Cambridge Journal of Science & Policy

A Long Overdue End to Flicker: The 2020 EU Lighting Efficiency Regulations

Communication | Editorial | Invited contribution | Perspective | Report | Review

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Abstract

Flicker, the temporal modulation of light, is an unwanted effect found in energy efficient light bulbs. It is caused by cheap ballasts, the power supplies that are required for their operation. As energy efficient light bulbs were pushed into consumer's homes by EU and US energy efficiency regulations, it has become a health concern: Flicker has been linked to eyestrain, headaches and migraines. Literature and studies on these effects were widely known by the time the first energy efficiency legislation was passed. Complex and thus more expensive ballasts have always been able to provide high quality, flicker free light, but were adopted only slowly. When fluorescent lights made their way into consumer's homes in the early 2000s, regulation was enacted that all but eliminated the flicker caused by their ballasts. When it became clear that LEDs would soon replace their fluorescent counterparts, no legislative action was taken to ensure the same performance standards. Instead, priority was given to lower lamp cost.This resulted in the widespread use of cheap power supplies in LED products released during the past decade. To consumers, the flicker behavior of lamps seemed arbitrary and a general property of LED light bulbs, rather than the result of an inadequate, yet low-cost power supply. This led to reservations about the new technology amongst consumers. The latest EU lighting energy efficiency regulation (EU) 2019/2020 finally made LED based light bulbs flicker free by enacting strict performance limits on ballast performance. The United Kingdom must adopt similar standards or risk seeing all those low-quality light bulbs that cannot be sold on the EU market on store shelves. This policy brief aims to inform about the fundamental cause of flicker in artificial lighting, its negative effects on wellbeing and considers the drivers of EU legislative response in support of advances in lighting technology.

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1 Introduction

We are surrounded by artificial light wherever we go. It has become integrated into our environment, be that it in the office, in factories, hospitals or at home. Yet, its importance for economics and human well-being cannot be understated. Historically, human productivity has been directly correlated with the available amount of artificial light [1]. Such was our hunger for fuelling the lamps that provided us with the urgently needed illumination, that humans hunted entire species of whales to the brink of extinction for their fat-rich blubber. Even today, more than 10% of total produced electricity is used to light our homes, streets and factories [2].

Following the commercialization of the incandescent light bulb by Thomas Edison in 1879, efficiency improvements were few and far between. Better glowing filaments and inert gas fillings eventually led to halogen light bulbs still on store shelves today. Their low average efficiency of 15 lm/W mean that more than 90% of energy was radiated as heat instead of visible light. Edison also experimented with fluorescent lights but initially did not pursue their development further. Operating at a higher efficiency of 100 lm/W, their large scale deployment in factories and offices started in the 1920s. Research into light emitting diodes (LEDs) started in the 1950s and led to the first use of red LEDs in computers and calculators in the 1960s. High cost and low light output limited their use to indicator lights. Only when Shuji Nakamura and colleagues achieved a performance breakthrough in blue LEDs in 1993 did scientists start to see the possibility of general illumination applications for LEDs [3]. Since the first prototypes of red LED lights in 1968, light output increased 30-fold per decade with prices falling 10-fold. Today, efficiencies in excess of 200 lm/W have been achieved.

In the wake of technological improvements, the first regulations on lighting energy efficiency were proposed shortly before the turn of the 21st century. In 2009, the incandescent light bulb was being phased out in Europe and the United States [4, 5]. The projected savings resulting from the enforcement of increasing minimum efficiency requirements (Figure 1) are impressive. Regulations put in place in 2009 and 2012 are currently saving EU consumers 20 Bn.€ annually, compared to a scenario without any legislative action on the behalf of energy efficient lighting. Electricity consumption was decreased by 93 TWh annually, the equivalent of the total consumption of Croatia [6].

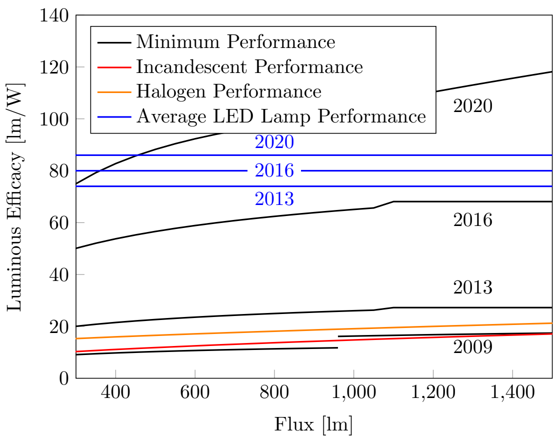

Figure 1: Minimum required efficacy for lamps set out in EU regulations 244/2009, 1194/2012 and 2017/2020. The performance curve for the year 2009 still shows a discontinuity at 900 lumens, an exception originally made for household bulbs. Efficacy takes into account the wavelength-dependent sensitivity of the human eye and describes how efficiently electrical power is converted to the radiant power of a light source. Sources: [4, 7, 8].

Yet these energy efficiency regulations were implemented at a time when the most affordable technology able to meet requirements were fluorescent lights. These contained considerable quantities of mercury and produced a spectrum that is known to interfere with the human circadian rhythm [9], increase the likelihood of eye disease [10] and alter cognitive performance [11]. More importantly, a completely new problem came with the use of fluorescent and LED lighting: flicker, the visual unsteadiness of light output. The discomfort and health issues that came with it were addressed by legislation in fluorescent lights as they entered consumer's homes but were disregarded for LEDs until recently. For once, public concern about EU legislation was supported by scientific evidence from the very beginning.

More than a decade into the post-incandescence era, the European Union has finally fixed legislation to include strict performance requirements

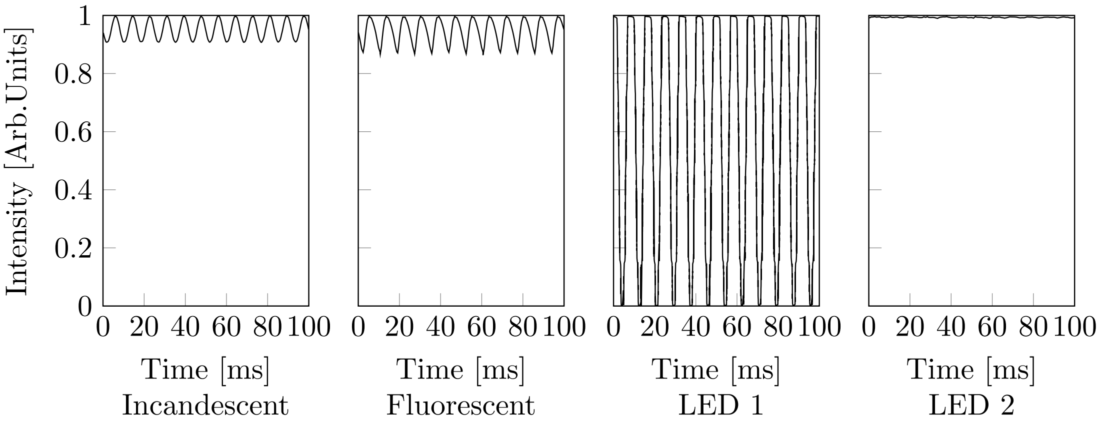

Figure 2: Time-dependent light intensity of incandescent, fluorescent and two different LED light bulbs. The incandescent bulb shows little modulation in its light intensity and thus good flicker performance. Significant increases in modulation can be seen for the fluorescent bulb. LED 1, equipped with a cheap ballast, displays levels of modulation that cause flicker at a level that is classified as 'dangerous' according to the safety guidelines from Figure 3. LED 2, equipped with a more complex and more expensive ballast, shows no visible flicker. Source: [12].

on all aspects of light quality and energy efficiency. Earlier concerns about the problem were relegated with references to the higher cost of the needed technology. Considering the history of flickering lights can provide useful insights into how negligence has fuelled public concern and contributed to consumer uncertainty.

Theory of Flicker

Flicker, the temporal modulation of light intensity, is a ubiquitous phenomenon. We are confronted with it in the form of rays of sunlight shining through roadside trees or flashing neon signs. At certain combinations of frequency and intensity, flicker can have unwanted effects on health.

Temporal modulation of intensity in artificial light sources can have different causes, but fundamentally stems from the use of alternating current (AC) of roughly 50Hz in our electrical mains. Following the 'War of the Currents' between Thomas Edison and George Westinghouse in the late 1880s, AC power distribution systems became widespread [13]. Current in our appliances reverses direction 50 times per second, effectively switching all electrical lamps on and off at twice that rate.

Following the commercialization of tungsten-filament incandescent light bulbs at the turn of the twentieth century, this had little effect on the quality of light. The afterglow of the tungsten filament in incandescent bulbs is long enough to smear the effect of the AC current. The first prominent examples of flickering appliances only came to market in the 1930s in the form of fluorescent light tubes. No afterglow is present in this technology, owing to their fundamentally different mode of operation. Connected directly to the grid, these lamps produced flickering at a rate of between 100-120Hz. LED lamps too have no afterglow momentum and cannot be connected directly to power mains[1]. Dedicated electronic power supplies, called ballasts by lighting professionals, are thus used for both technologies. In theory, they should mitigate flicker and protect the light bulbs from surges in the electricity grid. However, the increased cost associated with high performance ballasts makes them the bottleneck of light quality and ultimately responsible for flicker. The comparison of time-dependent intensity of the different types of light bulbs discussed is shown in Figure 2.

[1]Confusion is sometimes caused by 'Driverless LEDs', which in fact *do* have drivers (ballasts), which are integrated into the circuit board on which the LEDs are mounted.

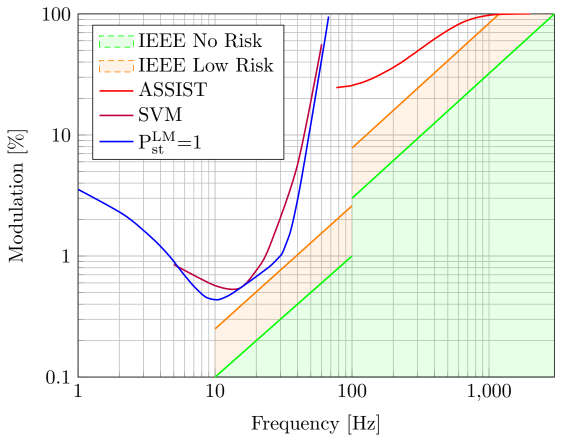

Figure 3: Limits for human perception of flicker, according to different models : ASSIST by Rensselaer Polytechnic Institute, the IEEE and SVM/P_{st} by the IEC. Below the curves, flicker is invisible to the human eye. The shaded areas give an approximate risk assessment for health issues caused by exposure to flicker. The human nervous system is most sensitive to flicker in the range of 10<f<50Hz, as can be seen from the curves. The $P_{st}^{LM} = 1$ curve has been adopted as a minimum performance limit in EU Regulation 2019/2020. It is equivalent to the levels of flicker present in incandescent light bulbs. Sources: [14, 15, 16].

Reliably measuring flicker is a challenge in and of itself. A meaningful metric must include both the waveform of the light intensity, the base frequency of flicker and the frequency dependence of human flicker perception, shown in Figure 3. Still, the most commonly reported metrics today describe only basic waveform properties like minimum and maximum values [12]. Out of many recent attempts made to combine frequency, modulation and human visual response into a compound metric [17], the European Union has settled on P_{st}^{LM}, the short-term flicker indicator. Defined by the International Electrotechnical Commission, it takes into account the frequency-dependent sensitivity as well as base frequency and waveform. The output is a real number, indicating the likelihood of flicker detection by an average observer. Lower numbers indicate lower levels of flicker and thus lower likelihood of detection. A value of $P_{st}^{LM} = 1$ corresponds to the amount of flicker produced by a 60W incandescent lamp with average mains voltage modulation. This value is chosen such that a 50% of human test subjects can identify flicker [18]. Values of $P_{st}^{LM} = 1$ are achieved by fluorescent lamps with electronic ballasts, while values of $P_{st}^{LM} > 1$ are easily achieved by inadequately driven LEDs.

As can be seen from the bibliometric analysis in Figure 4, the health effects of lighting flicker had been an active area of research before the advent of LED lighting for general illumination in 2010. Such was the concern about flicker that even the effects on captive birds were studied, showing that the amount of flicker affected mate choices made by females [19]. Exposure to light flickering at 100Hz has been linked to eyestrain, headaches and migraines, even though this rate of flicker is above the human perceptual flicker-fusion frequency of around 60 Hz [20]. Effects of flicker on humans were summarized most recently in a 2010 review by the IEEE, the largest professional organization of electrical engineers [20].

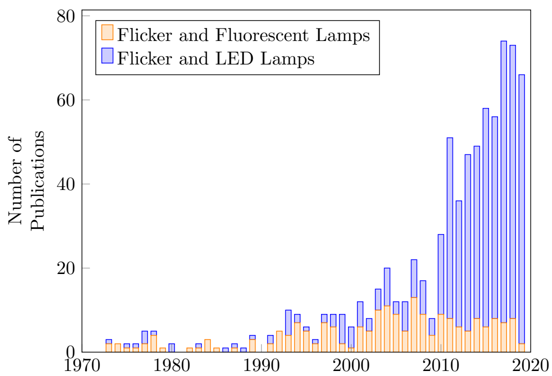

Figure 4: Stacked plots of the number of publications dealing with flicker related to lighting technologies. Data from Elsevier Scopus.

The Ballasts

Fluorescent lamps and LEDs alike have no afterglow and translate the rapidly changing mains current directly to light. For both the mitigation of flicker and their electrical properties, they require ballasts. These components regulate the amount of current flowing though the lamp and protect it from surges in the grid.

Magnetic ballasts for fluorescent lamps used a simple copper coil to achieve this. Capacitors were later added to improve efficiency. This gave rise to the characteristic plinking noise upon switch-on and the buzzing sound during operation. Essentially, the lamp still operated at the electrical mains frequency of 50Hz, resulting in flickering at a rate of 100Hz [21].

Electronic ballasts that used additional electrical components to increase the current frequency were introduced in the 1970s. By the end of the decade, not only their superior flicker performance, but also their positive effect on fluorescent lamp efficiency had been recognized [22]. Because of their increased complexity and the use of active electrical components, their overall cost was higher than their magnetic counterparts.

For LEDs, much like for fluorescent lights, lower flickering and higher efficiency are attained by complex multi-stage electronic drivers that include more expensive components and are more costly in manufacturing than their magnetic counterparts.

The Regulation of Lighting Efficiency

Since 2009, three different pieces of legislation have set minimum performance requirements for lamps in the EU. Regulations *(EC) No 244/2009*, *(EU) No 1194/2012*, and *(EU) 2019/2020* each set minimum performance requirements in increasing stages. 2009 exceptions for lamps with a luminous flux below 900 lm, shown in Figure 1, were soon repealed and resulted in a phase out that was more commonly referred to as the 'light bulb ban'. The latest regulation is not only increasing the minimum required efficiency even further, it also limits flicker dramatically. The requirement is now for LED lamps to perform at a level of $P_{st}^{LM} \leq 1$, never exceeding the level of flicker found in a 60W incandescent light bulb.

The Regulation of Flicker

Energy efficient lighting was first used in office buildings and factories. For these industrial applications, basic flicker standards were quickly set, as flicker was known to cause nasty accidents caused by the stroboscopic effect in rotating machinery. Only around 2000 did fluorescent lights find their way into consumer's homes as a result of energy efficiency regulations. At that time, electronic ballasts had gradually replaced magnetic ballasts where cost was less of a concern and high efficiency was of paramount importance. In low cost applications, lamps continued to 'flicker on'. As prolonged exposure to flickering lights thus became more prevalent, measures were taken to quickly phase out old magnetic ballasts. In the US, the *Energy Policy Act* of 2005 extended efficiency standards to magnetic ballasts, effectively phasing them out in 2010 [5]. In the EU, *Regulation (EU) No 347/2010* finally prohibited the use of magnetic ballasts in lamps following the introduction of minimum efficiency requirements in 2010 and 2012 [23]. This effectively ended visible flicker in fluorescent lights.

By 2010, it had was clear that LEDs would soon replace their fluorescent counterparts [24]. But while a 2013 study following up Commission Regulation (EC) No 244/2009 concluded that *'modern CFLs are basically flicker-free due to their electronic high frequency ballasts'*, it dismissed all further concerns on this effect by arguing that there was lack of scientific evidence pointing to it causing more serious conditions such as epilepsy. It also acknowledged the discomfort caused by flicker [25]. The absence of any regulations on this important quantity was explained in the study as conflicting with goals set for compactness and cost of LED lamps. This was corroborated by other authors [26] and ran contrary to a prior warning in the 2009 impact assessment prepared for the 2012 EU legislation which concluded, that *'These technologies have important energy saving potentials, but may have (still) some functional drawbacks [...]. If these new energy saving technologies are "pushed" prematurely, it may well have a detrimental effect on their long-term success'* [27]. Thus, while the detrimental health effects of flickering lights were well recognized and successfully addressed for fluorescent lights, economic and environmental considerations led to an omission of similar requirements in the legislation at the time. No cost-benefit analysis prepared for the legislation impact assessment considered the health effects or the potential public backlash against lower quality lighting.

Resulting Public Concern

LED light bulbs are saving consumers hundreds of dollars per year in electricity costs [28], have a

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significantly longer lifetime and contain no toxic metals. But existing legislation in the EU and the US left LED ballasts unregulated, which has led to a market situation where flicker in light bulbs is completely arbitrary [29]. Some products show no flicker, while some have dangerous levels, as defined by the IEEE and shown in Figure 3 [16]. The uncertainty that came with this market situation has since been used to justify legal action against lighting energy efficiency regulations. Four bills opposing a phase-out were drafted in the US. While one bill sought to limit federal involvement in energy efficiency programs more broadly [30], all sponsors cited health concerns as the primary reason for the bill. In the United Kingdom, an interest group called the Spectrum Alliance similarly lobbied to amend the existing regulations [31].

Looking beyond the EU and Conclusion

Nearly ten years after the first commercial LED bulbs made it to store shelves, the technology has matured, now providing higher efficiency, longer lifetimes and lower lifecycle costs compared to incandescent or fluorescent alternatives. EU energy efficiency policy played a key part in helping the technology gain market penetration and generate the impressive energy savings it did [6]. With the latest regulations, quality of light too will finally surpass that of incandescent light bulbs.

Yet for consumers in the United Kingdom, the situation is not as clear. For one, lamps are traded globally. Foreign markets thus benefit from increasing efficiency requirements in the European Union. However, if the United Kingdom does not adopt similar requirements on flicker, producers have an opportunity to dump those lamps that do not meet EU regulations on the UK market. To reduce flicker and all the discomfort and health issues that come with it, it is therefore imperative that the UK follows suit and adopts EU legislation on lighting efficiency and quality of light.

On a larger scale, legislation that has well documented potential to impact consumer health must look beyond its original motivation of increasing efficiency and ensure that regulatory frameworks exist to ensure all effects of new technologies are considered holistically and their externalities are mitigated. Efficiency regulations for combustion engines serve as an excellent example, having been introduced not only to reduce carbon emissions, but also to improve air quality and by extension increase consumer health and well-being.

Acknowledgements

The author would like to thank Prof Laura Diaz Anadon and Dr Sergey Kolesnikov for valuable discussions and input. The author gratefully acknowledges funding from the Swiss Study Foundation.

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Conflict of interest The Author declares no conflict of interest.