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Energy Effective LED Module for Poultry Lighting

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Abstract – **The aim of this work is design and thermal management of energy effective LED module for poultry lighting. The spectral sensitivity of fowls differs significantly from that of humans and primary objective of this work is to match as close as possible the spectral power distribution of artificial light source to the spectral characteristics of the poultry vision. In different stages of growth of poultry adequate illumination of premises varies very widely. Therefore essential requirement to luminaires for such purposes is the possibility of their luminous flux to be dimming over a wide range while retaining its spectral distribution. These tasks have been successfully resolved in the designed module by selecting the appropriate LEDs and management regimes. Proper thermal management ensures safety regimes of operation of the LED module even at heaviest ambient conditions (temperatures up to 45ºC).**

Keywords – **LEDs' thermal management, poultry lighting, power LEDs**

I. INTRODUCTION

Current trends in the design of lighting equipment are related with making sources with continuous spectrum, similar to that of the sun. This is appropriate when it comes to humans needs lighting, natural circadian rhythm maintaining and true color reproduction [1-7]. For a number of industrial applications the use of specialized light sources, whose spectral and power characteristics are consistent with the characteristics of the illuminating object, is much more efficient. It is known [1, 2] that the poultry eye's spectral sensitivity differs significantly from the human one – Fig. 1.

Spectral characteristics of the most popular light sources in the recent past (incandescent and fluorescent) differ significantly from the optimal for chicken farms, as it can be seen in Fig. 2 and Fig. 3 [4].

Dimming these light sources is problematic and further reduces their energy efficiency. In contrast dimming of LED light sources is easy to implement and allows the management of their luminous flux widely with minor decrease of luminous efficacy.

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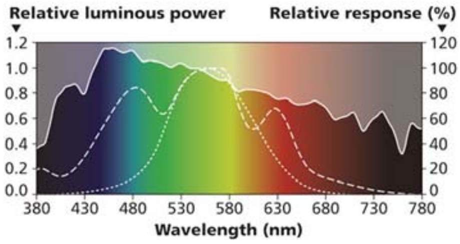


Fig. 1. Fowl (dashed) and human (dotted) spectral sensitivity, compared to sunlight spectrum (solid line) at noon [4].

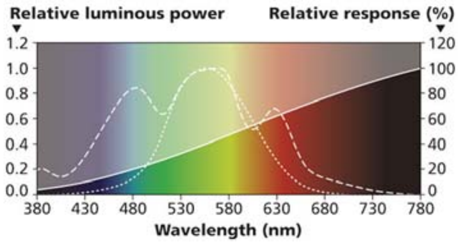


Fig. 2. Fowl (dashed) and human (dotted) spectral sensitivity, compared to incandescent spectrum (solid line).

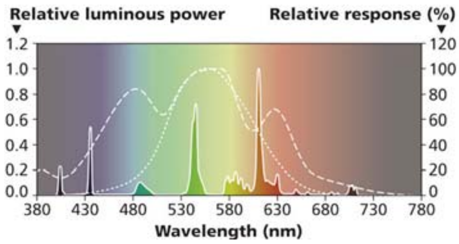


Fig. 3. Fowl (dashed) and human (dotted) spectral sensitivity, compared to fluorescent spectrum (solid line).

Application of LEDs with appropriate spectral and power characteristics enables the creation of light sources with characteristics very close to optimum. Advantages of LED lighting equipment allows solving very important problems in poultry farming because illumination affects directly poultry growth, amount of feed being consumed, maturation, reproduction, sexual activity, behavior, egg production, aggression, feather picking, etc [4 - 7].

II. PROBLEM STATEMENT

LEDs' properties allow creation of light sources with optimal characteristics considering variety of luminarie features appropriate spectral distribution of the radiation, resistant to external influences, long operational life, possibility of dimming light flux over a wide range, etc.

Domestic fowl have enhanced sensitivity to green (peak at 550 nm), reds (peak at 640 nm), blues (peak at 450 nm) and ultraviolet (peak at 385 nm) light Fig. 1.

The major task in the creation of light sources for poultry is the selection of LEDs with appropriate spectral and power characteristics. There is not a single solution; the criteria for selection may diverse.

In the literature some solutions are known – [4, 5, 6], without mentioning what type and how many LEDs are being used – Fig. 4a, 4b.

A significant problem in the use of these light sources is connected with the control of their luminous flux. In various stages of development birds need different levels of illumination, and the differences are big.

As it can be seen from Fig. 4a and Fig.4b some problems can occur at dimming – spectral characteristics of lamp's luminous flux are changed and move away from the optimal spectral distribution.

That's why the other important task is to choose the proper power source for LED lamp and the manner of dimming.

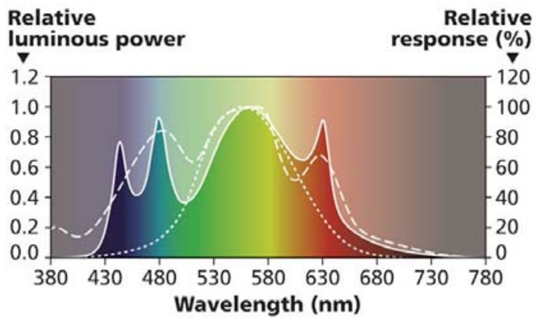


Fig. 4a. LED lamps' characteristics compared to desirable spectral characteristics for poultry housing [6].

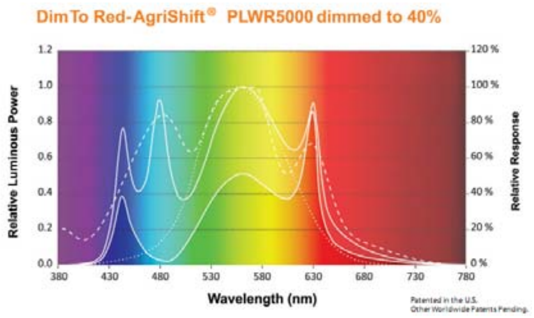


Fig. 4b. LED lamps' characteristics compared to desirable spectral characteristics for poultry housing [6].

As housing for poultry are not air-conditioned another important stage in the design is connected with the correct thermal management of the LED lamp. It is necessary ensuring trouble free operation and long life at ambient temperatures up to 50°C.

III. Experimental Results

3.1. Selection of LEDs with suitable characteristics to achieve the goals of development.

Analysis of the possibility of obtaining the desired spectral composition (suitable as a solution to the goals set above) by combining different types of LEDs based on the data specified by the manufacturer is done. A combination of LEDs suitable for achieving the desired SPD (spectral power distribution) is chosen - LEDs XLamp XTE, XPC and XPE family, CREE Inc. There are several advantages in the selection of LEDs of one type - electrical characteristics are similar, thermal resistance and the thermal loads during operation are close, dimming and thermal management are easier. The combinations of warm white, neutral white, blue and red LEDs are used for design of the experimental module.

Some of electrical and thermal characteristics of used LEDs are presented below:

- Thermal resistance between junction and solder point $R_{th\ j\text{-}sp}$:

for white LEDs $R_{th\ j\text{-}sp} = 12°C/W$; blue LEDs $R_{th\ j\text{-}sp} = 12°C/W$; for red LEDs $R_{th\ j\text{-}sp} = 10°C/W$ [1].

- Forward voltage at nominal current:

$U_F = 2.2V$ for red LEDs; $U_F = 3.3V$ for blue LEDs; $U_F = 3.2V$ for white LEDs [1].

All LEDs are powered by a constant current source.

All of LEDs are soldered on MCPCBs with thermal resistance solder point – heat sink $R_{th\ sp\text{-}h} = 1°C/W$ [1].

Experimental equipment for spectral measurement of Stellar Net Inc is used.

3.2. Experimental results - spectral power distribution (SPD) of the LED modules.

Some experimental LED modules for poultry housing are realized and tested. Proper spectral characteristics are achieved for these modules:

1 - The first module contains three warm white (XTE), two neutral white (XPC), two blue (XPE), and one red (XPC) LEDs; all LEDs are connected in series and operate at 350 mA constant current. Spectral power distribution (SPD) of the luminous flux of this module is shown in Fig. 5.

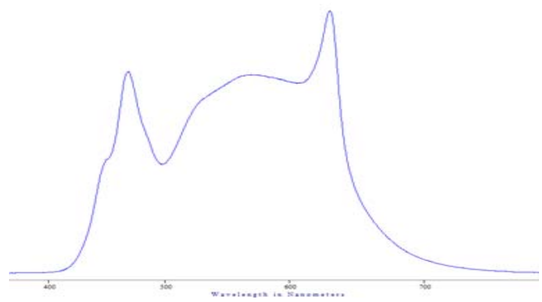


Fig. 5. SPD of the first LED module's luminous flux for poultry housing.

2 - The second module contains two warm white (XTE), three neutral white (XPC), two blue (XPE), and one red (XPC) LEDs; all LEDs are connected in series and operate at 350 mA constant current.

Fig. 6. Photo of the second LED module for poultry housing.

Spectral power distribution (SPD) of the luminous flux of this module is shown in Fig. 7.

In Fig. 6 a photo of the LED module is presented.

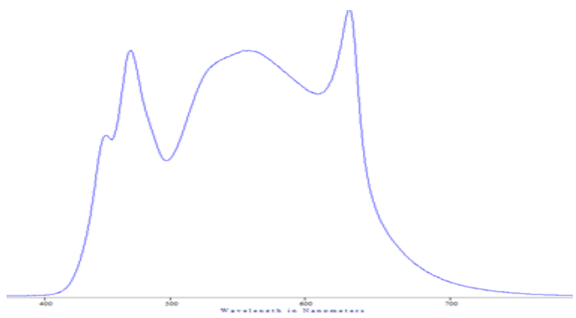
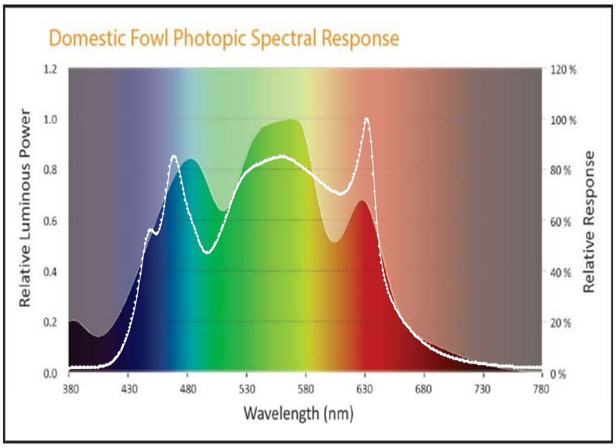


Fig. 7. SPD of the second LED module’s luminous flux for poultry housing.

SPD of the second module’s luminous flux, compared to the desirable SPD for poultry housing [6, 7] is shown in the Fig. 8.



Data source: “Spectral sensitivity of the domestic fowl (Gallus g. domesticus)” N. B. PRESCOTT AND C. M. (1999)

Fig. 8. Spectral power distribution of the second module’s luminous flux (white line), compared to the desirable SPD for poultry housing [6, 7].

As it can be seen SPD of the LED module’s luminous flux is very close to the desired SPD.

Adequate illumination of premises varies widely in dependence of the stage of poultry growth. Therefore essential requirement to luminaires for such purposes is the possibility for their luminous flux to be dimmable over a wide range while retaining its spectral distribution. As it can be seen in Fig. 4b, it may be potential problems at dimming - spectral characteristics of luminous flux can change.

The essential advantage of driving LEDs by constant current supply is possibility to dim luminous flux widely at unchanged form of the SPD.

As it can be seen in Fig. 9 at dimming to 80%, 60%, 40% and 30% the SPD of luminous flux of the second module remains unchanged.

As can be seen from Fig. 8 and Fig. 9 the achieved spectral characteristics are suitable and are very close to optimal for poultry lighting. The shape of the spectral characteristics is not altered by dimming, which is a significant advantage for adjusting the desirable value of illuminance in the poultry housing.

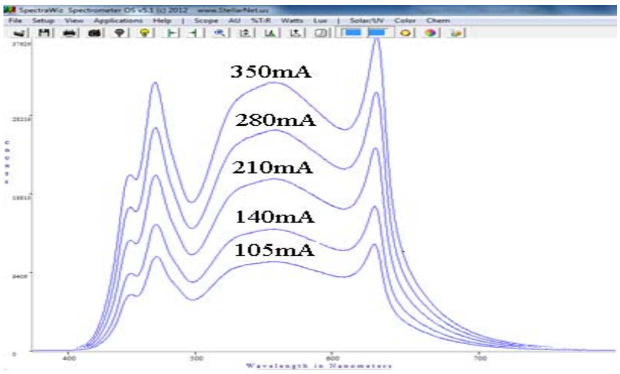


Fig. 9. Spectral power distribution of the second module at dimming to 80% (280mA), 60% (210mA), 40% (140mA) and 30% (105mA).

3.3. Thermal management.

Thermal resistance model, described in [1], is used, Fig. 10.

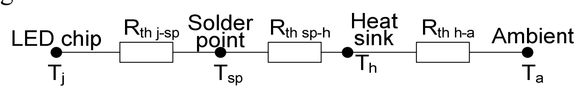


Fig. 10. Thermal resistance model [1]:
$R_{th\ j\text{-}sp}$- thermal resistance from junction to solder point;
$R_{th\ sp\text{-}h}$- thermal resistance solder point - heat sink;
$R_{th\ h\text{-}a}$- thermal resistance heat sink - ambient; T_j, and T_{sp}, - junction and solder point temperatures.

Experimental investigations of solder points’ temperature distributions at different operating currents and different ambient conditions are achieved using an infrared camera, ThermaCam E300 – FLIR Systems and corresponding junction temperatures are calculated, equation (1) [1]:

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

P_{LED} is the power of one LED chip:

$$P_{LED} = I_F * U_F; \quad (2)$$

The heat sink with thermal resistance about 1.5°C/W is used. The choice was made because of the shape of the cooling radiator, which serves as the body of the lamp and ensure hermetic isolation of LEDs from the environment.

Experimental investigations of LEDs’ thermal loading.

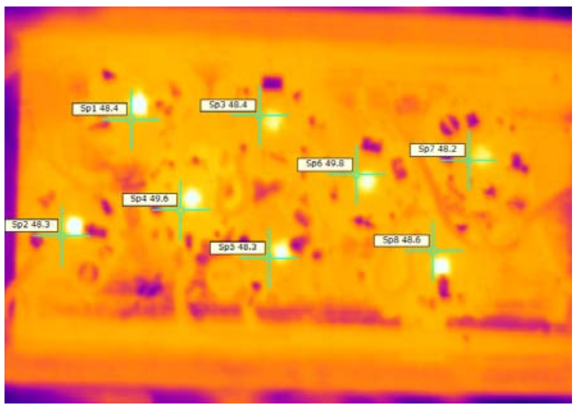


Fig. 11. IR photo of the LED module; solder points’ temperatures distributions.

The main results for different type of LEDs at maximum operating currents are presented below – Fig. 12 – Fig. 14.

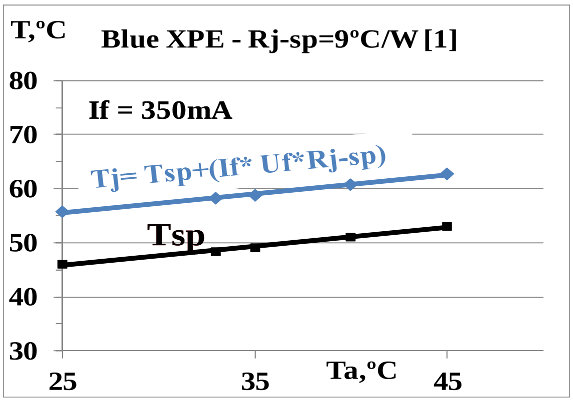


Fig. 12. Solder point's temperature Tsp (measured) and junction temperature Tj (calculated) dependences on temperature of the ambient air Ta for the blue XPE LED.

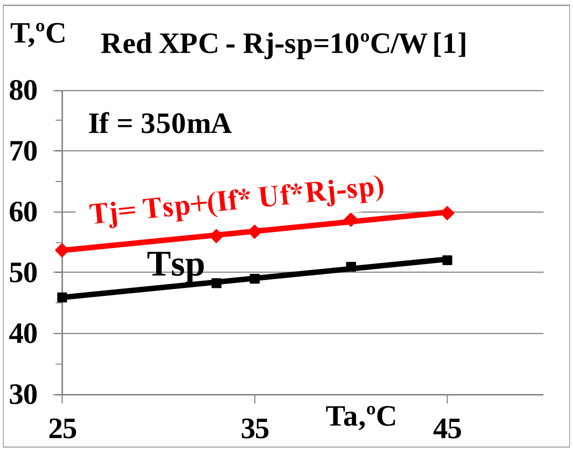


Fig. 13. Solder point's temperature T_{sp} (measured) and junction temperature T_j (calculated) dependences on temperature of the ambient air T_a for the red XPC LED.

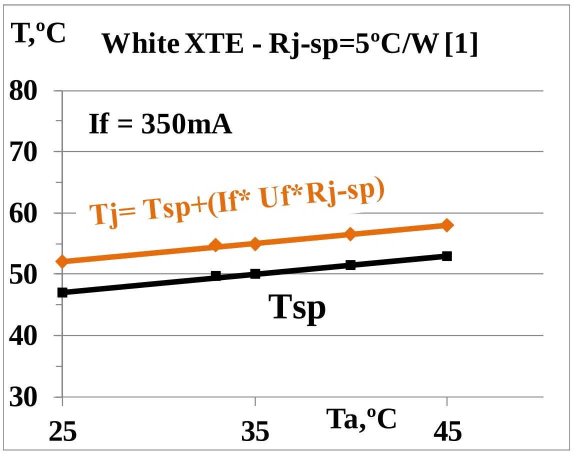


Fig. 14. Solder point's temperature T_{sp} (measured) and junction temperature T_j (calculated) dependences on temperature of the ambient air T_a for the white XTE LED.

The results presented in Fig. 12 – Fig. 14 shows that the operating temperatures of the LEDs are far from dangerous which provides reliable operation and long life of the developed lighting equipment.

IV. Conclusion

LED module for illumination of poultry houses is designed and produced. A particular combination of LEDs is selected in order to achieve a close match between the spectral distribution of the lamp and the eye sensitivity of different types of domestic fowl. Spectral power distribution of the designed luminaire is very close to the optimal spectrum, recommended in literature. Proper choice of LEDs ensures good energy efficiency of the luminaire and allows easy dimming.

Acknowledgement

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