux of the LED lamps H4-2 type (high beam) is less than that of a standard filament lamp, but is within the area of recommended luminous flux of the UNECE Regulations.

LEDs' thermal load investigations of H4-1 type LED lamps

The design of the lamps of this type is constructively identical to the H7-1 type lamps, the difference being only in the fixation and control of the operation of the LED modules.

A) LED lamps H4-1 type (low beam)

The dependence of the LED solder point temperature T_{sp} from the ambient air temperature is shown in Fig. 7a.

In this lamp, only one LED module (P_{LED} ≈ 14W) lights up at low-beam operation. If it is XHP50, CREE corp., which is a promotional material, the resistance between the solder point and the p-n junction is $R_{th\ j\text{-}sp}$ = 1,2°C/W, and the temperature difference between them is:

$$T_j - T_{sp} = R_{th\ j\text{-}sp} * P_{LED} \approx 16°C \quad (3)$$

The obtained results show that at ambient temperatures above 65°C, the heat load of the LEDs is close to the maximum allowable.

Table 9

Voltage supply, current consumption, and power of an LED lamp H4-type 2 - high beam

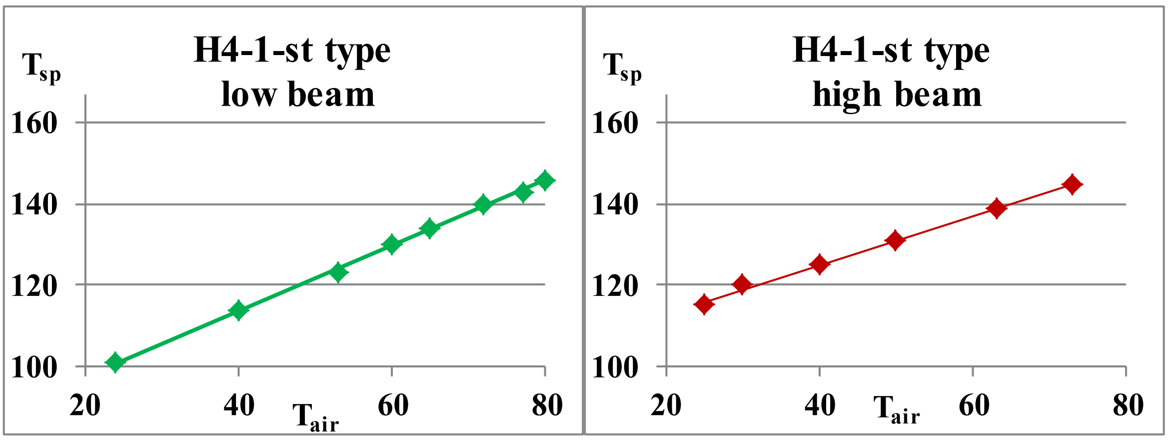
U,V	I,A	P,W
9	2,19	19,71
9,5	2,04	19,38
10	1,93	19,3
10,5	1,82	19,11
11	1,74	19,14
11,5	1,65	18,975
12	1,58	18,96
12,5	1,52	19
13	1,45	18,85
13,5	1,41	19,035
14	1,36	19,04
14,5	1,31	18,995

Table 10

Current, power, and light flux at 13.2 V voltage supply for LED headlamp H4-2 type and for standard halogen lamp (high beam)

LED headlamp H4 - 2 type (high beam)		Standard halogen lamp H4 (high beam)
U,V	13,2	U,V
I,A	1,43	I,A
P,W	18,876	P,W
F,lm	1038	F,lm

The LED H4-1 type lamps are also subjected to long-term tests in real operating conditions in a Ford Focus vehicle. Experimental studies were performed during the summer at ambient temperatures above 30° C.



a) b)

Fig. 7. Temperature dependences of the LEDs' solder point temperatures T_{sp} on the ambient air temperature T_{air} for LED lamp H4-1 type: a) low beam, b) high beam

The results show that at real operating conditions, the LED modules work in much lighter heat load. The T_{sp} temperature does not exceed 85 ° C when the car is moving . The heat load of the LEDs is maximum for a standstill and a running engine—then the T_{sp} reaches 100 ° C. These modes of operation are acceptable, which means that this passive cooling is sufficient, and a long and reliable operation of LED lamps of this type can be expected.

B) LED lamps H4-1 type (high beam)

The dependence of the LED solder point temperature T_{sp} from the ambient air temperature is shown in Fig. 7b.

Measurements made at real operating conditions due to the specific use of high-beam driving have shown that the LEDs in the H4-1 type lamps are operating at safe thermal load.

LEDs' thermal load investigations of H4 -2 type LED lamps

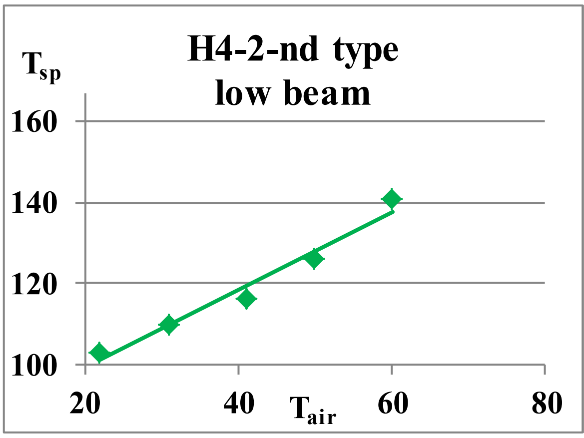
A) LED lamps H4-2 type (low beam).

The dependence of the LED solder point temperature T_{sp} from the ambient air temperature is shown in Fig. 8a. For this type of lamp at an ambient temperature above 50 ° C, the LEDs operate at a temperature load close to or above the maximum allowable.

B) LED lamps H4 - 2 type (high beam)

The dependence of the LED solder point temperature T_{sp} on the ambient air temperature is shown in Fig. 8b.

As can be seen from the presented results, in this mode of operation, the LEDs in H4-2 type lamps at ambient temperatures above 35 ° C operate under unacceptable temperature loads, which is a prerequisite for insufficient life of the luminaire and increased danger of accidents.



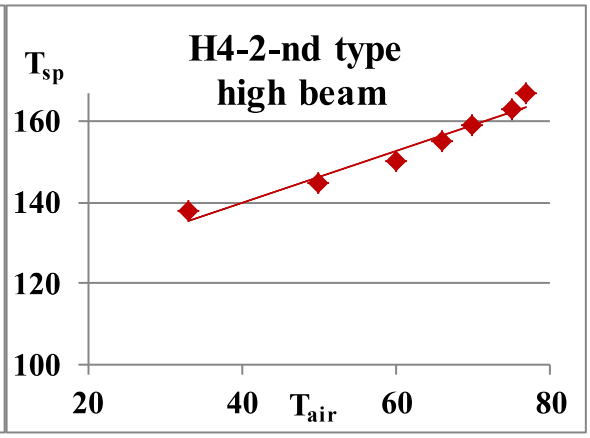


Fig. 8. Temperature dependences of the LEDs' solder point temperatures T_{sp} on the ambient air temperature T_{air} for LED lamp H4-2 type: a) low beam, b) high beam

4. CONCLUSIONS

The electric and light characteristics of LED auto headlamps for the replacement of H4 and H7 halogen lamps were tested. On the basis of the obtained experimental results, the following conclusions can be made:

1. All tested LED auto headlamps are powered by drivers that provide the same electrical power to the lamp and the same luminous flux regardless of the voltage supply.

2. The light flux of the tested LED auto headlamps complies with the UNECE rules and is commensurate with the light output produced by halogen auto headlamps of the same type, but they differ significantly with the values specified in the promotional material—fewer times.
3. The power consumption of the LED lamps is 2 to 4 times less than the power consumed by the standard car halogen lamps of the same type with a comparable light flux.
4. At real operating conditions of the LED auto headlamps, the heat loads of the LEDs may be problematic. In the tests, the reached LEDs' solder point temperatures in some of the lamps are above 120 ° C, which is unacceptable.

References

1. *XLamp LED Thermal management.* Available at: http://www.cree.com/led-components/media/documents/XLampThermalManagement.pdf.
2. *LED Luminaire Design Guide.* Available at: http://www.cree.com/led-components/media/documents/LED_Luminaire_Design_Guide.pdf
3. *XLamp long – term lumen maintenance.* Available at: http://www.cree.com/led-components/media/documents/XLamp_lumen_maintenance.pdf.
4. Mashkov, P. & Gyoch, B. & Beloev, H. & Pencheva, T. LEDs' operation optimizing by active cooling at high ambient temperatures. *XV Национална конференция с международно участие BulLight / България Светлина 2014.* 10 – 13 Юни 2014. Созопол, България. Стр. 48 - 52. [In Bulgarian: XV NATIONAL CONF. BulLight 2014, Sozopol].
5. Mashkov, P. & Pencheva, T. & Gyoch, B. LEDs' Thermal Management Aided by Infrared Thermography. *Micro Tech – 2010.* Cambridge, England. P. 68-73.
6. Zhu, X. & Zhu, Q. & Wu, H. & Chen, C. Optical design of LED-based automotive headlamps. *Optics & Laser Technology.* Vol. 45. 2013. P. 262–266.
7. Wang, J. & Cai, Y. & Zhao, X. & Zhang, C. Thermal design and simulation of automotive headlamps using white LEDs. *Microelectronics Journal*. Vol. 45. 2014. P. 249-255.
8. Ye, H. & Mihailovic, M. & Wong, C.K.Y. & van Zeijl, H.W. & Gielen, A.W.J. & Zhang, G.Q. & Sarro, P.M. Two-ph ase cooling of light emitting diode for higher light output and increased effi ciency. *Applied Thermal Engineering.* Vol. 52. 2013. P. 353-359.
9. Li, J. & Ma, B. & Wang, R. & Han, L. Study on a cooling system based on thermoelectric cooler for thermal management of high-power LEDs. *Microelectronics Reliability*. Vol. 51. 2011. P. 2210-2215.
10. Tamburo, R. & Nurvitadhi, E. & Chugh, A. & Chen, M. & Rowe, A. & Kanade, T. & Narasimhan, S.G. Programmable Automotive Headlights. *Computer Vision – ECCV 2014.* V. 8692. P. 750-765.
11. Wördenweber, B. & Wallaschek, J. & Boyce, P. & Hoffman, D.D. *Automotive Lighting and Human Vision*. Springer Berlin Heidelberg. 2007. 409 p.
12. *Progression_automotivelightingtechnologies_yole_april2016.* Available at: http://www.yole.fr/iso_album/illus

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