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**Original Scientific Paper**

# LIGHT FLICKER AND POTENTIAL BIOLOGICAL EFFECTS

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**Abstract**. *Electric light sources could produce light flickers that might have biological effects. Although light flicker is not always visible to the human eye, it may impact certain human health. Eye strain, headaches, migraines, impaired vision, and, in sensitive people, photo epilepsy are just a few of the negative impacts of light flicker. Many international organisations have been working on lighting standards measurement in response to the growing concern about the flicker rate. This paper's aim is, besides summarising data from the literature, to give measured data for the flicker rate of some light sources available in Serbia and suggest further steps in the light designing process regarding flicker to avoid adverse biological effects.*

**Key words**: *flicker, lighting, biological effects*

## 1. INTRODUCTION

Light flicker is a directly visible change in a light source's luminance due to variations in the voltage of the power supply. It is also defined as the instability of the visual sensation caused by a light stimulus whose value varies over time [1]. A device for light flicker measuring, known as an IEC flicker meter, is defined by Standard IEC 61000-4-15. This device uses a model of a 60 W incandescent bulb as a reference for testing the sensitivity of electrical light sources to variations in supply voltage [2].

For a long time, many countries around the world have implemented regulations prohibiting the sale of incandescent bulbs, encouraging the use of more efficient lighting technologies, i.e., lighting that uses light-emitting diodes - LED [3]. However, this trend directly impacts the quality of electricity because new technologies used for electric light sources increase current and voltage harmonics in the network [4, 5].

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Many researchers have recently worked on developing new instruments to evaluate light flicker due to modern lighting technologies [6–9]. Besides that, much effort was invested in studying the sensitivity of new light sources to voltage fluctuations. The first results of these studies showed that new light sources are less sensitive to voltage fluctuations than incandescent bulbs [10,11].

With the evolution of technology, recent research has shown that this assumption was not always valid [12-13]. To reduce the light flicker of LED sources to a level that does not cause discomfort, it is necessary that all components that are essential for the operation of LED, such as the controller or dimmer, LED driver and LED chip itself, are compatible. Unfortunately, manufacturers are often guided by the size and price of the product and ignore the fact that this can lead to unpleasant light flickering and specific potential biological effects. Therefore, modern lighting technologies are no longer resistant to light flicker [14]. With the assistance of IEC-SC77A-WG2, the working group MT1 IEC-TC34 created an immunity procedure to assess the sensitivity of lighting equipment during the design phase [15]. Respecting the protocol ensures that newly manufactured light sources will be less sensitive to voltage changes than incandescent lamps.

The majority of the research solely took into account periodic voltage variations. However, one of the sudden fluctuations is rapid voltage changes, frequently related to singular occurrences or actions that repeatedly occur over an extended period, such as starting and stopping a motor. Researchers that have looked into the characteristics of rapid voltage changes [16–19] and the relationship with light flicker indices [10, 20] have concluded that more study and standardisation are required. The most recent edition of the IEC 61000-4-30 standard [21] was published as a result of these efforts.

## 2. Types of Light Flicker

The effects of light flicker depend on the ambient illumination, people's sensibility, and the actions being carried out in a particular space. Two types of light flicker may be distinguished:

- Visible light flicker - consciously noticed and deemed unpleasant light fluctuation. This flicker of light has a biological effect,
- Invisible light flicker - flicker that cannot be consciously noticed. Most individuals cannot detect light flicker if the frequency is over 60 Hz.

Generally, light flicker is not always harmful. Visible light flicker can be used intentionally for music concerts, i.e., stroboscopic effects. Also, cyclists use visible flicker as a flashing light for safety. However, it may have possible biological consequences in specific settings where children or adults are exposed to light for many hours each day, such as schools, offices, hospitals, industrial locations, and even homes. Some of the adverse health effects associated with light flicker include headaches, eye strain, blurred vision and migraines, worsening of autism symptoms in the case of children, and photo epilepsy. Some studies have stated that children, especially those under the age of three, are more exposed to the effects caused by flickering light than adults. Children are more sensitive to blue light, and blue light-emitting diodes (LEDs) used in toys can produce photochemical eye damage [22].

Flickering light in certain industrial production facilities can cause problems with workers' performance because it interferes with their work. Flicker can also lead to accidents due to its stroboscopic effect by altering the perception of rotating or moving machine parts.

## 3. FLICKER QUANTIFICATION

Flicker percentage (%F) and flicker index (FI) are parameters to determine light flicker. The Illumination Society of North America (IESNA) in the Illumination Manual has defined these two parameters [23]. The percentage of flicker is the relative measure of the cyclic variation in the output of a light source. It is sometimes known as the percent modulation or modulation depth [23]. A lower percentage of flicker refers to less flickering [23].

The percentage of light flicker (%F) can be calculated by using the following formula:

$$\%\mathrm{F} = 100 \cdot \frac{L_{max} - L_{min}}{L_{max} + L_{min}} = 100 \cdot \frac{\Delta L}{L_{max} + L_{min}}, \quad (1)$$

where $L_{max}$ is the maximum light output (luminance of light source) while $L_{min}$ is the minimum light output (luminance of light source), as can be seen from Figure 1:

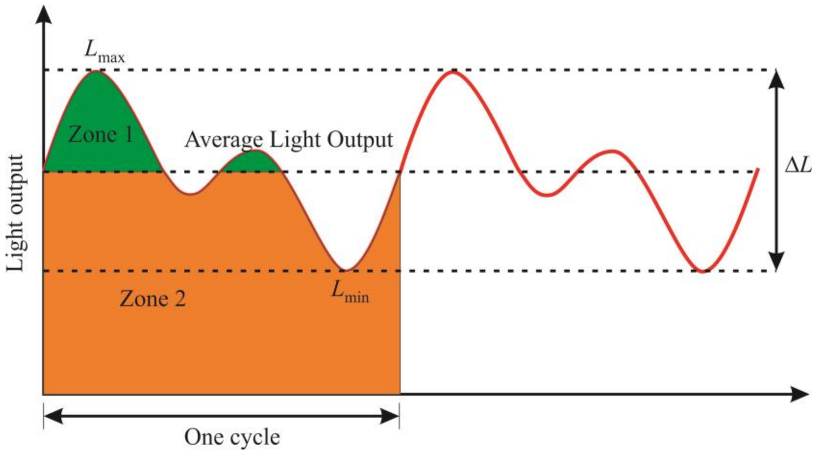



**Fig. 1** Periodic waveform reference used for calculation of flicker metrics [23]

The flicker index can be defined as a measure of the cyclic variation in the output of a light source, taking into account the waveform of the light output [23]. The light flicker index ranges from 0 to 1, where 0 indicates no light flicker. Higher values of the light flicker index indicate a greater possibility of detecting flicker [23]. Based on Figure 1, the formula for calculating the light flicker index, which takes into account the calculation of the areas of Zone 1 and Zone 2, is defined as [23]:

$$\mathrm{FI} = \frac{\mathrm{Zone\,1}}{\mathrm{Zone\,1} + \mathrm{Zone\,2}}. \quad (2)$$

Unfortunately, there is no widely recognised definition of "safe flicker" (maybe the term "safe flicker" is merely an oxymoron?). A flicker percentage of less than 10% and a flicker index of less than 0.05 are regarded as "excellent" (the lower the number, the better). The greater the flicker frequency, even if 120 Hz is the average for artificial light sources, the better. It is considered that frequencies greater than 1000 Hz have no detectable biological or physiological effects on people. A set of "recommended practices" is available under IEEE 1789, published by the IEEE (Institute of Electrical and Electronics Engineers) [24]. The IEEE rules advise a limit of no more than 8% flicker in Europe (at 100 Hz) and 9.6% in the US, considering both the amplitude and frequency of the flicker (at 120 Hz). While some individuals are more sensitive to flicker than others, and these thresholds are not ideal, they provide a helpful framework. Risk level areas represented by flicker percentage versus frequency are shown in Figure 2. The green area represents the no-effect zone, while any darkened part (orange or green) represents the low-risk area.

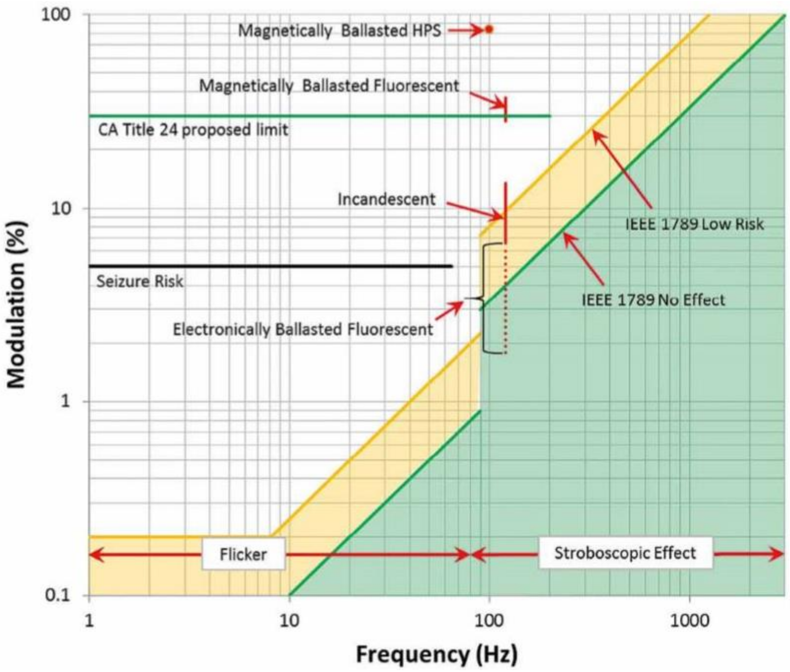



**Fig. 2** Risk level areas represented by Flicker Percentage versus Flicker Frequency [24]

One of the ways of presenting the characteristics of lamps with LED sources, according to flicker, is by defining labels like those used to display energy efficiency [25]. In the study [25], the researchers proposed defining the Light Flicker Index (LFI) value based on the incandescent bulb's reference value. When determining the reference value, i.e., specifying the LFI for an incandescent bulb, a factor of 10 has been introduced for easier presentation. The range of suggested LFI ranges from 0, which represents an ideal flicker-free lamp, to a value over 10. LFI values greater than 10 have light sources that are more sensitive than the reference incandescent lamp, and their sensitivity to conditions is considered power supply excessive. Suggested LFI classes are given in Figure 3.

LIGHT FLICKER INDEX CLASS DEFINITIONS

| Class | LFI RANGE |
|---|---|
| A | LFI < 2 |
| B | 2 ≤ LFI < 4 |
| C | 4 ≤ LFI < 6 |
| D | 6 ≤ LFI < 8 |
| E | 8 ≤ LFI < 10 |
| F | 10 ≤ LFI |

**Fig. 3** Proposal for light flicker index marking - LFI [25]

## 4. EXPERIMENTAL RESULTS

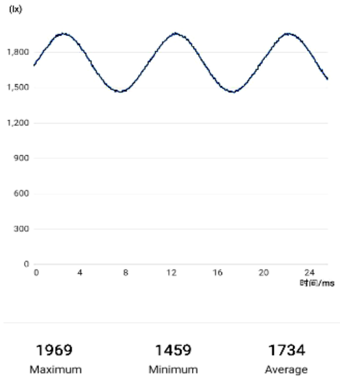
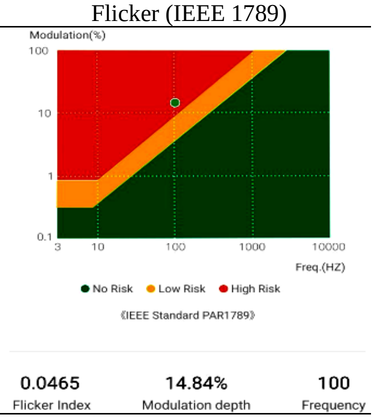
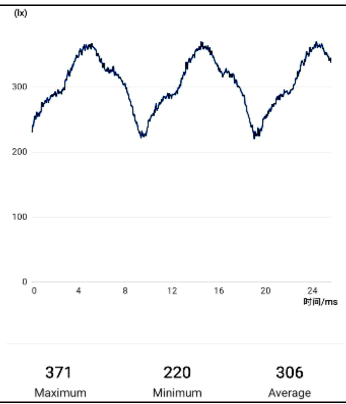
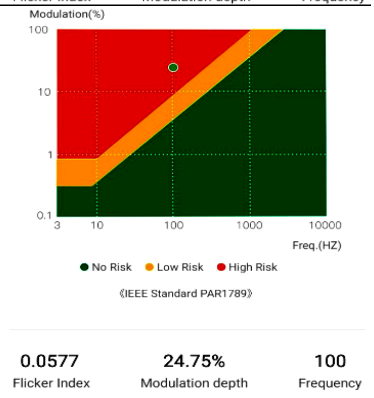
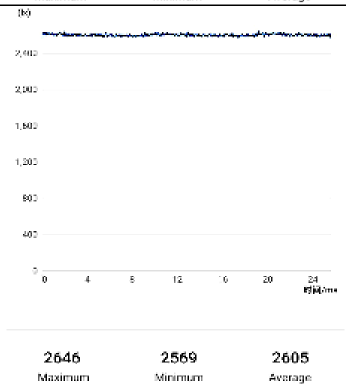
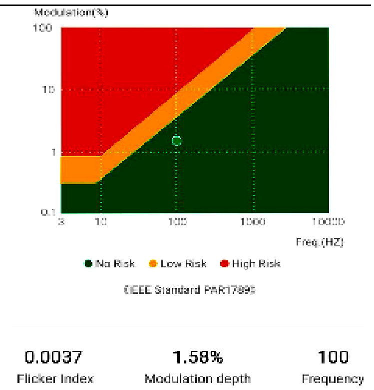
To compare results for luminaires available on the market in Serbia with results taken from literature, the flicker index and percentage flicker of LED luminaires, commonly used at homes, offices, schools and industrial facilities, were measured. Besides measurements of LED lighting fixtures, the measurement was also done for incandescent lamps as a reference value, and fluorescent tubes with magnetic ballast since luminaires with that type of light source are widely used in schools and offices in Serbia.

Measurement is performed in the laboratory with dark conditions using Opple light master pro g3, which has an accuracy of 5%, with the software Light master pro for analysing experimental results. The measuring device with a holder for bulb measurement is shown in Figure 4.

**Fig. 4** Measuring device Opple light master pro g3 with holder for bulbs

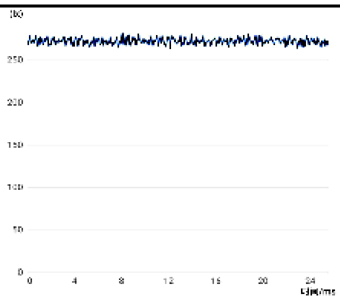
Measured results are shown in Table 1, while summarized results are presented in Table 2. Based on the measured results, one can conclude that fluorescent lamps with magnetic ballast, widely used in schools in Serbia, have higher FI and %F than incandescent lamps, indicating that this type of lighting should be changed. On the other hand most of the measured LED lamps have acceptable FI and %F values, even the dimmable ones, but we could still find LED fixtures with unacceptable data regarding flicker.

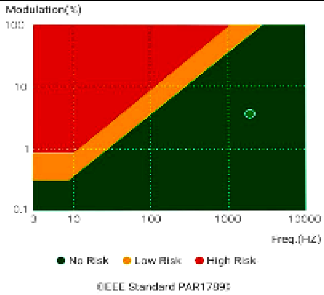
**Table 1** Flicker percentage and flicker index of measured light sources

| No. | Type | Waveform | Flicker (IEEE 1789) |
|---|---|---|---|
| I | Incandescent bulb 40W |  |  |
| II | Fluorescent tube with magnetic ballast |  |  |
| III | LED filament bulb, dimmable (100% light output) |  |  |

IV

LED filament bulb, dimmable (min. light output)

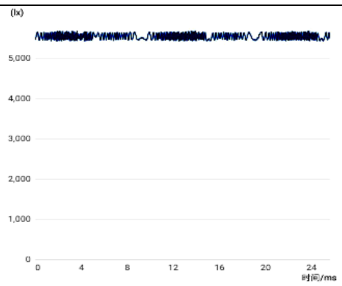


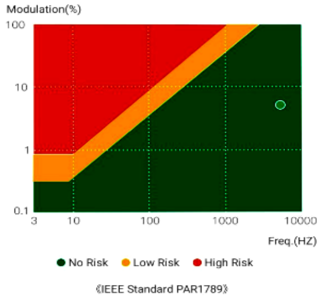




| 282 | 264 | 272 | 0.0078 | 3.86% | 2007 |
|---|---|---|---|---|---|
| Maximum | Minimum | Average | Flicker Index | Modulation depth | Frequency |

V

LED bulb (opal white globe)

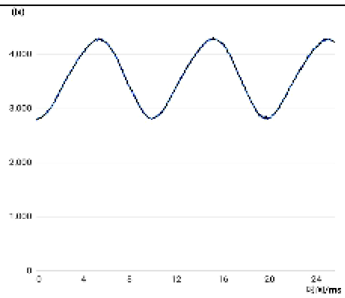


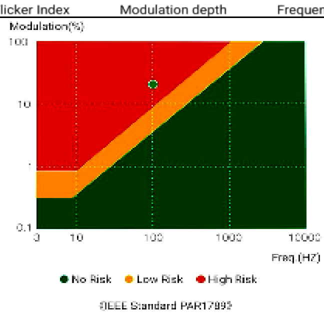




| 5694 | 5427 | 5549 | 0.0159 | 5.43% | 5462 |
|---|---|---|---|---|---|
| Maximum | Minimum | Average | Flicker Index | Modulation depth | Frequency |

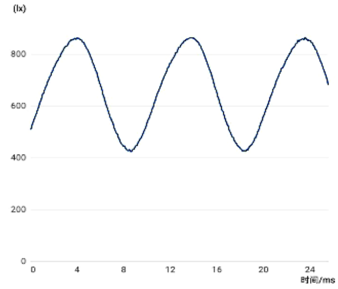
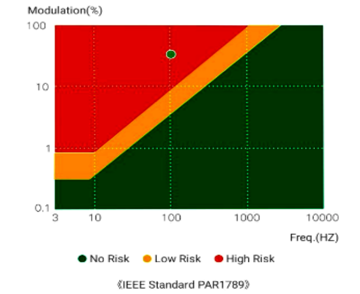
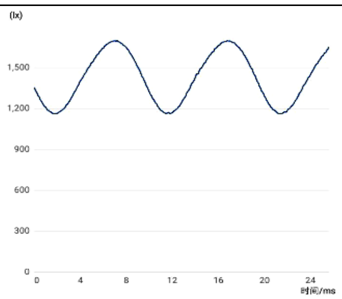
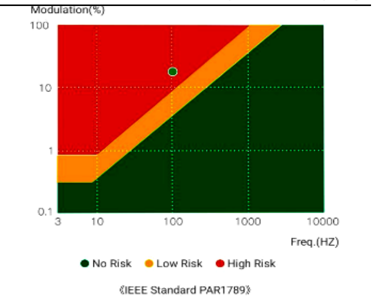
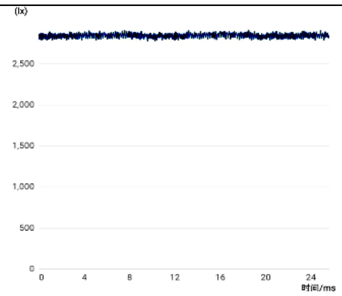
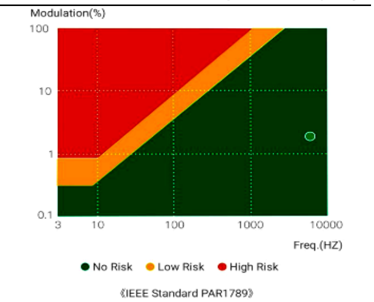
VI

LED downlighter

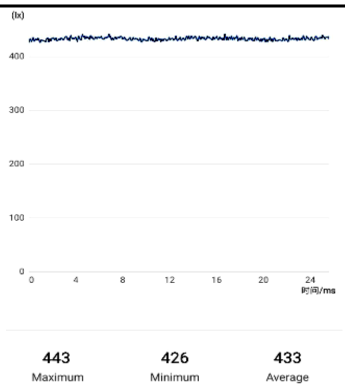


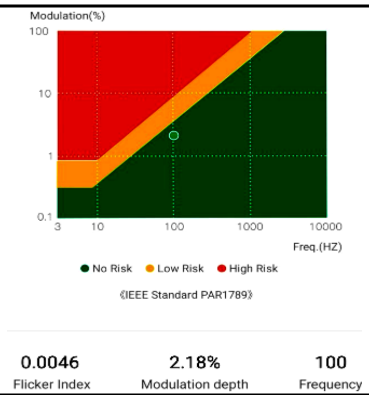




| 4306 | 2784 | 3589 | 0.0644 | 20.98% | 100 |
|---|---|---|---|---|---|
| Maximum | Minimum | Average | Flicker Index | Modulation depth | Frequency |

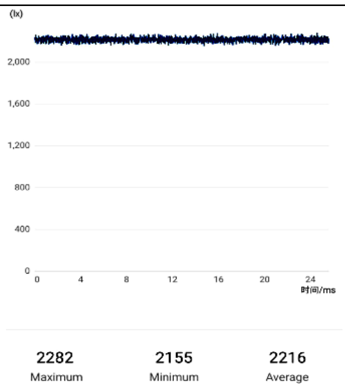
| | | | |
|---|---|---|---|
| VII | LED waterproof industrial luminaire - sample 1 | <br>865 Maximum<br>425 Minimum<br>676 Average | <br>0.1035 Flicker Index<br>33.75% Modulation depth<br>100 Frequency |
| VIII | LED waterproof industrial luminaire - sample 2 | <br>1702 Maximum<br>1159 Minimum<br>1417 Average | <br>0.0544 Flicker Index<br>18.66% Modulation depth<br>100 Frequency |
| IX | LED waterproof industrial luminaire – sample 3 | <br>2915 Maximum<br>2777 Minimum<br>2847 Average | <br>0.0053 Flicker Index<br>1.98% Modulation depth<br>6192 Frequency |

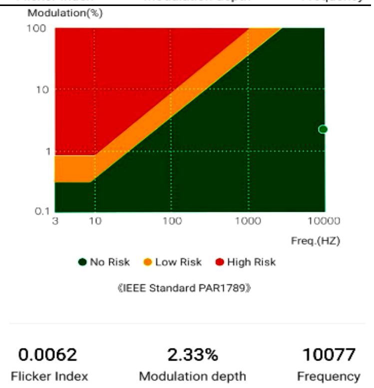
X LED waterproof industrial luminaire – sample 4



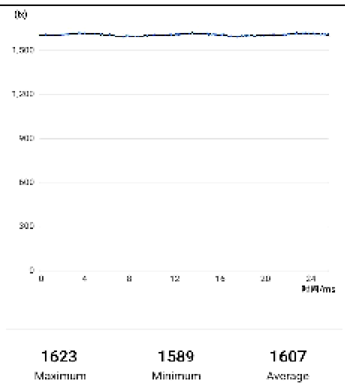




XI LED High Bay industrial luminaire




XII LED panel (for schools, offices, etc.)



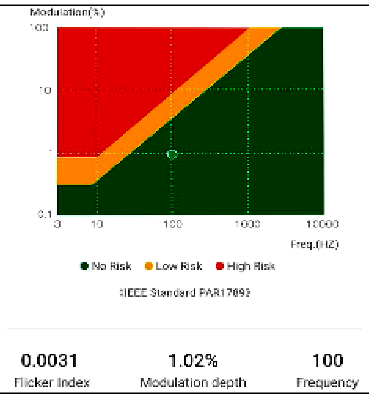



**Table 2** Flicker percentage and flicker index of measured light sources

| No. | Type | Percent flicker | Flicker index |
|---|---|---|---|
| I | Incandescent bulb 40W | 14,84 | 0,0465 |
| II | Fluorescent tube with magnetic ballast | 24,75 | 0,0577 |
| III | LED filament bulb, dimmable (100% light output) | 1,58 | 0.0038 |
| IV | LED filament bulb, dimmable (min. light output) | 3,86 | 0.0078 |
| V | LED bulb (opal white globe) | 5,43 | 0.0159 |
| VI | LED downlighter | 20,98 | 0,0644 |
| VII | LED waterproof industrial luminaire – sample 1 | 33,57 | 0,1035 |
| VIII | LED waterproof industrial luminaire – sample 2 | 18,66 | 0.0544 |
| IX | LED waterproof industrial luminaire – sample 3 | 1,98 | 0,0053 |
| X | LED waterproof industrial luminaire – sample 4 | 2,18 | 0,0046 |
| XI | LED High Bay industrial luminaire | 2,33 | 0,0062 |
| XII | LED panel (for schools, offices, etc.) | 1,02 | 0,0031 |

## 5. Potential Biological Effects

As there is concern about the potential biological effects caused by excessive exposure to LED flicker, the P1789 Committee of electrical and electronics engineers was formed to investigate the problem of LED flicker and make certain recommendations that would be implemented in practice.

Based on the research carried out by the committee, the following health effects were identified due to exposure to flickering light: photo epilepsy, the stroboscopic effect (in which moving objects appear to slow down or stop), increased behaviour that continues among people suffering from autism, migraine or intense paroxysmal headache often associated with visual disturbances and nausea, Asthenopia (eyestrain with nonspecific symptoms), including fatigue, eye strain, blurred vision, headache, and reduced performance of visual tasks. In addition, anxiety, panic attacks and dizziness have also been identified as potential effects of flickering.

## 6. Conclusion

A high level of energy efficiency, improved lighting regulation, longer life and better lighting quality have contributed to the market's growing share of LED lighting. This growth is supported by labelling these benefits on product packaging, an essential part of the global trend to improve energy efficiency. However, in recent years, studies have shown that some LED sources available on the market can have a high level of light flicker compared to incandescent ones. The measurement results presented in this paper for the available light sources in Serbia are consistent with these claims. As LED light sources can have a relatively high level of light flicker compared to conventional lights, measures have been developed to quantify flicker on a global level by introducing lighting standards. In addition, labelling is proposed to be indicated on each product. As light flicker is significant in terms of health and potential biological effects, it is necessary to consider this aspect during the lighting design stage.

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# FLIKER SVETLOSTI I POTENCIJALNI BIOLOŠKI EFEKTI

*Električni izvori svetlosti mogu proizvesti treperenje svetlosti (fliker) koje može izazvati potencijalne biološke efekte. Iako fliker nije uvek vidljiv ljudskom oku, on može uticati na zdravlje ljudi. Naprezanje očiju, glavobolje, migrene, oštećen vid i, kod osetljivih ljudi, foto epilepsija, samo su neki od negativnih uticaja flikera. Mnoge međunarodne organizacije rade na izradi standarda koji se odnose na fliker kao odgovor na rastuću zabrinutost zbog njegovog štetnog uticaja na ljude. Cilj ovog rada je, pored sumiranja podataka iz literature, da prikaže izmerene podatke za nivo flikera nekih izvora svetlosti dostupnih u Srbiji i predloži dalje korake u procesu projektovanja osvetljenja kako bi se izbegli štetni biološki efekti flikera.*

Ključne reči: *fliker, osvetljenje, biološki efekti*