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Thermal testing of road luminaires with sodium and LED lamps

Abstract. *The paper presents the results of thermal testing of road lighting luminaires fitted with high pressure sodium lamps (400W) and LEDs (100W). An analysis of the theoretical heat flow paths in the luminaires and the results of laboratory testing of selected luminaires, results of examined the dynamics of temperature rise and the effect of external temperature (ambient) to the heating of the thermally sensitive elements of the lighting luminaires were also mentioned in the presented paper.*

Streszczenie. *W pracy przedstawiono wyniki badań termicznych opraw oświetlenia drogowego wyposażonych w sodowe i ledowe źródła światła mocy 400 i 100W. Dokonano analizy teoretycznej dróg przepływu ciepła w oprawach oraz przedstawiono wyniki badań laboratoryjnych wybranych opraw oświetleniowych. Zbadano dynamikę przyrostów temperatury oraz wpływ temperatury zewnętrznej (otoczenia) na nagrzewanie się termicznie wrażliwych elementów opraw oświetleniowych* ***(Badania cieplne opraw drogowych z lampami LEDowymi i sodowymi).***

Keywords: thermal testing of road lighting luminaries, sodium and LED light sources.
Słowa kluczowe: badanie cieplne opraw drogowych, sodowe i ledowe źródła światła.

Introduction

High pressure sodium lamps, with power rating ranging from 50W to 1000W, a commonly used as light sources in road lighting luminaires. The efficiency of sodium lamps is about 30%, with the remaining 70% of the rated power converted into heat almost completely. The ballast installed inside the luminaire may be considered an additional source of heat. The ignitor and the control system composed of electronic circuits, most often located inside the luminaire, are the elements subject to highest danger.

LED diodes are an alternative source of light, used more and more often in road lighting luminaires. The rated power of such lamps, when installed in road lighting luminaires, ranges from 20W to 300W, with about 75% of the power radiated as heat from individual LED diodes. When grouped into modules, individual, high power (1W - 1.5W) LEDs, operating with approximately 25% power efficiency, are at the same time a source of heat and elements that are most exposed to thermal degradation.

Theoretical analysis

Just like in luminaires with sodium light sources, the exchange of heat in luminaires with semiconductor light sources (LEDs) is subject to laws on conduction (Fourier's law), transfer (Newton's law) and radiation (Stefan-Boltzmann's law) [3]. In both cases, the location of the source generating heat (source of light: a sodium or an LED lamp) is generally identical, but thermal sensitivity applies to completely different elements in a sodium luminaire, than in an LED luminaire. Although a sodium lamp generates a lot of heat and heats up to relatively high temperatures (the outer bulb may reach up to 200^{o}C), it is made of materials resistant to such temperatures and is not a thermally sensitive element of the entire luminaire. In such luminaires, mainly all electronic systems (ignitors, control circuits, etc.) are subject to thermal risk and should be protected against overheating first of all. This is achieved by spatial separation, shielding sources of light from electronic components and equipping them with proper radiators for dissipating the generated heat. Fig. 1 shows the transfer of thermal energy in such luminaires.

The main location where heat is generated in luminaires with LED light sources is, just like with sodium lamps, the source of light (the LED), however, due to its low resistance to high temperatures, the LED itself is the most thermally challenged component of the luminaire [2].

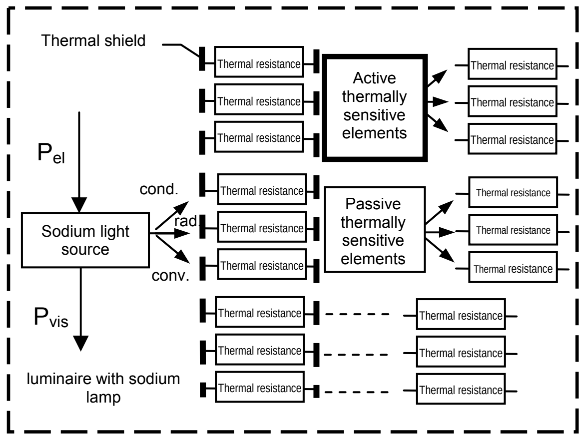

Fig. 1. Diagram of thermal power transfer in luminaires with sodium lamps

Hence, the diodes (or sets thereof) in such luminaires should be installed directly on radiators and care should be taken to properly dissipate the generated heat into the surroundings (preferably, outside the luminaire) [1, 4]. The phenomenon of heating up of electronic elements inside the luminaire is of much less importance in this case. Fig. 2 presents, by means of a diagram, the transfer of heat within luminaires with LED light sources.

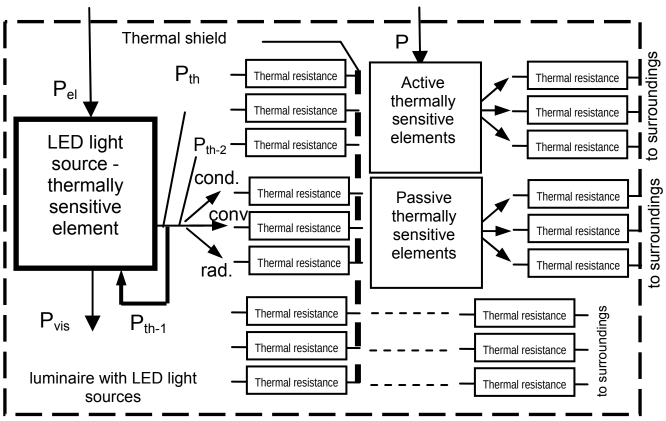

Fig. 2. Diagram of thermal power transfer in luminaires with LEDs

Scope of thermal examination and measurement system

A number of luminaires with sodium and LED light sources, with power rating from 100W to 400W, by various makers, were examined by measuring temperature in various points of the luminaire. The researchers selected power ratings at which the heating up of luminaire components becomes a significant issue and identified which luminaire elements are affected.

Tables I and II present the types and pictures of examined luminaires.

Table I Selected types of examined luminaires

No.	Luminaire type	Lamp type	Pwr [W]
1	SGS306 TP PE 400W	SON-T-Plus-400W	400
2	IVF 4 7035B 400W	SON-T-Plus-400W	400
3	LED4UC2	HP LEDs	107

Table II Selected luminaires

Examined luminaires		
		
SGS306 TP PE 400W	IVF 4 7035B 400W	LED4UC2

The measurements were taken as shown in Fig. 3, using NiCr-Ni thermocouples, 0.2 mm diameter, and a 4-channel recorder type C 309 by CENTER. SE309 graphics software was used for final data processing.

The following were measured for sodium lamps: the temperature of the upper surface of the ballast (T1), of the side surface of the ballast or the ignitor, if present inside the luminaire as a separate electronic element (T2), of the atmosphere inside the chamber holding the electronic circuits and the ballast (T3) and of the ambience (T4).

The following were measured for LED lamps: the temperature of the upper surface of the LED lens (T1), of the radiator, in the middle of a rib (T2), of the atmosphere inside the luminaire (T3) and of the ambience (T4).

Measured results

The recorded temperature graphs and their maximal (stabilized) values are, for luminaires in Table I and II, as follows:

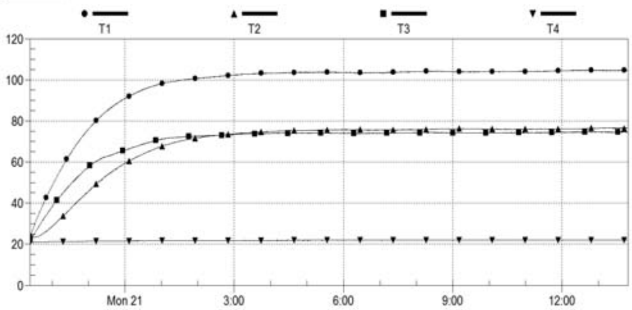

Fig. 4 Temperature change graph for SGS 306 SON-T 400W luminaire at ta = 20°C

Table III Maximal (stabilized) temperatures of SGS 306 SON-T 400W luminaire

No.	Temperature measurement point	Symbol	Max temp. [°C]
1	upper surface of ballast	T1	104.8
2	side surface of ballast or ignitor	T2	76.7
3	atmosphere inside chamber	T3	74.8
4	external atmosphere	T4	22

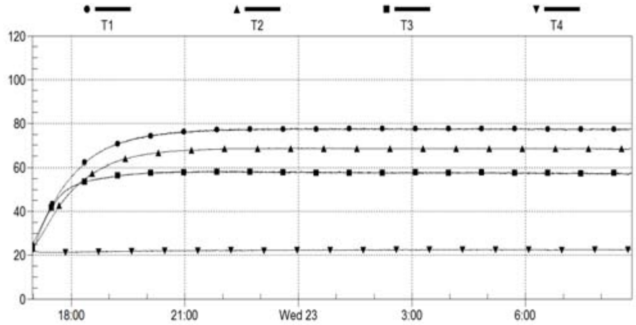

Fig. 5 Temperature change graph for IVF4 7035 B CII S 400W luminaire at ta = 20°C

Table IV Maximal (stabilized) temperatures of IVF4 7035 B CII S 400W luminaire

No.	Temperature measurement point	Symbol	Max temp. [°C]
1	upper surface of ballast	T1	77.9
2	side surface of ballast or ignitor	T2	68.6
3	atmosphere inside luminaire	T3	58.6
4	external atmosphere	T4	22

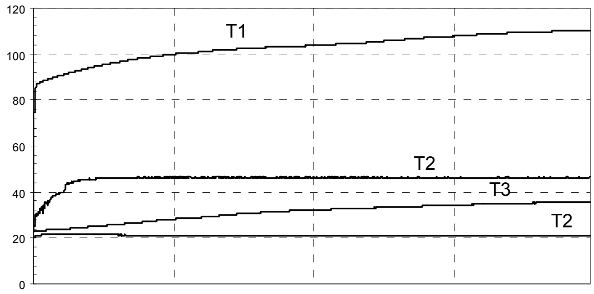

Fig. 6 Initial temperature change graph for LED4UC2 100W luminaire at ta = 20°C

Table V Maximal (stabilized) temperatures of LED4UC2 100W luminaire

No.	Temperature measurement point	Symbol	Max temp. [°C]
1	LED lens tip	T1	115.1
2	luminaire radiator	T2	46.5
3	atmosphere inside luminaire	T3	37.5
4	external atmosphere	T4	21.2

A test to explain the impact of external atmosphere temperature on the temperature of the examined elements of a luminaire was also performed. Table VI presents the obtained results for luminaires equipped with sodium light sources at ta=20 °C and ta=30 °C.

The analysis of the measurement data makes it possible, too, to determine the dynamics of heating up of the most sensitive elements of the examined luminaires. Tables VII and VIII present the obtained results.

Table VI Temperature of thermally sensitive elements at various ta T1-T4 as in Fig. 4-5

Luminaire type	Pwr [W]	Temperatures [°C]				
		ta	T1	T2	T3	T4
SGS 340 SON-T 400W	400	20 °C	104.8	76.7	74.8	22
		30 °C	110.5	80.7	78.8	31.1
IVF4 7035B CII S 400W	400	20 °C	77.9	68.6	58.6	22
		30 °C	81.2*	70.5*	65.5	31.1

Table VII The dynamics of temperature rise in thermally sensitive elements of luminaires with LEDs

Luminaire type	Temperature rise * ΔT		Heating time
LED4UC2 100W	% of max value	°C	s/min/h
	50	46	3 s
	75	69	3 min 10 s
	80	73.6	8 min 20 s
	95	87.4	53 min
	100	92	about 2 h

* for LED luminaire, the temperature rise above ambient temperature was measured on LED lens

Table VII The dynamics of temperature rise in thermally sensitive elements of luminaires with sodium light source

Luminaire type	Temperature rise * ΔT		Heating time
SGS 306 SON-T 400W	% of max value	°C	s/min/h
	50	41.3	1 h
	75	61.9	2 h
	80	66.1	2 h i 20 min
	95	78.5	4 h i 20 min
	100	82.6	about 14 h

* for SGS luminaire, the temperature rise above ambient temperature was measured on upper surface of ballast

Summary

When considering thermal limits of the operation of a luminaire, only the heating up of its thermally sensitive elements is a significant issue. Mostly, these include semiconductor control and adjustment elements (including ballast), for which manufacturers have specified operating temperature limits. Other components of luminaires (such as the body, lampshade and reflector) practically fail to achieve temperatures that would make their operation hazardous.

When locating the thermally sensitive elements in a separate part of the luminaire, outside the direct impact of the radiating light source, thermal limits may only exist for light source power ratings equal or greater than 400W, in the case of luminaires in standard size, with sodium source of light.

Regardless of the power and location of LEDs in luminaires where the said LEDs are the light source, such LEDs are subject to thermal hazard. This is due to the fact that LEDs are both thermally sensitive elements of luminaires and sources of significant heat.

The change in ambient temperature has slight effect on stabilized temperatures of elements of an operating luminaire.

For the examined luminaires, the time of stabilization of the temperature at 95% of its maximal value (quasi-stabilized conditions) is 1-5 hours, whereas 50% of the stabilized value is achieved after a few seconds for LEDs, and after about 1 hour for sodium lamps.

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