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REPLACEMENT OF FLUORESCENT LIGHT SOURCES WITH LED

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Abstract: The replacement of existing light sources with LED technology is usually the result of the pursuit of better energy efficiency as well as trends in interior design (lighting). All technical systems have a lifetime that is difficult to estimate. The analysis performed in this paper is the result of the ballast failure of the office lighting system FLU installed in 1995, which resulted in a short circuit, followed by a noise explosion and partial melting of the copper winding housing. There was no real fire hazard, as protective and design measures prevented more unpleasant consequences than the failure of the lighting in the room. The paper shows the practical steps of lighting replacement from the initial thermographic analysis of the event to the modeling of the room using ReluxDesktop software to identify suitable luminaries that comply with the current standard EN 12464-1, which defines the requirements for lighting indoor workplaces.
Keywords: FLU, ballast, LED, thermography, Relux

INTRODUCTION

Fluorescent tubes (FLU) are the common form of lighting in business premises. The reason is economic advantages. FLU Tubes convert more than 20% of electrical energy into a useful form, light [1]. For comparison, classical incandescent bulbs convert 3% to 5% of electrical energy into light, but their (in)efficiency is accepted/tolerated by consumers and is sometimes due to application conditions (high or too low ambient temperatures). While households in the European Union were legislated to switch to more efficient light sources in 2009, in the US the transition to newer technologies begins in 2023 [2]. The figure shows the principle energy balance of the light source FLU according to [1]

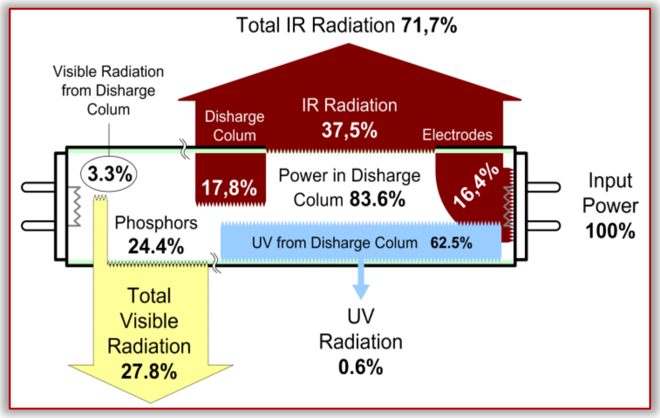

Figure 1. Energy balance of the FLU light source

Almost all business areas that have not been remodeled in the last ten years use some form of FLU tubes as light sources. They work on the principle of fluorescence and photoluminescence. Photoluminescence is a phenomenon in which UV electromagnetic radiation is converted into light with the help of a phosphor coating. There are two types of photoluminescence: materials can emit light while radiation is present, which we call fluorescence, and there are also materials that continue to emit light after excitation ceases, which we call phosphorescence.

Solid materials exhibit both properties, while gases can only exhibit fluorescence. There is a whole range of luminescent materials: phosphorus, beryllium, various silicon-cadmium and zinc compounds, etc. They are all characterized by the fact that the emitted light has a longer wavelength than the excitation wavelength. The mentioned phenomenon was first discovered by George Gabriel Stokes in 1852 [3]. The basic electrical diagram of the light source FLU can be seen in Figure 2.

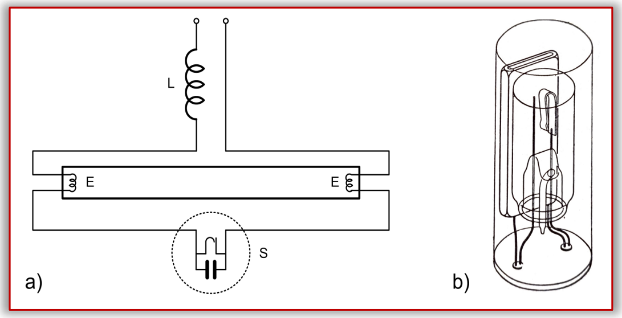

Figure 2. Circuit diagram of the FLU lighting system a) and starter switch b)

The principle of operation of the lighting system FLU (see Figure 2.) is based on the fact that when the lighting system FLU is switched on, the start switch (S) causes a short circuit, heating two tungsten electrodes (E). The heating of the electrodes causes an initial breakthrough of argon, which is ionized at lower voltages and lower temperatures, and the heat generated contributes to the vaporization of mercury vapors.

The mercury vapors begin to emit radiation at 253.7 nm, which is converted to visible light on the phosphor layer. To regulate the process and prevent burnout, a ballast is added that causes a voltage drop in the circuit and a decrease in current. The process of voltage drop and current regulation occurs continuously as the voltage of the power system changes. From the energy balance (and the circuit diagram, Figure 2.), it can be seen that all the energy flows through the ballast, causing it to heat up. In recent times, in order to reduce flicker and switching current, electronic ballasts have been developed, but the physical background of light emission has remained the same.

REPLACING FLUORESCENT LIGHT SOURCES WITH LED TECHNOLOGY

Analysis of unanticipated failure of FLU lighting ballast

Motivation for this work was the failure (explosion) of the ballast of a FLU lighting fixture located in the cabinet 2-29 of the Faculty of Electrical Engineering, Computing Science and Information Technologies Osijek at the location Kneza Trpimira 2b. The lighting fixture was installed in 1995 as part of the modernization of the lighting system. On average, the light sources (tubes) were replaced every 5 years, while a visual inspection did not reveal any problems with the ballasts (change in color of plastic or connector). On June 23, 2022, the room temperature reached 29 °C. The cabinet, which is protected from the sun by tree canopies, must be artificially illuminated according to EN 12464-1:2021, [4] so the lighting was in operation. An explosion occurred in one of the lamps, accompanied by smoke and unpleasant odor. Thermographic inspection shows the first three minutes of the event, which caused a short circuit and turned off the entire lighting system. Figure 3 shows the thermal pattern immediately after the explosion.

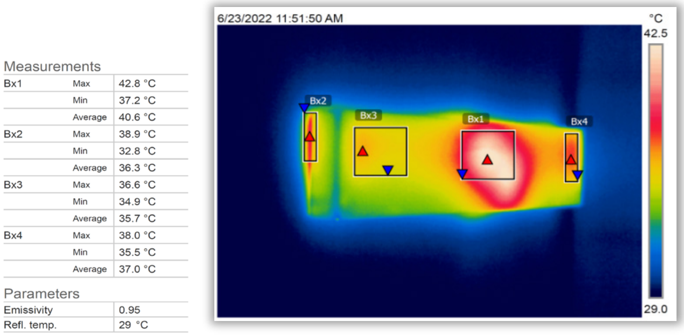

Figure 3. Thermal pattern immediately after ballast failure

Figure 4 shows a piece of ballast that came loose and fell onto the diffuser of the lamp, causing the temperature to rise to 138 °C. After half a minute, another piece of ballast falls onto the diffuser, but it cools quickly. By removing the diffuser, the cause of the short circuit and the extent of the damage could be determined (Figure 6 and Figure 7).

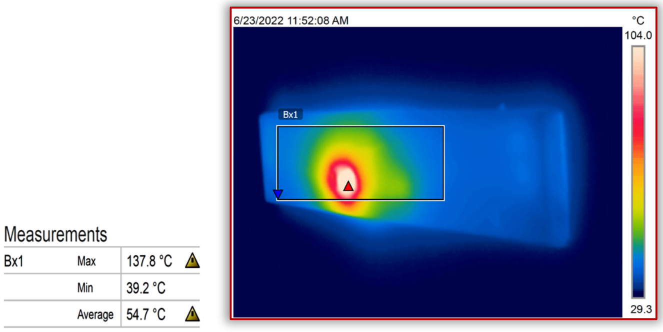

Figure 4. A piece of molten ballast falls on the base of the diffuser

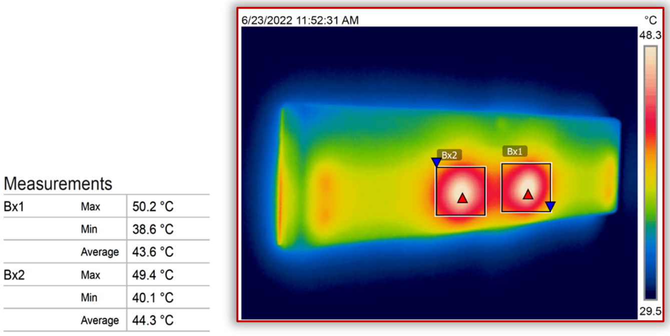

Figure 5. Two pieces of ballast on the base of the diffuser in gradual cooling

Figure 6. The diffuser of the lighting fixture and pieces of the plastic housing of the ballast previously observed by thermographic inspection

Figure 7. The extent of damage due to a short circuit of one of the ballasts

A thermographic inspection of the ballast also revealed the limitations of the Flir 60bx infrared thermal imaging camera, which measures up to 150°C. The indicated temperature does pose a fire hazard, but due to the sheet metal support separated from the ceiling structure by joints and the design solution, the fire hazard is minimal. The approximate temperature of the other two ballasts can be seen in Figure 8 and is 90 °C.

Measurements

Bx1	Max	150.2 °C
	Min	102.0 °C
	Average	140.4 °C
Bx2	Max	97.2 °C
	Min	90.5 °C
	Average	96.2 °C
Bx3	Max	89.0 °C
	Min	87.9 °C
	Average	88.6 °C

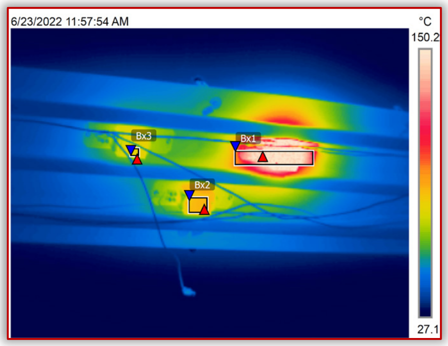

Figure 8. Partial thermographic analysis due to the limited temperature range of the camera

Implementation of corrective actions on the office lighting system

After inspection, the entire lamp was turned off (not just the defective circuit) because the connecting conductors had insulation damage, as shown in Figure 7. The location of the defective lamp in the office is shown in Figure 9, and the affected lamp itself is highlighted by a red ellipse.

Figure 9. The location of the faulty lamp in the office

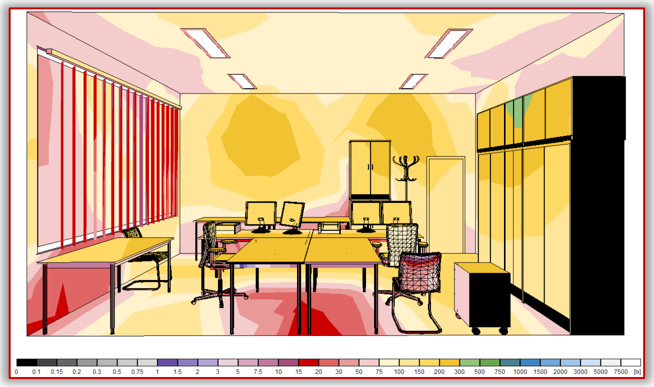

Figure 10. Analysis of the initial conditions assuming that all lighting fixtures are in operation

Before the lighting system was put into operation, it was necessary to plan corrective actions. The process begins with analyzing the initial condition by modeling the office space in RELUX program support and determining the lighting parameters, i.e., how they meet the requirements of the standard EN 12464-1:2021 Light and lighting - Lighting of work places - Part 1: Indoor work places. Figure 10 shows the situation where lighting levels on work surfaces do not exceed 300 lx. It was clear that simply replacing lamps was not the optimal solution.

The main problems of the existing system are the replacement and disposal of the FLU tubes every five years, the higher power consumption compared to today's affordable LED lighting and, above all, the impossibility of predicting the life of the remaining ballasts, which are 28 years old.

Another benefit of replacing FLU with LED is seen in the potential reduction of the characteristic 100 Hz flicker of FLU, but also in the significant increase in color rendering index due to the richer spectral composition of the LED source. In Figure 11, the spectral composition of the LED illumination is represented by a blue curve, while the spectrum of the FLU illumination is represented by an orange curve [5]. The spectrometer used for the analysis of light sources for the purpose of this paper is SPECTRA 1, manufactured by Kvant [6].

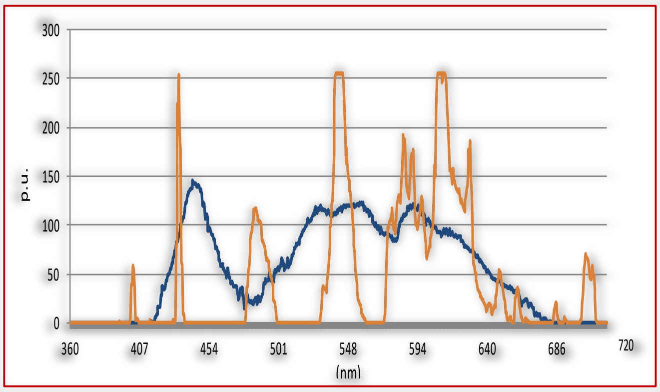

Figure 11. Comparison of the spectral composition of LED (blue) and FLU light source (orange)

Modeling of a new LED lighting system

The development of the new system was preceded by an analysis of the currently available sources in the Osijek area. Considering the fact that in the LED technology 85% of the energy is converted into light, while the energy balance from Figure 1. gives information about the efficiency of the source FLU of 27%, based on the existing installed power per lamp of 3 × 36 => 108 W, we can roughly estimate that the equivalent source LED should be in the order of 60 W [7]. This does not consider the reduction in luminous flux that results from the useful life of the source. When modeling the initial condition shown in Figure 10; the luminous flux per source was 2500 - 3350 lm, which was reduced by the diffuser and the age of the light source. Considering the spectral composition, we decided to make a first analysis with the Schrack lamp Solo LED 1 × 55 W 6000 lm, [8], price 52,17 €. The model of the system with new lamps is shown in Figure 12, while the illumination values can be seen in Figure 13.

Figure 12. Lighting system model with new Solo LED 55 W lamps

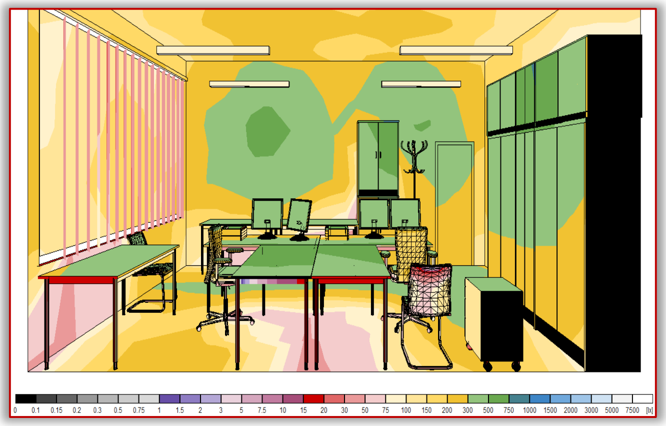

Figure 13. Results of surface illumination using Solo LED 55 W lamps

The analysis of the data obtained from the simulation shows that the new scene proposal provides values that comply with EN 12464-1:2021 and that the luminous flux of 6000 lm per lamp meets the needs of the users of the room with an illuminance of 500 lx to 750 lx on the work surface.

Installation of new lamps and lighting measurements

The installation of the new lamps took a little more time because of the arrangement of the sockets and the painting of the ceiling. Figure 14 shows the ceiling immediately after installation. The installed power was reduced from 456 W (4 × 3 × 38 W) to 220 W (4 × 55 W). If the results of the simulations prove to be good, the tariff model shows that for an investment of 208.68 €, 635.96 kWh can be acquired at current market prices, which, based on an worst case scenario of 2000 working hours per year, gives a simple payback time of the investment of one year and four months (2695 hours). These figures are very reassuring, since the guarantee on the lamps is two years and the cash flow cannot assume a negative balance.

Figure 14. New LED lighting immediately after installation

The need to make measurements lies in the basic premise of any modeling process, which is that no model is perfect and must be verified by measurement. Figure 15. shows a comparison of the spectral properties of the human eye, the new light source, and the measurement device used to make the measurements.

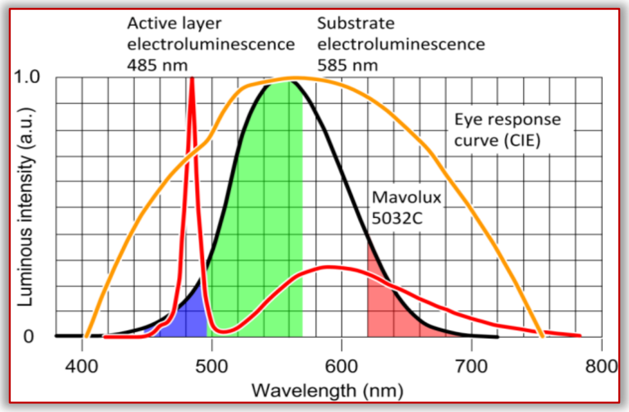

Figure 15. Comparison of the spectral response curve of the Mavolux luxmeter (black), the human eye (orange) and the spectrum of the LED white source (red), [9]

Measurements at several points were used to determine the average values on the work surfaces, which ranged from 680 lx to 943 lx [10]. Figure 16 shows the measured value on the work surface of the table located at the site of the investigated defective lamp FLU.

Figure 16. Verification of model with lighting measurement

CONCLUSIONS

Replacing existing light sources with LED technology may not always be a justifiable option from an energy efficiency standpoint. Special care should be taken when replacing FLU light sources because they have relatively high efficiency, long life, and low maintenance costs. When it comes to workplace lighting, the basic requirement is to provide enough illumination for the performance of work tasks. Standard EN 12464-1:2021 defines minimum lighting levels for certain activities. For light sources with many working hours, the energy balance stimulates the use of technology LED.

In the practical example presented in the study, the simple payback time of the investment through electricity savings is one year and four months. The analysis carried out did not consider the cost of installation, since it was carried out under exceptional circumstances. It remains an open question whether the mentioned event could have been prevented by regular thermographic inspections.

The available thermographic camera with a temperature range up to 150°C proved to be insufficient for the analysis of electrical lighting installations.

Before corrective measures are taken or light sources are replaced, calculations should be made to determine the acceptable shapes of lighting fixtures and the distribution of luminous flux. After the modification, it is necessary to confirm the success of the intervention by measurements. Calibrated instruments should be used for measurement, considering their characteristic detection properties.

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