·Review·

Which lamp will be optimum to eye? Incandescent, fluorescent or LED *etc*

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Abstract

• **Low frequency flicker, high frequency flicker, strong light, strong blue light, infrared, ultraviolet, electromagnetic radiation, ripple flicker and dimming flicker produced by different lamps have negative impact on vision, eyes and health. Negative impact on eyes resulting in myopia or cataract *etc* the solution is to remove all the negative factors by applying upright lighting technology and that is optimum to vision, eyes and health.**

• **KEYWORDS:** low frequency flicker; high frequency flicker; strong light; infrared; ultraviolet; electromagnetic radiation; ripple flicker; dimming flicker
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INTRODUCTION

Light can result in damage through photothermal, photomechanical, and photochemical mechanisms. We call that light toxicity.

Photothermal damage occurs by the transfer of radiant energy, a photon, from light to the retinal tissue; Sunlight exposure is a risk factor for macular degeneration.

Photomechanical damage refers to tissue damage resulting from mechanical compressive or tensile forces generated by the rapid introduction of energy into the melanosomes of the retina pigment epithelium. These compressive and tensile forces are thought to generate sonic transients or shock waves that can also result in permanent damage to the retina pigment epithelium or photoreceptors.

Photomechanical damage is thought to be caused by high irradiances in the range of megawatts or terawatts per cm squared and exposure times in the range of nanoseconds to picoseconds. The damage is related to power multiplying the exposure times, so for microseconds (light variation frequency is Megahertz), irradiances in the range of kilowatts; for milliseconds (light variation frequency is kilohertz (kHz), irradiances in the range of several watts. High frequency flicker light at several kHz with power greater than several watts will cause photomechanical damage.

Photochemical damage is associated with both long-duration exposure times as well as lower-wavelength light exposure. Class I damage is characterized be relatively low level of irradiance (below 1mW/cm^2)of white light, and the exposure may take place over hours to weeks; class II injury is characterized by exposure to high irradiances (above 10mW/cm^2) of white light with an action spectrum peaking at shorter wavelengths of white light[1]. So exposure to high blue light irradiance cause photochemical damage.

Different Lamps´ Light and Impact on Eyes

Incandescent lamp Since 1879, Thomas Edison invented the first commercially practical incandescent lamp (US patent 223 898). The lamp is often connected to 220volt 50Hz alternating current (AC) or 110volt 60Hz AC power line. The voltage applied across the lamp is shown in Figure 1.

Incandescent lamp brings "flicker light" with low frequency (50 or 60Hz): the brightness of the lamp is proportional to the magnitude of voltage across the lamp. The brightness goes up to maximum when voltage reaches peak; the brightness drops down to minimum when voltage crosses 0 volt.

For 220AC volt 50Hz, the brightness changes from brightness to darkness back and forth for 50 times per second. This kind of light is "flicker light" with low frequency.

Pupil of the human eyes will shrink in a bright environment and will expand in a dark environment. In a second, pupil will shrink and expand 50 times with variation of the lamp brightness. So eyes constantly adjust the pupil and are very tired ultimately leading to the eye muscle relaxation. Then eyes cannot effectively regulate the pupil and myopia is caused.

Research for flicker light impact on vision Nantong University in China found myopia can be induced by low frequency "flicker light" [2]. La Trobe University in Australia found low frequency temporal modulation of light promotes a myopic shift [3]. The Ohio state University found highly nearsighted people are at greater risk of several vision-threatening problems such as retinal detachments,

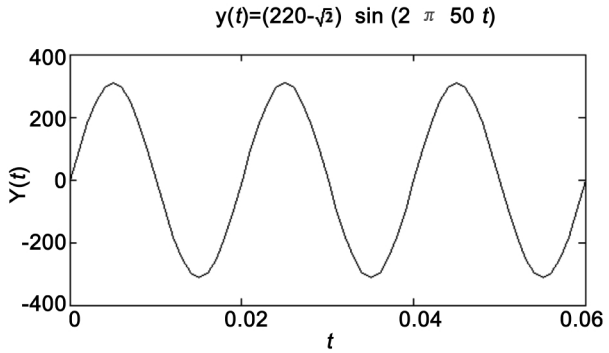

Figure 1 The voltage waveform across incandescent lamp: horizontal axis is time, vertical axis is voltage.

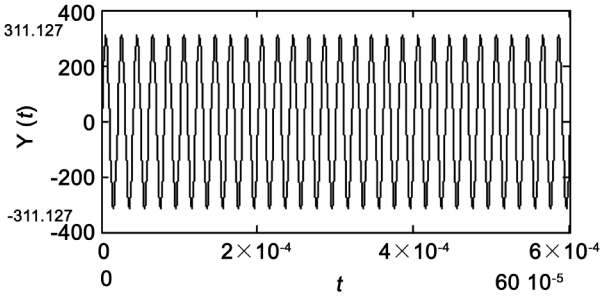

Figure 2 Voltage waveform of fluorescent lamp: horizontal axis time; vertical axis voltage.

choroidal atrophy, cataracts and glaucoma[4]. Duke University found High-grade myopia is a leading cause of blindness[5].

Incandescent lamp brings infrared light The filament of incandescent lamp can reach thousands of degree Celcius and energy created by halogen bulbs is in the form of infrared radiation (heat). The infrared that cause cataracts has wavelength 1 500-800μm. This part of shortwave infrared can penetrate the cornea then is absorbed by the lens. As a result, the thermal effects cause lens protein denaturation and cataracts after long time. This is photothermal damage.

Research for infrared impact on eyes Uppsala University in Sweden found near infrared radiation may cause cumulative damage in the ocular lens [6]. Department of Biomedical Engineering, University of Texas at Austin did the experiment and found the 1300-nm ocular damage data have yielded unusual characteristics where Continuous Wave retinal damage was observed in rabbit models[7].

Fluorescent lamp George Inman invented fluorescent lamp (U.S. Patent 2259040) that was first sold in 1938.

The fluorescent lamp uses ballast to create AC voltage above 20kHz, original fluorescent lamp has high frequency voltage inside low frequency envelope. Later power factor correction (PFC) is added in fluorescent lamp so that new fluorescent lamp has only high frequency voltage across lamp. The voltage waveform is shown in Figure 2.

Fluorescent lamp brings "flicker light" with high frequency. High frequency flicker light at several kHz with power greater than several watts will cause photomechanical damage.

Light variation is so fast that eyes cannot keep up, so the pupils will not shrink even under strong peak light condition. Strong light will project on the retina and retina will be hurt after long time. AC peak voltage cause glare on the retina and dry eye. Meanwhile, close strong light will cause retention phenomenon on the retina, eye muscle contraction and accelerate vision decrease. Long-term high-brightness light can cause keratitis (corneal epidermal necrosis, loss), eye pain, photophobia and tearing.

Strong light effects: 1) corneal injury; 2) lens damage, mainly for thermal effects injury, the posterior subcapsular cortex muddy, an average of 10 years of cataract formation; 3) vitreous injury; 4) retinal damage, causing macular retinal choroidal damage, central vision loss, fundas as same as Eclipse retinitis, or even blindness for long term.

Research for strong light impact on eyes Wright State University and University of Wisconsin/Oshkosh did research and found in most species prolonged intense visible light exposure can lead to photoreceptor cell damage[8].

Department of Ophthalmology, University of Florida-College of Medicine found association between severity of light exposure and age-related macular degeneration that is a leading cause of blindness[9].

Service d'Ophtalmologie, CHU Sart Tilman, Liège, French doctors found: all the ocular structures, from cornea to retinal layer, can be damaged by exposure to the light radiations. Acute keratitis combined with conjunctivitis will result from an intensive photonic exposure[10].

Incandescent lamp brings ultraviolet light The electric current (in the gas) excites mercury vapor which produces short-wave ultraviolet light that then causes a phosphor coating on the inside of the bulb to fluoresce, producing visible light. So fluorescent lamps emit ultraviolet (UV).

Long term exposure to ultraviolet light may cause cataracts, macular disease, blurred vision and image distortion symptoms. Long-term UV radiation can cause skin aging black and skin cancer.

Long-term repeated ultraviolet radiation can cause chronic blepharitis, conjunctivitis, conjunctival elasticity and gloss loss, and pigment hyperplasia. UV-induced electric photophthalmia is a common eye disease.

UV can cause solar ophthalmia, actinic conjunctivitis, electric ophthalmia, flash eye, arc eye, welder flash eye and industrial photophthalmia, *etc.* All these are called the customary system electric ophthalmia, the ultraviolet radiation keratoconjunctivitis.

Research on ultraviolet impact on eyes Service d'ophtalmologie, CHU Salt Tilman, Liege, French doctors did research and found : pterygion more likely represents the consequence of chronic exposure to the ultraviolet rays.

Exposure to the ultraviolet rays has been involved in the appearance of the typical yellow pigments of the nuclear cataract. The progression of retinal degenerations might be influenced by uncontrolled exposure to ultraviolet rays[10].

Department of Natural Sciences, Fordham University, New York City found ultraviolet radiation is also a risk factor for damage to the retinas of children. The removal of these wavelengths from ocular exposure will greatly reduce the risk of early cataract and retinal damage[11].

Resonant circuit in fluorescent lamp ballast generates high-frequency electromagnetic radiation GSM mobile phone has maximum instantaneous power as 2 Watts. CDMA and GSM mobile phones have regular 0.2 Watts. 3G phones has less power. In 1985, U.S. scientists Lynn speculate that electromagnetic radiation from cell phone may induce cancer. Fluorescent lamp power is much higher than 2 watts and is turned on longer than cell phone.

In recent years, U.S. found the electromagnetic radiation impact on the human body: 1) cell carcinoma induction; 2) abnormal hormone; 3) intense calcium loss; 4) triggering dementia; 5) abnormal pregnancy and abnormal birth; 6) high blood pressure and heart disease; 7) electromagnetic hypersensitivity; 8) depression increase.

Lamp brightness changes with high frequency above 20khz, the flicker is invisible flicker PAR1789 of IEEE found Flicker from electric light whether visible or invisible flicker, for some populations it can be a trigger for headaches, migraines, fatigue, epilepsy, and other neurological responses.

Flicker has been shown to degrade reading performance, provide a distraction or annoyance for sensitive individuals (including subtle changes in behavior in vulnerable groups), and interact with moving machinery to endanger industrial workers IEEE PAR1789, 2010; Veitch, 1995) for extensive reference list on health effects of flicker).

There has been emerging concern about health effects in lighting due to "invisible" flicker (IEEE PAR1789, 2010). Most humans are unable to perceive flicker in light above 60-90Hz, but there still remain measurable biological effects above the critical fusion frequency. Electroretinogram (ERG) responses indicate that invisible flicker is transmitted through the retina, (Berman, 1991). Some researchers have shown that this flicker may lead to headaches and eye strain (IEEE PAR1789, 2010; Wilkins 2010)[12].

Research for high frequency cyclic light University of Wisconsin, Recent work by Albert *et al* [13] has shown the development of progressive stages of retinal degeneration and choroidal neovascularization after long-term intense cyclic light exposure in albino rats.

Light emitted diode Nick Holonyak Jr. (born November 3, 1928, in Zeigler, Illinois) invented the first practically useful visible LED (US patent 3249473) in 1962.

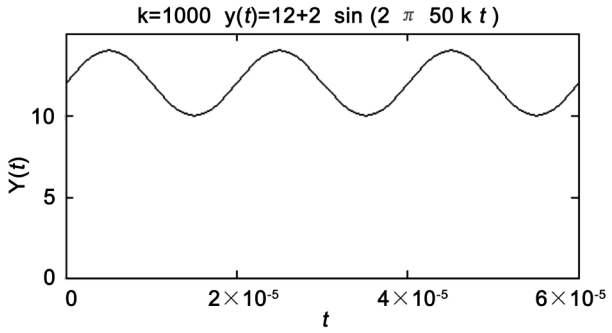

Figure 3 LED voltage: horizontal axis is time, vertical axis is voltage.

Lamp brings ripple with low or high frequency Switching power supply is used to apply DC voltage across LED. Though the DC voltage has low frequency or high frequency ripple to cause brightness variation, the magnitude of the ripple is much less than AC voltage magnitude of fluorescent lamp. And it can save power and energy. The voltage waveform across the LED lamp is shown in Figure 3.

Low frequency ripple flicker cause the pupil constantly to adjust resulting in eyestrain or myopia, high frequency ripple flicker causes pupil cannot keep up adjusting, strong light on the retina hurt the retina. The high frequency ripple is invisible ripple. High frequency flicker light at several kHz with power greater than several watts will cause photomechanical damage.

Output ripple flicker: the relation between current and voltage of LED is exponential, so a little voltage ripple drift can cause current many times change. Shockley diode equation describes the current *vs* voltage relation for light emitted diode:

$I=I_s\times(e^{V/(n\times V_T)}-1)$, I is the diode current, I_S is the reverse bias saturation current (or scale current), V is the voltage across the diode, V_T is the thermal voltage, V_T=25.85mv, n is the ideality factor, n =1-2.

The current *vs* voltage is an exponential curve. When voltage changes a little, current changes dramatically.

From Figure 3, we see most of power supply has some voltage ripple. The ripple is the voltage small variation near the DC voltage across LED lamps. From Figure 4, we see when the LED voltage has a small change from Va to Vb, LED current has a dramatic change from ia to ib. The brightness is proportional to output power. When you draw a horizontal line from operating point to current axis and draw a vertical line from operating point to voltage axis. Output power of the operating point is the area of the rectangular composed of these two lines, current axis and voltage axis. We can see when the operating point changes from a to b, the area increases at least 1/3. The brightness increases at least 1/3.

If such a brightness change is in low frequency, the pupils will keep adjusting and cause eyestrain. For long term, myopia is induced.

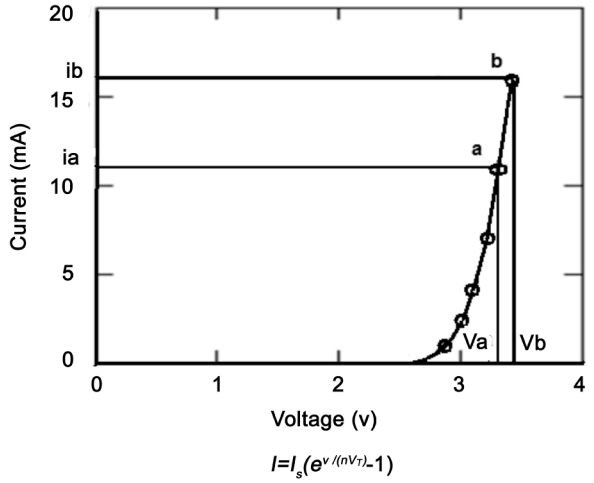

Figure 4 current *vs* voltage for LED.

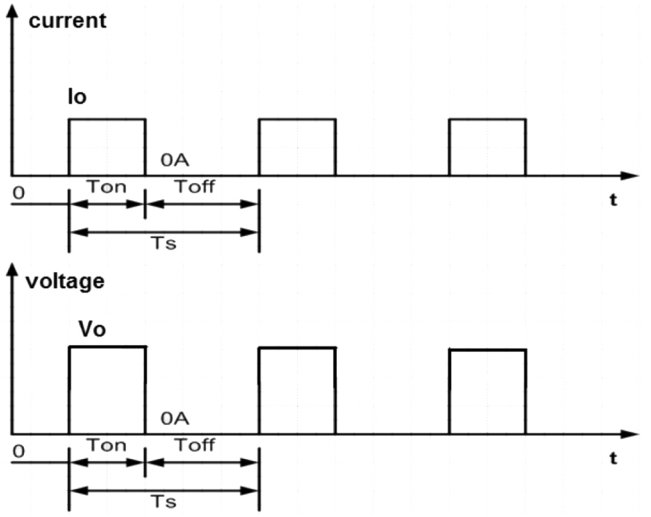

Figure 5 The current through LED and voltage across LED during dimming for the LED on market.

If such a brightness change is in high frequency, the pupil cannot keep up, it will hurt the retina. High frequency flicker light at several kHz with power greater than several watts will cause photomechanical damage.

University of Wisconsin, Recent work by Albert *et al* [13] has shown the development of progressive stages of retinal degeneration and choroidal neovascularization after long-term intense cyclic light exposure in albino rats.

Arnold Wilkins, Dept. of Psychology, University of Essex, UK; Jennifer Veitch, National Research Council Canada, Ottawa, Canada and Brad Lehman, Dept. Elect.& Comp. Eng, Northeastern University, USA did research on LED flickering on health: low-frequency flicker between 3 and 70Hz can cause seizures; invisible flicker (70Hz) above can cause malaise, headache and visual impairment[14].

Market LED lamps contain low frequency visible flicker, high frequency invisible flicker, ultraviolet, infrared, strong red, strong green or strong blue light that are harmful to human eyes.

Research for strong red, strong green and blue light impact on eyes Peking Union Medical College found monochromatic strong red promotes myopic shift for guinea pigs[15].

Fudan university found that monotonic green light is involved in the development of myopia[16].

North Grumman Information Technology in Texas USA found monochromatic blue strong light "can induce a veiling glare intense enough to degrade visual performance[17].

University of Texas Southwestern medical center found monotonic blue light can cause macular degeneration and other vision problem[18].

Karolinska Institute in Sweden found blue light induce photochemical damage and apoptotic cell death[19].

National Institute of Environment found blue light induce retinal injury[20].

Columbia university in US found Blue light induce damage to retinal pigmented epithelial cells[21].

Some LED switching power supplies bring strong electromagnetic radiation higher than international standard. Strong electromagnetic radiation may cause cancer.

Market Dimming way brings high frequency brightness flicker by turning on and off the dimming switch with high frequency. High frequency flicker will hurt retina.

LED is turned on for time Ton and is turned off for time Toff. Ton+Toff=Ts, Ts is the switching period. For time Ton, the current through the LED lamp is Io, the voltage across LED lamp is Vo, the output power of LED lamp is Po=VoIo; For time Toff, the current through the LED lamp is 0, the voltage across LED lamp is less than threshold voltage, the output power of LED lamp is 0. The process is repeated for the next cycle and so on. The lamp brightness is proportional to the average power of LED. Average power P = (IoVoTon+0)/Ts, P=IoVoTon/Ts. Let D=Ton/Ts, P=IoVo D; Duty cycle is the ratio of the duration of the LED turn-on to the total switching period. So the brightness can be adjusted by adjusting duty cycle D with high frequency. The pupils cannot keep up, the strong light will hurt retina.

The waveform of Io and Vo for LED is shown as Figure 5.

Io is the current through LED and Vo is the voltage across LED; Ton is the time when LED is on and Toff is the time when LED is off; Ts is switching period.

Battery without feedback will bring voltage variation and cause low frequency brightness flicker. Low frequency flicker cause eyestrain and myopia.

Solution to the problems above Integrated circuit voltage regulator is used by upright lighting Limited Liability Company to remove ripple flicker. There is no low frequency or high frequency ripple flicker. The LED lamp brightness is constant and vision is protected to maximum.

Transfer function: Vout/Vin -Gmp×ro-pass/(Aol×B)+(1/B)×(Vref/Vin); Aol is low frequency open gain,

Gmp is transconductance Gmp=Id/Vgs, ro-pass is output

Table 1 All lamps' bad factor comparison and impact on vision, health

All lamps' bad factor	Incandescent	Fluorescent	Market LED	Upright lighting LED	Impact on vision and health
Low frequency visible flicker	Yes	Tradional: yes PFC: no	Some have	No	Myopia, headaches, migraines, fatigue, epilepsy, and other neurological responses. Degrade reading performance, provide a distraction or annoyance for sensitive individuals.
Infrared	Yes	No	Some have	No	Ocular lens damage, CW retinal damage, lens protein denaturation and cataracts. This is photothermal damage.
Peak strong light	Yes	Yes	Yes	No	Keratitis (corneal epidermal necrosis, loss), eye pain, photophobia and tearing, injury to corneal, lens, retina, vitreous injury, dry eye, photoreceptor cell damage; age-related macular degeneration, macular retinal choroidal damage.
Ultra violet	No	Yes	Some have	No	Pterygion, retinal degeneration, cataract, retinal damage, photochemical lesions in the neural retina and retinal pigment epithelium, macular disease, blurred vision and image distortion symptoms, chronic blepharitis, conjunctivitis, conjunctival elasticity and gloss loss, and pigment hyperplasia. UV-induced electric photophthalmia, customary system electric ophthalmia, the ultraviolet radiation keratoconjunctivitis, skin aging black or skin cancer. This is photochemical damage.
Unsafe EMI	Yes	Yes	Some have	No	Cell carcinoma induction, abnormal hormone, intense calcium loss, triggering dementia, abnormal pregnancy and abnormal birth, high blood pressure and heart disease, electromagnetic hypersensitivity, depression increase.
High frequency invisible flicker	No	Yes	Yes	No	Retinal degeneration, choroidal neovascularization, photomechanical damage, headaches and eye strain.
Unsafe blue light	Yes	Yes	Yes	No	Veiling glare intense enough to degrade visual performance, macular degeneration and other vision problem, photochemical damage and apoptotic cell death, and retinal injury. Blue light induce damage to retinal pigmented epithelial cells.
Dimming high frequency flicker	Yes	Yes	Yes	No	Retinal degeneration, choroidal neovascularization, photomechanical damage.

resistance and has very small value; B is feedback voltage divider ratio, Vref can be thought as 0 for Vref does not change with frequency. Vout/Vin=Gmp×ro-pass/ (Aol×B), Aol is huge about 100 000-1 000 000, but Gmp=0.3ms, ro-pass=1-2m ohm very small. So Vout/Vin=0.3m×2m/ 100 000=6/1 000 000 000 000 almost 0.

Vout is almost 0 for signal between low frequency and high frequency, LED has no ripple.

The LED voltage waveform measurement is shown in Figure 6. The black bold line is the DC voltage across LED lamp. The voltage across LED is constant without ripple. premium LED material is selected that does not contain ultraviolet, infrared, strong red, strong green or strong blue light that is harmful to human eyes. Blue light is minimized and energy distribution is optimized. Optimized filter is designed by upright lighting LLC to meet electromagnetic standard solve electromagnetic radiation problem. upright lighting LLC changed the current through LED to dim without switching. Increase current to make lamp brighter and decrease current to dim lamp without turn on/off the lamp. So there is no flicker light during dimming.

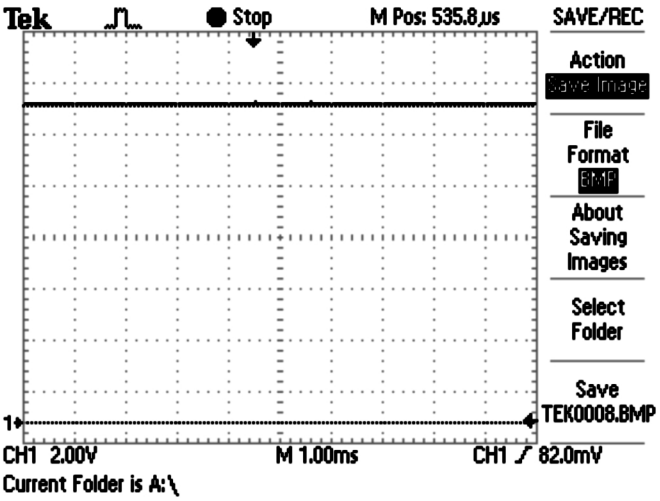

Figure 6 Upright lighting LLC LED DC voltage waveform without ripple.

DISCUSSION

Standard P1789 of IEEE Make Basic Definitio[22] Flicker: a rapid and repeated change over time in the brightness of light. The effects of flicker can range from non-specific malaise to epileptic attacks. Visible Flicker: Flicker that is perceivable by human viewer. Invisible Flicker: Flicker that is not perceivable by a human viewer.

Incandescent Lamp Brings 1) low frequency visible flicker that cause myopia; 2) Infrared that cause cataracts. The infrared radiation of high intensity can produce corneal damage, probably cataract, and genuine thermal injury of the retina.

Fluorescent Lamp Brings 1) High frequency invisible flicker that cause malaise, headache and visual impairment; 2) Strong light at peak brightness projected on retina that will cause retinal light damage, acute keratitis and conjunctivitis; 3) Ultraviolet that may cause acute photokeratto conjunctivitis, aging of the lens, senile cataract, conjunctival carcinoma and malignant melanoma of the eye; 4) Electromagnetic interference (EMI) that will cause headache, migraines, fatigue, epilepsy and eye strain.

Light Emitted Diode Brings 1) High frequency ripple

invisible flicker that will cause malaise, headache and visual impairment; 2) some LED brings infrared that cause cataracts; 3) Some LED brings ultraviolet that cause cataract, pterygion, retinal degeneration and macular degeneration; 4) Strong red light or strong green light that will cause myopia; 5) Strong blue light cause macular degeneration, photochemical damage, apoptotic cell death and retinal injury; 6) EMI that will harm people's health.

LensAR Inc, Winter Park, Florida, USA found: Cataract and age-related macular degeneration (AMD) are two major causes of blindness, with cataract accounting for 48% of world blindness and AMD accounting for 8.7% . Both cataract and AMD affect an older population over 50 years old and while cataract is largely treatable provided resources are available, AMD is a common cause of untreatable, progressive visual loss. There is evidence that AMD is linked to exposure to short wavelength electromagnetic radiation, which includes ultraviolet, blue and violet wavelengths[23].

The summary of the conclusion is listed in Table 1.

The solution based on circuit and patent of Upright Lighing LLC remove all of the following: infrared, ultraviolet, strong red light, strong green light, strong blue light, low frequency visible flicker light, high frequency invisible flicker light, ripple flicker light, electromagnetic radiation and dimming flicker. The solution from upright lighting LLC supply constant brightness to eyes and is optimum to eye without any bad factor.

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REFERENCES

1 Youssef PN, Sheibani N, Albert DM. Retinal light toxicity. *Eye (Lond)* 2011;25(1):1-14

2 Yu Y, Chen H, Tuo J, Zhu Y, Effects of flickering light on refraction and changes in eye axial length of C57BL/6 mice. *Ophthalmic Res* 2011;46(2): 80-87

3 Crewther SG, Barutchu A, Murphy MJ. Low frequency temporal modulation of light promotes a myopic shift in refractive compensation to all spectacle lenses. *Exp Eye Res* 2006;83(2):322-328

4 Walline JJ, Lindsley K, Vedula SS, Cotter SA, Mutti DO, Twelker JD. Interventions to slow progression of myopia in children. *Cochrane Database Syst Rev* 2011;7(12):CD004916

5 Hornbeak DM, Young TL. Myopia genetics: a review of current research and emerging trends. *Curr Opin Ophthalmol* 2009;20(5):356-362

6 Söderberg PG, Optical radiation and the eyes with special emphasis on children. *Prog Biophys Mol Biol* 2011;107(3):389-392

7 Vincelette RL, Welch AJ, Thomas RJ, Rockwell BA, Lund DJ. Thermal lensing in ocular media exposed to continuous-wave near-infrared radiation: the 1 150-1 350-nm region. *J Biomed Opt* 2008;13(5):054005

8 Organisciak DT, Vaughan DK. Retinal light damage: mechanisms and protection. *Prog Retin Eye Res* 2010;29(2):113-134

9 Chalam KV, Khetpal V, Rusovici R, Balaiya S. A review: role of ultraviolet radiation in age-related macular degeneration. *Eye Contact Lens* 2011;37(4):225-232

10 Xhauflaire G, Uhoda E, Rakic JM. Eye and ultraviolet light. *Rev Med Liege* 2005;60 Suppl 1:99-102

11 Roberts JE, Ultraviolet radiation as a risk factor for cataract and macular degeneration. *Eye Contact Lens* 2011;37(4):246-249

12 Lehman B, Wilkins A, Berman S, Poplawski M. Proposing measures of flicker in the low frequencies for lighting applications. Energy Conversion Congress and Exposition (ECCE), 2011 IEEE. Date of Conference:17-22 Sept.2011, page(s):2865-2872

13 Albert DM, Neekhra A, Wang S, Darjatmoko SR, Sorenson CM, Dubielzig RR et , Sheibani N. Development of choroidal neovascularization in rats with advanced intense cyclic-light-induced retinal degeneration. *Arch Ophthalmol* 2010;128(2):212-222.

14 Wilkins A, Veitch J, Lehman B. LED Lighting Flicker and Potential Health Concerns: Energy Conversion Congress and Exposition (ECCE), 2010 IEEE. Date of Conference: 12-16 Sept. 2010, page 173

15 Long Q, Chen D, Chu R. Illumination with monochromatic long-wavelength light promotes myopic shift and ocular elongation in newborn pigmented guinea pigs. *Cutan Ocul Toxicol* 2009;28(4):176-180

16 Wang F, Zhou J, Lu Y, Chu R. Effects of 530nm green light on refractive status, melatonin, MT1 receptor, and melanopsin in the guinea pig. *Curr Eye Res* 2011;36(2):103-111

17 Zuclich JA, Previc FH, Novar BJ, Edsall PR. Near-UV/blue light-induced fluorescence in the human lens: potential interference with visual function. *J Biomed Opt* 2005;10(4):44021

18 Walker DP, Vollmer-Snarr HR, Eberting CL. Ocular hazards of blue-light therapy in dermatology. *J Am Acad Dermatol* 2012;66 (1): 130-135

19 Algvere PV, Marshall J, Seregard S. Age-related maculopathy and the impact of blue light hazard. *Acta Ophthalmol Scand* 2006;84(1):4-15

20 Wielgus AR, Collier RJ, Martin E, Lih FB, Tomer KB, Chignell CF, Roberts JE, Blue light induced A2E oxidation in rat eyes-experimental animal model of dry AMD. *Photochem Photobiol Sci* 2010;9 (11): 1505-1512

21 Sparrow JR, Nakanishi K, Parish CA. The lipofuscin fluorophore A2E mediates blue light-induced damage to retinal pigmented epithelial cells. *Invest Ophthalmol Vis Sci* 2000;41(7):1981-1989

22 Arnold Wilkins, Brad Lehman. Biological effects and health hazards from flicker, including flicker that is too rapid to see. 2/15/10, IEEE Standard P1789, http://grouper.ieee.org/groups/1789

23 Edwards KH. Intraocular lens short wavelength light filtering. *Clin Exp Optom* 2010;93(6):390-399