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EFFECTS OF THERMAL DISSIPATION ON LIGHT QUALITY AND USEFUL LIFE OF LED DISCHARGE LUMINAIRES

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In the present work, an exhaustive study of the impact of thermal dissipation on the luminous behavior of LED luminaires compared to incandescent ones is carried out. In LED luminaires, it is key to maintain the heat dissipation temperature of the light-emitting diodes within an operating range. The high temperatures in the electronic components are not essential to dissipate the heat generated. We carried out an experimental study of the thermal dissipation of several luminaires, both LED and discharge technology, analyzing the data obtained through a thermographic camera. The data was taken periodically, for 8h simulating real operating conditions, until the temperature has remained stable, after some time has elapsed since its connection to the electrical network. Subsequently, the data was analyzed to check whether there was a safe thermal dissipation, that is, that the maximum dissipation temperature did not exceed the limit temperature of the most restrictive material of what each of the studied luminaires is composed of. Thermal dissipation is the order of the day, materials are being investigated to be used as heat sinks that promote greater durability of LEDs associated with thermal conductivity.

Keywords: LED; discharge; thermal dissipation; light quality; useful life; urban lighting

EFECTOS DE LA DISIPACIÓN TÉRMICA EN LA CALIDAD LUMÍNICA Y VIDA ÚTIL DE LUMINARIAS DE DESCARGA POR LED

En el presente trabajo se realiza un estudio exhaustivo del impacto de la disipación térmica en el comportamiento lumínico de luminarias LED comparativamente con las incandescentes. En las luminarias LED, es clave mantener la temperatura de disipación térmica de los diodos emisores de luz, dentro de un rango de operación. Las altas temperaturas en los componentes electrónicos no son siendo fundamental disipar el calor generado. Realizamos un estudio experimental de la disipación térmica de varias luminarias, tanto de tecnología LED como de descarga, analizado los datos obtenidos a través de una cámara termográfica. Los datos se tomaron de manera periódica, durante 8h simulando condiciones reales de funcionamiento, hasta que la temperatura se ha mantenido estable, pasando un tiempo desde su conexión a la red eléctrica. Posteriormente se analizaron los datos para comprobar si se producía una disipación térmica segura, es decir, que la temperatura máxima de disipación no sobrepasara la temperatura límite del material más restrictivo de lo que se componen cada una de las luminarias estudiadas. La disipación térmica está a la orden del día, se está investigando materiales para ser utilizados como disipadores de calor que fomentan una mayor durabilidad de los LED asociada a la conductividad térmica.

Palabras clave: LED;descarga; disipación térmica; calidad lumínica; vida útil; iluminación urbana;

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1. Introduction

The use of discharge technology luminaires in urban lighting began in 1931 when the first mercury vapour lamps appeared in Europe. In the year 1955, a more advanced and technological evolution lamp appeared with respect to mercury vapour, called high pressure sodium vapour lamp (VSAP). The characteristics of the street lighting fixtures were improved with these lamps, but the luminous efficiency and the chromatic reproduction were the weak point of these.

Parallel to the VSAP lamp and about the year 1960, the first metal halide (HM) lamps appeared. Inside the discharge tube, metal additives are added to enhance certain areas of the visible spectrum so that it increases its performance, both bright and colored.

It was from the year 2000, when the greatest technological revolution occurred regarding consumption and energy efficiency in public lighting with the development of LED technology luminaires due to these luminaires were based on the development of power LEDs.

Currently in the field of public lighting, LED diodes of high luminosity are used, they are more complex because they incorporate elements to dissipate the heat that allow to withstand greater currents to provide more luminous flux.

LED lighting has the advantage of a longer lifetime and the luminous efficiency has also been improved, as a result, the market for LED lighting devices has grown rapidly recently [1]. However, due to this fact, there is a serious heat dissipation problem, as almost 70% of the total energy consumed by the LED lighting device is emitted as heat and must be removed for higher efficiency and longer lifetime. The performance and lifetime of LED luminaires will become poor and short if the heat is not properly dissipated [2].

Nowadays, more power is required to be applied to the LED fixture to produce more light output, therefore the total heat generated by the LED luminaire will also increase significantly [3]. All electronic devices and circuits generate excess heat and require increased attention to avoid premature failure [4]. Therefore, in order to commercialise high-power LED devices, the problem of heat dissipation must first be overcome [5].

When it comes to heat dissipation, the heatsink is the most important component to reduce the junction temperature. Most heatsinks are designed with fins to increase their contact surface with the air and dissipate more heat [6]. It will be necessary to improve the design of the luminaire components to facilitate the thermal dissipation and allow air to pass through the heatsink of the luminaires to lower the temperature of the electronic devices. To improve cooling, vents can be incorporated to improve the flow of air from inside the luminaire to the outside.

The distribution of the LEDs and the effect of the number of LEDs lit affects the junction temperature and strongly participates in LED degradation [7]. Most luminaires contain aluminium heat sinks as a solution. Materials with new alloys and formulations for effective heat dissipation are currently being investigated, for example, aluminium nitride has been developed for application as a thin layer on heatsinks that has certain advantages over conventional dielectrics based on polymers or ceramic substrates such as excellent heat dissipation and low thermal resistance [8]. The issue of heat dissipation is the order of the day, materials are being investigated for use as heat sinks that promote increased durability of LEDs due to improved thermal dissipation [9]

A good design of the luminaire where air circulation is favoured for the benefit of the dissipation of the junction temperature of the LEDs will favour the lifetime and improve the efficiency and reliability of the LEDs by having better luminous properties [10]. Apart from the design, a good selection of materials of the luminaire components where the thermal conductivity is high favours the thermal dissipation of the luminaire.

2. Instrumentation and methods

2.1 Instrumentation

A thermal imager camera (Fluke, Model: Ti25) was used to measure the thermal dissipation for the both types of luminaires (LED and discharge) under real operating conditions. The technical characteristics are detailed in the following table:

Table 1. Table of specifications thermal imager camera. Source: Fluke Ti25 user manual

1. ***Attribute***	2. ***Value***
3. Thermal sensitivity	4. ≤90mK
5. Temperature Measurement Range	6. -20 → +350ºC
7. Maximum Accuracy of Temperature Measurement	8. ±2ºC
9. Field of vision H x V	10. 23 x 17º
11. Update frequency	12. 9 Hz
13. Minimum Focus Distance	14. 15 (Thermal Lens) cm, 46 (Visual Lens) cm
15. Type of Focus	16. Manual
17. Detector Resolution	18. 160 x 120 pixel
19. Display size	20. 3,7 inches
21. Display Resolution	22. 640 x 480 pixel

2.2 Method

A simple methodology is proposed to study the thermal dissipation of new LED lighting equipment compared to discharge technologies.

Figure 1: Experimental Set-up for the measurement of thermal dissipation. Source: Own elaboration

In the previous set-up, the luminaires under test will be supplied under real operating conditions, a night-time operating regime was simulated in a completely darkened room at a normal ambient temperature of 20°C [11] and with an interval of 8 hours of continuous operation of the luminaires, which is normally the time the luminaires remain switched on during the night on a normal operating day [12]

A total of seven urban luminaires were analysed, of which five corresponded to LED technology and two to discharge technology (Metal Halide and High Pressure Sodium Vapour)

The process followed in the investigation was as followed:

1. The study of thermal dissipation phenomena of street lamps consisted in two days of analysis of the seven luminaires. LED lighting and discharge technologies were tested during eight hours and there were thirteen data measurement intervals, which are broken down into:
    a) *Transitional state*: The temperature evolves quickly compared to time, this state is characterised by a rapid increase in temperature in each of the street luminaires.
    b) *Steady state*: The temperature changes slowly and there is hardly any temperature increase in the individual luminaires. In this state the luminaire reaches its maximum operating temperature.
2. The collected data were used to drawn the heat dissipation characteristic curve of each luminaire and then the results were compared. With this results, it was

possible to evaluate the dissipation performance of each type of technology and finally draw conclusions from this study.

3. Equipment under test

The following table shows the technical characteristics of the seven urban luminaires that have been tested in this study.

Table 2. Table of technical specifications street lamps. Source: Own elaboration

23. Luminaire	*24. Technology*	*25. Power*	*26. Luminous flux*	*27. Colour temp*
28. LEDUS LGL1AS	29. LED	30. 60W	31. 6000lm	32. 6000K
33. LEDUS LRLT1A	34. LED	35. 80W	36. 8000lm	37. 6000K
38. Philips Mini Iridium	39. LED	40. 20W	41. 4321lm	42. 4000K
43. NaviaP Solydi	44. LED	45. 50W	46. 5450lm	47. 5500K
48. ATP Air 7	49. LED	50. 200W	51. 28284lm	52. 4500K
53. High P Sodium Vapour	54. Discharge	55. 250W	56. 28000lm	57. 2000K
58. Metal Halide	59. Discharge	60. 100W	61. 10500lm	62. 2800K

4. Results

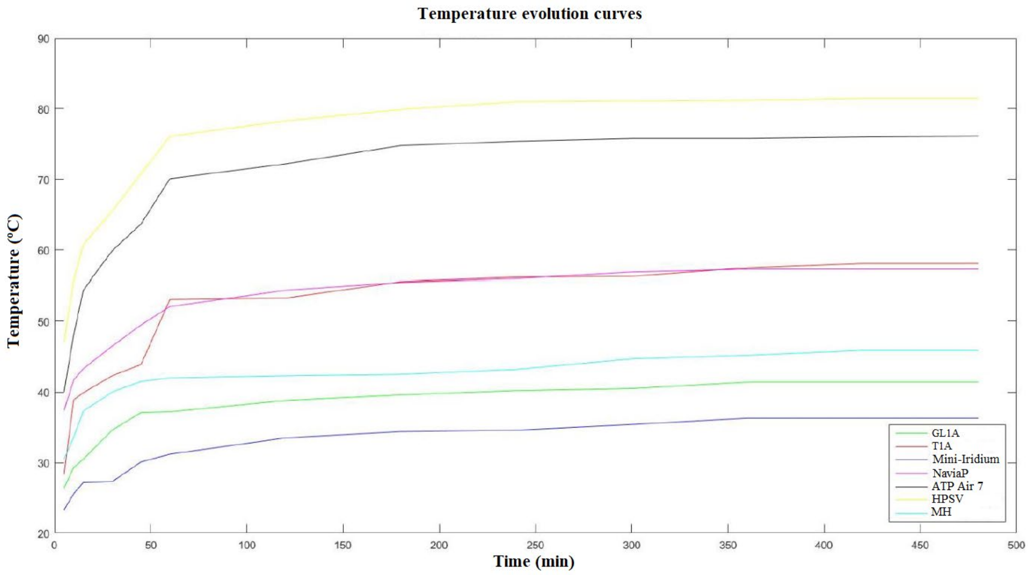
In this paper, an experimental study of the thermal dissipation of seven luminaires, both LED and discharge technology, was carried out and the data obtained were analysed using a FLUKE TI 25 thermal imager camera in the lighting technology laboratory of the University of Jaén.

When making measurements of the heatsink with the thermal imager and being a specific material with a certain alloy or formulation in the material compound, several types of emissivities have been used to obtain the exact temperature.

The maximum temperature of the dissipation system (heatsink) and housing of each of the urban luminaires was measured in simulated real operating conditions in a totally opaque room. Data were taken continuously from the ignition of the equipment until thermal stabilisation was reached. Using the data collected, the heat dissipation curve of each of the luminaires was made and compared with each other. The first step was to analyse whether a safe thermal dissipation was produced, that the maximum dissipation temperature did not exceed the limit temperature of the most restrictive material of which each of the luminaires is made.

In order to observe the thermal dissipation curve of some luminaires compared to others and to check the influence of the power of the luminaire on the maximum dissipation temperature, a graph was made for comparison, showing all the temperature evolution curves, represented in the same graph.

Figure 2: Comparison of maximum temperature evolution of luminaires. Source: Own elaboration



The temperature remains stable after approximately five hours of operation, as shown in the figure. It can be seen that the ATP and High Pressure Sodium Vapour luminaires reach a higher temperature due to their rated operating power of 200W and 250W respectively, which is significantly higher than the rest of the luminaires. As expected.

The following table 3 shows the maximum temperatures obtained in the last measurement of each luminaire in the heatsink or housing depending on the luminaire and the diffuser. It is appreciated that depending on the design, technology, power, distribution of LEDs and materials, the temperatures vary from one luminaire to another.

Table 3. Summary table of the maximum temperatures of each luminaire. Source: Own elaboration

63. Luminaire	*Maximum temperature 64. heatsink (°C)*	*Maximum diffuser temperature (°C)*
65. ATP Air 7	66. 72,7	67. 40,2
68. NaviaP Solydi	69. 55,4	70. 39,3
71. LEDUS LGL1AS	72. 39,3	73. 67,8
74. LEDUS LRLT1A	75. 51,5	76. 52,1
77. Philips Mini Iridium	78. 33,7	79. 34
80. HPSV Luminaire	81. 79,8	82. 69,5
83. MH Luminaire	84. 43,2	85. 38,8

Figure 3: Power versus dissipation temperature graph. Source: Own elaboration

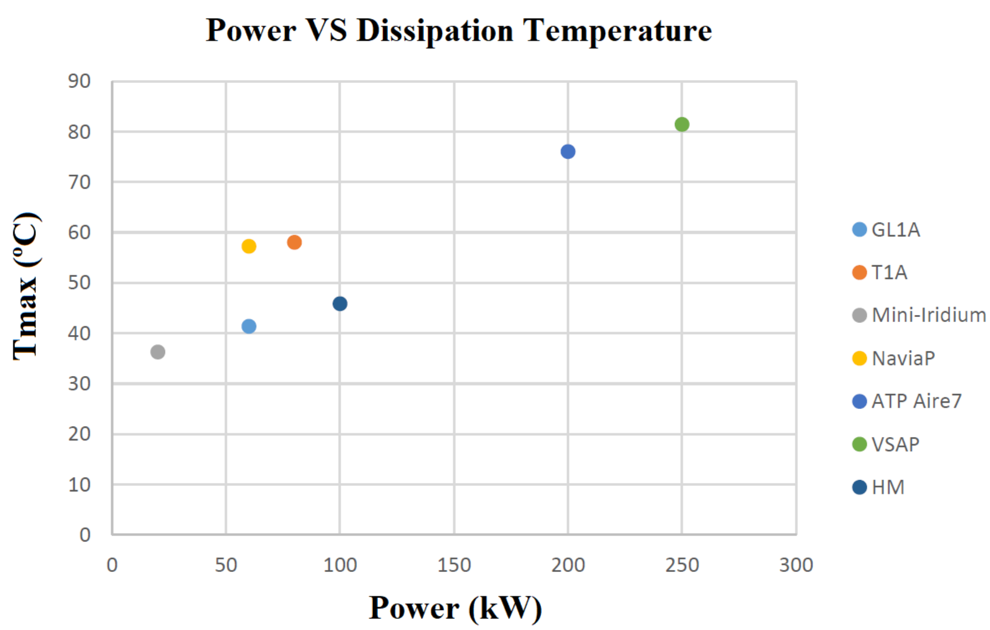


Figure 3 shows the nominal power of each luminaire versus the maximum dissipation temperature reached for each luminaire when the temperature has stabilized. It can be seen that there is no linearity of the nominal power with respect to the maximum temperature reached due to the different designs of the luminaires themselves and the characteristic materials that make up the luminaires. With proper luminaire design, having a sufficient heat sink contact surface and a selection of materials where thermal conductivity is high, thermal dissipation results will be improved [13].

As mentioned at the beginning of this section, high dissipation temperatures in luminaires are not adequate and can reduce the life of the LED of which the luminaire is composed, as well as the degradation of their luminous properties [14]. The problem of heat dissipation is a major handicap for lamps with LED technology and not so much for discharge lamps, since these are not affected by heat dissipation in terms of luminous properties, but they can affect the useful life time since they can affect the starting ballasts [15]

To study how the maximum temperature reached in the luminaire after its thermal stability affects the luminous properties of the LEDs that make up the luminaire, we will study the x-y chromaticity coordinates [16] of the CIE1931 colour space.

Subsequently, using the LED manufacturer data sheets for each luminaire, a study will be made of the evolution of the luminous coordinates Cx, Cy, as a function of the dissipation temperature [17], in order to finally obtain how much these coordinates have decreased, knowing the maximum dissipation temperature and to obtain the real impact of the temperature on the luminous properties.

In order to quantify how the colour quality of the light worsens, a comparative table of the evolution of the chromaticity coordinates of all LED luminaires due to the effect of temperature will be made.

Table 4. Comparison of chromaticity coordinates due to the effect of the maximum temperature. Source: Own elaboration

86. Luminaire	*87. ΔCx*	*88. ΔCy*
89. LEDUS LGL1AS	90. 1,3%	91. 1%
92. LEDUS LRLT1A	93. 0,5%	94. 1%
95. Philips Mini Iridium	96. 0%	97. 0%
98. NaviaP Solydi	99. 0,5%	100. 1%
101. ATP Air 7	102. 0,1%	103. 0,1%

As can be seen in table 4, the GL1A, T1A and NaviaP luminaires suffer a deterioration of the lighting properties (chromaticity coordinates) due to the maximum dissipation temperature, however, it can also be seen how the Philips LED luminaires and the ATP Air 7 are less vulnerable to the effects of high heat dissipation temperatures and practically keep their chromaticity coordinates constant.

The table also shows that the GL1A luminaire has the highest rate of deterioration of its luminous properties.

As far as discharge luminaires are concerned, the maximum dissipation temperature does not affect the chromaticity coordinates of the lamp, due to the fact that it implements a discharge technology and there are no junction temperatures as in the case of LED technology [18]

5. Conclusions

This study is focused on thermal analysis to perform verification of luminaire materials and verify that the LED temperature is not too high for the proper functioning of these light-emitting diodes, causing a variation of the luminous properties of the LEDs [19]. All electronic devices and circuits generate excess heat and require greater attention to avoid premature failures.

In this study, experimental data were acquired from five LED luminaires and two discharge luminaires of different wattages under the conditions of the lighting laboratory, with the FLUKE Ti 25 thermal camera, it is indicated that indeed the design is important due to the heat dissipation of the luminaires for the effective operation of the electronic devices.

At the time of favouring heat dissipation, the heatsink is the most important component to reduce the binding temperature. Most heatsinks are designed with fins to increase their contact surface with air and dissipate more heat. It will be necessary to improve the design of the components of the luminaire to facilitate the dissipation of heat and favour the passage of air through the heatsink of the luminaires to lower the temperature of electronic devices. To improve the cooling, ventilations can be incorporated to improve the flow of the air inside and that can go to the outside.

Due to which, it must be taken into account that public lighting discharge luminaires and where they are replaced by LED technology, ends up affecting the electronic devices if there is not good thermal dissipation. As previously mentioned in this section, the use of natural or forced ventilation would favour the heat dissipation of the electronic components.

Electronic devices are affected by high temperatures [20]. A high LED junction temperature varies the chromaticity, reducing the luminous properties, with GL1A luminaire being most affected by the high temperatures, in terms of variation of chromaticity coordinates, as it is the one with the greatest variation.

The thermal measurements give the engineer information about the temperature and the air flow inside the equipment. They allow engineers to design cooling systems to optimize the design and reduce energy consumption, weight and cost, and verify that there are no problems when the equipment is built. Most thermal simulation software uses computational fluid dynamics (CFD) techniques to predict the temperature and air flow of an electronic system.

It has been shown that the power input is proportional to the heat generated by the luminaire and depending on the design and choice of materials, the junction temperature of the LEDs is higher due to the low heat dissipation, which is detrimental to the proper functioning of the LEDs. The choice of an LED, which has a lower junction temperature than can be achieved in the luminaire, could reduce its properties by up to 100%, making the LED unusable for its intended purpose.

Currently, materials with new alloys and formulations for an effective thermal dissipation are being investigated, for example, aluminium nitrate has been developed to be applied as a thin layer in the dissipaters that has certain advantages over conventional dielectrics based on polymers or ceramic substrates such as excellent thermal dissipation and low thermal resistance. The topic of thermal dissipation is the order of the day, materials are being investigated to be used as heat sinks that promote greater durability of LEDs due to an improvement in thermal dissipation.

Due to which, it is necessary to bear in mind that the lighting fixtures of public lighting of discharge and where they are replaced by LED technology, leaving the housing of the luminaires previously installed, ends up affecting the electronic devices if there is not good thermal dissipation. As previously mentioned in this section, the use of natural or forced vents would favour the dissipation of heat from the electronic components.

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