Light Sleep

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Grade 6

Abstract

Research shows that light of low wavelengths is harmful to human sleep. It is known that light of lower visible wavelengths, those in the range of 400nm to 500nm, when seen by the human eye, suppresses a hormone called melatonin. Melatonin is a hormone that controls sleep and wake cycles. One of the best ways to prevent light of lower wavelengths from reaching the human eye is to avoid use of light sources emitting light of lower wavelengths during sleep time. The objective of this experiment is to identify these types of light sources commonly used at homes to avoid their usage. It is predicted that if LED lights of a higher color temperature (called the "daylight" type) are used, then they will emit the maximum amount of light at lower visible wavelengths.

Multiple commonly used light sources used at home, a spectrophotometer, a lux meter, and a computer are used for this experiment. The amount of lower wavelength light from each source is calculated using the relative light intensity distribution captured by the spectrophotometer and a software program written in Python, with each experiment performed 3 times for trials.

Results show that the daylight type of LED bulbs produce the most amount of light at low wavelengths.

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Question

What is the effect of different types of light sources used at home on the intensity of low wavelength (400-500nm) light (measured in lux) produced?

Research

I. Scientific Principles

A. Visible light and white light (Figure 1)

1. Visible light comprises of electromagnetic radiation with wavelengths from 400 nm (violet) to 700 nm (red).

2. White light is a mixture of light in the range of wavelengths 400-700nm in equal proportion.

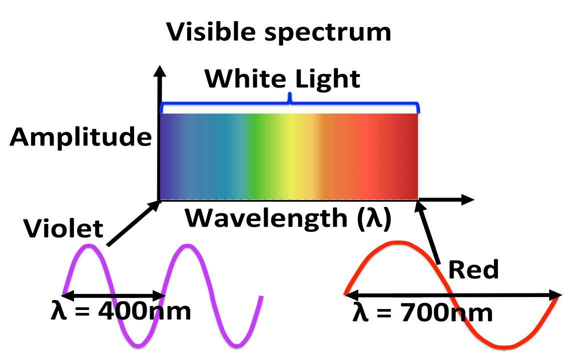

Figure 1: Visible spectrum and white light.

B. Light measurement and measures

1. A spectrophotometer is an instrument to split light into its component spectrum in the visible range.

a. It captures the intensity of each component wavelength in Analog-to-Digital Units (ADU).

b. ADU is a digital measure of the light intensity of each wavelength converted from analog to digital by the spectrophotometer.

2. The lumen is a measure of the total amount of visible light a source emits, and one lumen is defined as 1/4π times the amount of light a wax candle emits.

3. The lux is a measure of the intensity of visible light, and one lux is defined as one lumen per square meter.

2. A black body is an idealized object that emits electromagnetic radiation whose spectrum is determined solely by its surface temperature. The color temperature of a spectrum of electromagnetic radiation emitted by an ideal black body is its surface temperature measured in Kelvin. The color temperature of a light source is the same as that of a black body with a matching electromagnetic spectrum. Light sources with color temperature in the range of 2700-3000K are categorized as soft white, those with color temperature in the range of 3500-4100K as bright white, and those with color temperature in the range 5000-6500K as daylight.

C. Light sources

1. A halogen lamp (Figure 2) is an incandescent lamp that uses electric current through a tungsten filament inside a sealed bulb to produce heat and light mostly in the visible higher wavelength range; it uses halogen gas inside the bulb to redeposit evaporated tungsten to increase bulb life.

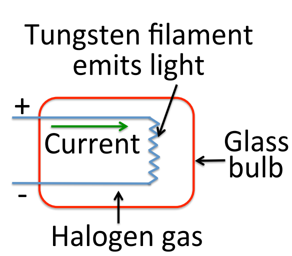

Figure 2: Halogen bulb.

2. A Compact Fluorescent Lamp (CFL) (Figure 3) comprises of a sealed bulb with a cathode (negative electrode) and an anode (positive electrode) along with an inert gas and mercury. It has an inside coating of phosphors, which are fluorescent (they absorb light of lower wavelength and emit light of a higher wavelength). The collision of electrons in the inert gas with those of mercury causes the electrons in mercury to shift to higher but unstable energy levels. When these electrons return to their original energy states, they emit ultraviolet (UV) light that is lower than 400nm in wavelength. The phosphor coating in the bulb absorbs this UV light and emits visible light.

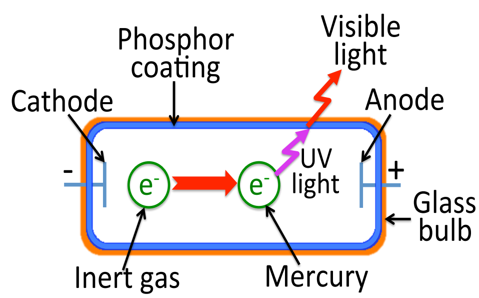

Figure 3: Compact Fluorescent bulb.

3. A Light Emitting Diode (LED) lamp (Figure 4) uses a special diode, a sandwich of semiconductor materials with a junction that allows current to flow in only one direction, that produces light when an electric current flows through it.

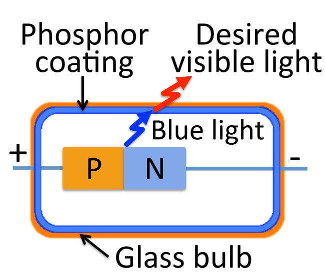

Figure 4: LED bulb.

It also has an outer bulb that has a coating of phosphors. The wavelength of light produced by an LED depends on the semiconductor and the phosphors used. Modern LED bulbs have semiconductors that emit light around 400-430nm (blue) in wavelengths, which are absorbed by the phosphors, which in turn, emit light of higher visible wavelengths.

D. Human sleep

1. Hormone melatonin controls human sleep and wake cycles.
2. Human sleep is adversely affected by lower wavelength (400 nm – 500 nm) light due to suppression of melatonin as shown in Figure 5.

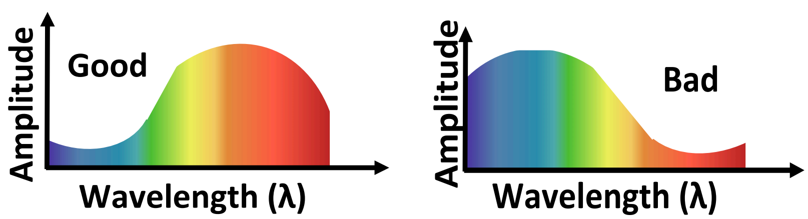

Figure 5: Impact of spectrum of light sources on human sleep.

II. Applications

A. Results can help determine what kind of light source emits least low wavelength visible light, hence causes least damage to sleep.
B. Results can help determine which light source is best for activities such as reading.
C. Experiment can be adapted to identify the type of light source that can help increase growth of some plants (e.g. lettuce has shown more leaf production under specific lighting conditions).

III. Research into Materials and Methods

A. What should be the different light sources to be used in this experiment?

B. What should be the controls to be used in this experiment?

C. Given a light source, what instrument can be used to split light from a source to its component wavelengths and capture their relative intensities? In what units are the relative intensities measured?

D. What instrument can be used to capture the absolute light intensity of light from a source? In what unit is that intensity measured?

E. Given the intensities of a range of wavelengths as a distribution curve, what method can be used to calculate the cumulative intensity of a sub-range of wavelengths?

F. What instrument can be used to measure the color temperature of a light source?

Hypothesis

It is predicted that if daylight LED lights are used, then they will emit the most amount of light intensity at lower visible wavelengths (400 – 500 nm).

Scientific Principles and Reasoning

Visible light is comprised of electromagnetic radiation of different wavelengths in the range 400nm (violet) to 700nm (red). White light is comprised of a mix of light of each of these visible light wavelengths at equal intensities. Light sources used at homes are not purely white light sources because they produce light at different visible wavelengths with different intensities. Some light sources tend to emit more intense light at lower visible wavelengths while some tend to emit more intensity at higher visible wavelengths. Incandescent and halogen light bulbs tend to have a warm yellowish glow implying that they may have more intensity at the red end (higher wavelengths) of the visible spectrum, while

LED and CFL light bulbs tend to have a brighter whitish or bluish glow indicating that they may either a balanced mixture or more intensity at the violet end (lower wavelengths) of the visible spectrum.

Materials

- 3 halogen bulbs of different wattage and belonging to soft white type
- 4 spiral CFL bulbs of different wattage and belonging to either soft white, bright white, or daylight types
- 11 LED bulbs of different wattage and belonging to either soft white, bright white, or daylight types
- iPhone SE
- Bulb holder with cable and electrical plug
- 110V electrical outlet
- RSpec Explorer spectrophotometer (used to split light to its spectrum) and software. This spectrophotometer displays the light intensity at each wavelength in the visible spectrum in terms of ADUs as a waveform whose X-axis is the wavelength, and the Y-axis is the intensity in ADU at each wavelength. This waveform can be stored in a file as sequence of (X, Y) pairs.
- Leaton L830 lux meter to measure light intensity
- Lightspectrum Pro Iphone App to measure color temperature of light source
- Cardboard with a slit to take a portion of light produced by the light source to be incident on the spectrophotometer
- Computer and RSpec Explorer software used to find distribution of intensity of different wavelengths and save to a file

- A Python program was written to calculate the cumulative intensity in the 400-500nm range (low wavelength) and that in the 400-700nm range (full visible spectrum) for each light source from the file saved from the RSpec spectrophotometer.

Setup

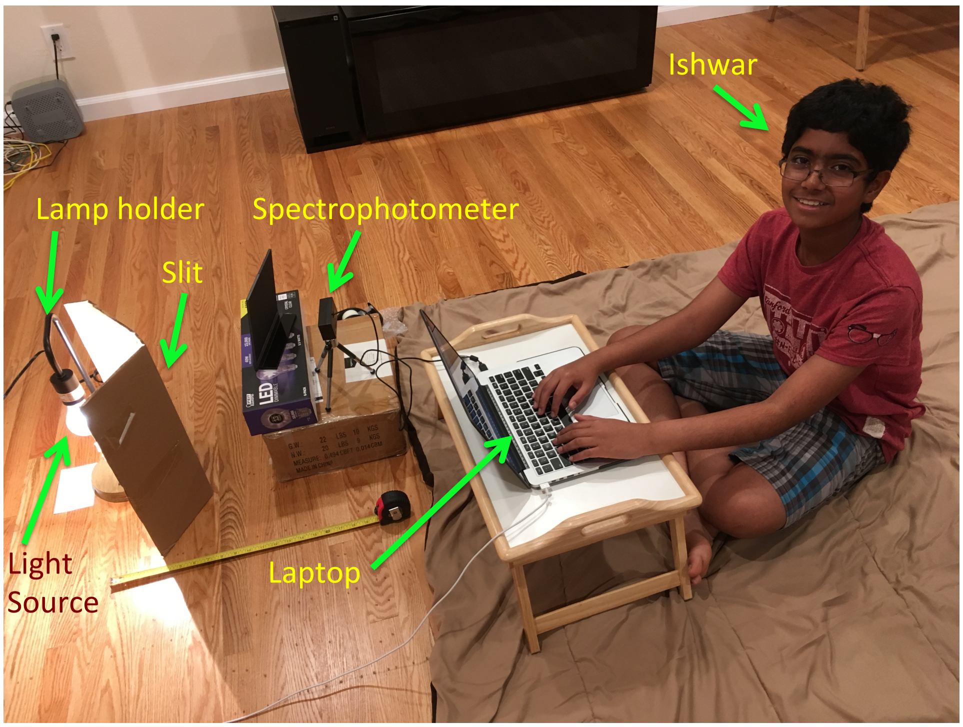

Figure 6: Experiment setup.

The experiment setup for measuring the distribution of intensities over all visible wavelengths from each light source is as shown in Figure 6.

Methods

The procedure for performing the experiment is given in the steps below.

1. Setup the light source in a dark room and plug the light bulb holder in the wall outlet and screw the light bulb in the holder.
2. Setup the RSpec Explorer spectrophotometer on the tripod to face the light source.
3. Connect the spectrophotometer to computer through USB cable.

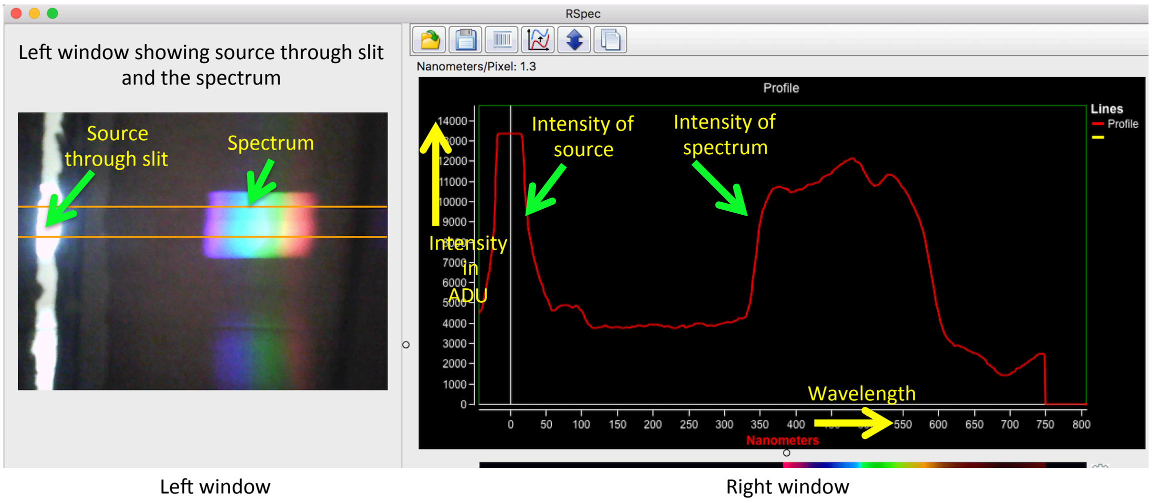

Figure 7: Intensities of light source and spectrum from RSpec Explorer software.

4. Start the RSpec software program. There are two main windows in the software. The left window shows the actual source and its spectrum, and a right window shows the graph of distribution of light intensity (in ADUs) at different wavelengths in the spectrum, as shown in Figure 7.
5. Turn on the light source.
6. Measure color temperature of light source using the Lightspectrum Pro iPhone app.
7. Align horizontal gridlines in the left window of RSpec program to contain the light source and its spectrum.
8. Move the spectrophotometer on the tripod so that the first vertical intensity peak in the right window of software aligns with 0nm.
9. Download a file that comprises of a set of (wavelength, intensity in ADU) pairs that represents the distribution of light intensity across a set of wavelengths of the visible spectrum of that light source from RSpec software to the computer.
10. Measure the light intensity of the source with the Leaton lux meter.

11. Repeat steps 7 through 10 two times more for a total of three trials with each source (by turning off and turning on the source) mentioned in materials and, for the control, with light in a naturally well-lit room during daytime.
12. Use the created Python program to process each downloaded RSpec file and calculate the cumulative intensity in the 400-500nm range (for low wavelength, as in area A in Figure 8) and that in the 400-700nm range (for the entire spectrum, as in area B in Figure 8).

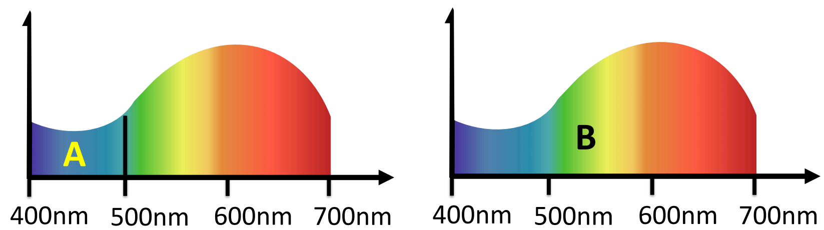

Figure 8: Intensities of low wavelengths and entire spectrum.

13. For each light source, calculate the ratio of intensity of low wavelength light to that of the full spectrum, the total amount of low wavelength light in lux, and the total amount of low wavelength light per unit power in lux per watt using Excel.

Variables and Groups

Independent variable:

The independent variable is the measured color temperature of each light source used.

Experimental groups: Halogen, fluorescent, and LED bulbs each with three types: soft white, bright white, and daylight. The soft white type is represented by color temperature range 2700-3000K, the bright white type by 3500-4100K, and the daylight type by 5000-6500K, and an iPhone SE in the normal mode, and the iPhone SE with night shift mode turned on. The night shift mode in the iPhone is intended to reduce the intensities at low wavelengths for use during nighttime.

Control group: Sunlight in a shaded part of a well-lit room, during daytime in the afternoon (3-5PM).

Dependent variables:

a. The relative intensity of the low wavelength (400-500nm) light emitted by each light source as measured by the ratio of the cumulative intensity in the 400-500nm range (for low wavelength) to that in the 400-700nm range (for full visible spectrum).
b. The total intensity of the low wavelength (400-500nm) light emitted by each light source measured in lux.
c. The total intensity of the low wavelength (400-500nm) light per unit power consumed by each light source in lux per watt.

Constants:

- Setting of experiment
- Ambient light level in the setting of the experiment
- Input voltage to each light bulb (110V AC)
- Type of spectrophotometer used (RSpec)
- Time of experiment (if performed over multiple days)
- Distance from bulb to spectrophotometer
- Height of light source relative to spectrophotometer
- Software used to calculate intensity profile (RSpec software)
- Computer used to connect to the RSpec spectrophotometer
- Spectrophotometer setting to take light from source

Challenges Overcome

One challenge was that the camera integrated with the spectrophotometer had an auto-brightness adjustment feature, potentially scaling its light intake for different light sources, thereby scaling the intensity of each wavelength of light displayed in the RSpec software. To overcome this problem, only the ratio of the intensity of low wavelength light to that of the entire visible spectrum from the light source was computed from the intensity distribution that was obtained from the spectrophotometer, instead of computing the actual absolute intensities. This ratio was then multiplied by the overall brightness of the corresponding light source, measured in lux, to calculate the absolute intensity of low wavelength light in lux.

Data

Table 1: Light intensities at lower wavelengths and total spectrum for each light source.

Light source type	Trial 1			Trial 2			Trial 3		
	Intensity at 400-500nm (ADU)	Intensity at 400-700nm (ADU)	Intensity (Lux)	Intensity at 400-500nm (ADU)	Intensity at 400-700nm (ADU)	Intensity (Lux)	Intensity at 400-500nm (ADU)	Intensity at 400-700nm (ADU)	Intensity (Lux)
CFL	521885	1275157	1239	526687	1285876	1237	523739	1279487	1233
CFL	522598	1349009	2024	519367	1338747	2020	526171	1353005	1936
CFL	222762	815775	1175	279843	981357	1188	286905	1000159	1186
CFL	434338	1111056	1364	431744	1105097	1361	421375	1075166	1283
Halogen	177502	580762	1742	174522	573993	1731	174526	575903	1728
Halogen	345474	1096556	1824	349284	1107174	1821	351520	1111262	1824
Halogen	174146	574125	949	171939	563757	946	173888	573106	944
LED	150384	584826	291	146998	574427	293	140790	554313	292
LED	281081	983774	1931	277381	976580	1918	274079	966102	1916
LED	173361	615517	723	175126	620155	722	174257	617011	720
LED	355216	1213329	3200	349009	1197455	3160	356445	1215039	3130
LED	158823	568496	3830	157787	565617	3810	158231	566189	3790
LED	385905	1157199	1543	383533	1151777	1541	383243	1149479	1539
LED	415095	1221073	2140	403351	1183241	2130	407640	1194678	2140
LED	448651	1265899	2240	452536	1272254	2260	450227	1268415	2260
LED	516983	1583569	3610	516043	1579577	3590	519480	1586789	3560
LED	326677	1137370	2042	338473	1174707	2035	339820	1178254	2030
LED	398768	1172235	1645	394845	1157650	1645	389051	1138295	1643
Room	720522	2051744	1239	721978	1958282	1133	721978	1958282	1457
iPhone	422693	894871	20	459740	993146	20.2	531378	1177383	19.4
iPhone NS	433422	1098174	17.3	355434	943128	17.5	431966	1098446	17

The data that is collected is shown in Table 1. Each row is for a different light source. The intensities of light at wavelengths in the range 400-500nm and those of light at wavelengths in the range 400-700nm as measured in ADUs along with the total intensity in lux are given in the last 9 columns for 3 trials.

Table 2: Amount of low wavelength light in each light source.

Light source type	Power (Watts)	Color Temperature (Kelvin)	Mean Ratio of intensity at 400-500nm to Intensity at 400-700nm	Mean Intensity at 400-500nm (Lux)	Mean Intensity at 400-500nm per unit power (Lux per Watt)
CFL	13	6850	0.409	506.155	38.935
CFL	19	5450	0.388	773.546	40.713
CFL	14	2871	0.282	333.28	23.806
CFL	14	6128	0.391	522.59	37.328
Halogen	53	3155	0.304	527.465	9.952
Halogen	72	3090	0.316	575.371	7.991
Halogen	43	3032	0.304	287.598	6.688
LED	5.5	3065	0.256	74.658	13.574
LED	8.5	2934	0.284	546.685	64.316
LED	6	2954	0.282	203.621	33.937
LED	15	3202	0.293	925.356	61.69
LED	10	4572	0.279	1064.012	106.401
LED	9	4299	0.333	513.605	57.067
LED	12	5456	0.341	727.921	60.66
LED	12	6700	0.355	799.984	66.665
LED	16	5262	0.327	1172.285	73.268
LED	12	3001	0.288	586.11	48.843
LED	9	5225	0.341	560.737	62.304
Room	-	5292	0.36	459.902	-
iPhone	-	7559	0.462	9.184	-
iPhone NS	-	4497	0.388	6.703	-

For each light source, the power consumed as given by the manufacturer, its measured color temperature, the calculated mean ratio of intensity of low wavelength (400-500nm) light to the total intensity of the visible spectrum (400-700nm) over all 3 trials, the calculated mean intensity of low wavelength light in lux, and the calculated mean intensity of low wavelength light per unit watt consumed are given in the columns of Table 2. Note that the power consumption of the control (sunlight in the room) and the iPhone is not determined.

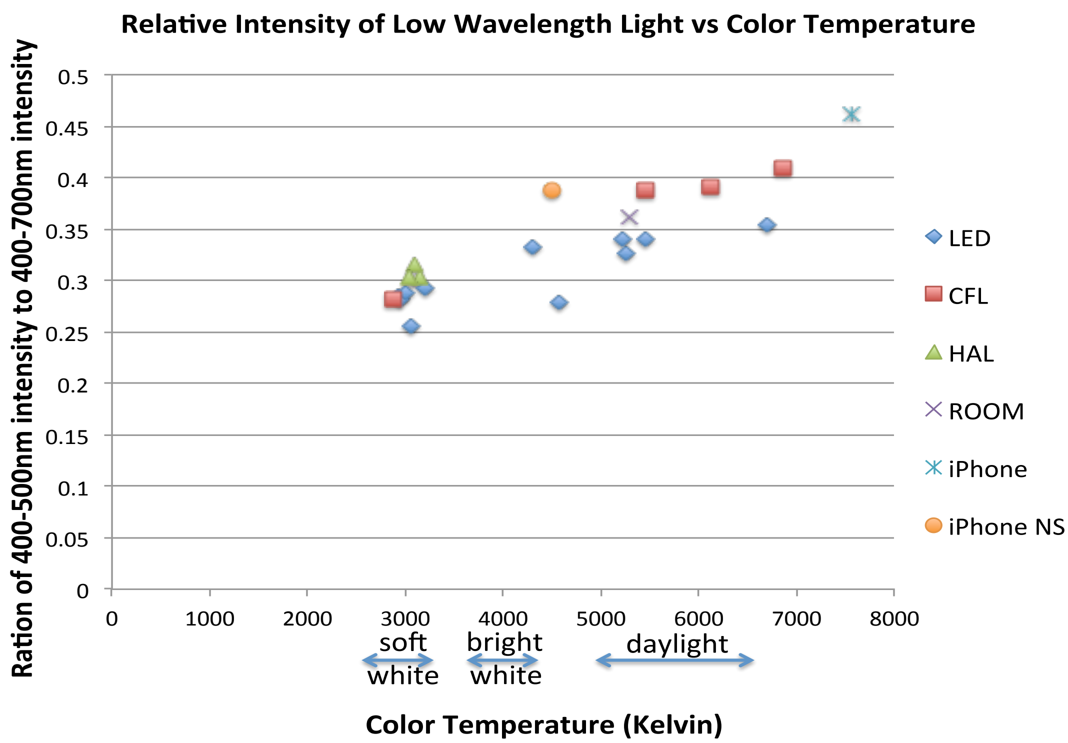

Figure 9: Relative light intensity at low wavelength for different sources.

The mean ratios of the intensity of low wavelength light (400-500nm) to that of the visible spectrum (400-700nm) for each of the light sources, halogen bulbs, CFL bulbs, LED bulbs, the iPhone in the normal mode, the iPhone with night shift turned on, and the sunlight in the shaded room (control) is plotted against the corresponding measured color temperature in Figure 9. Even though each of the bulbs came labeled with the manufacturer specified color temperature and with the type description of soft white, bright white or daylight, the measured color temperature was always higher than what the labels stated. This explains the fact that some of the light sources do not fall within any of the soft white, bright white and daylight categories in Figure 9.

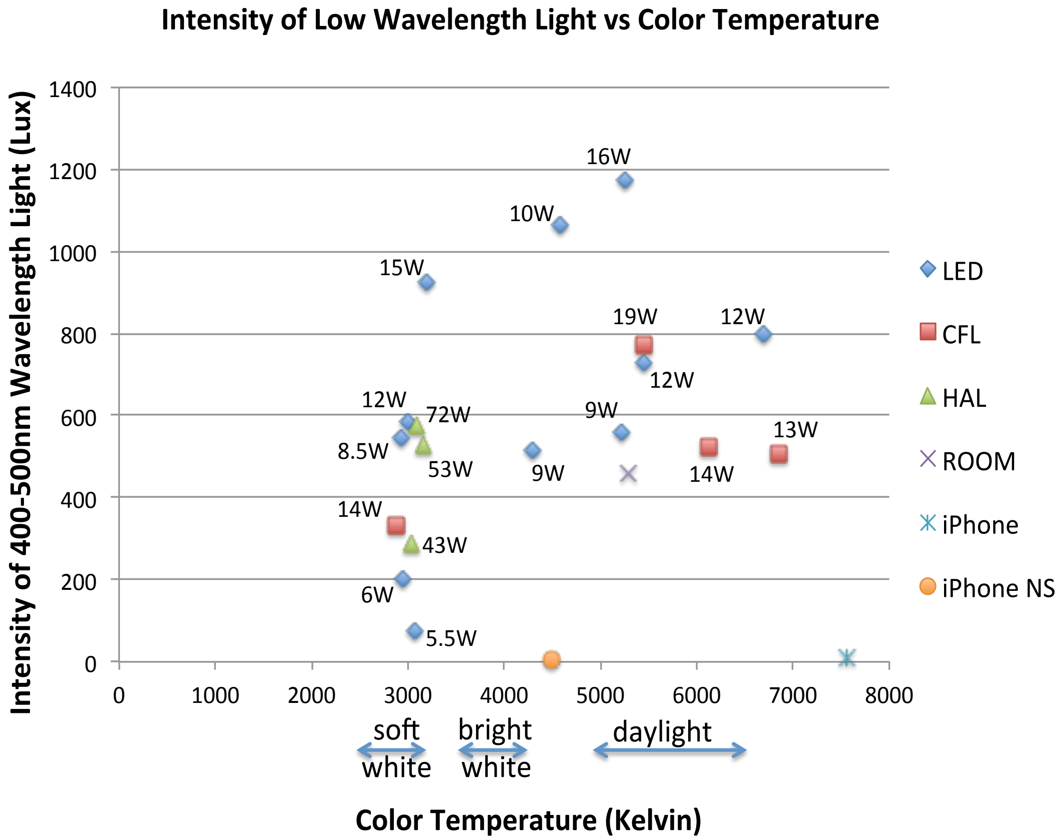

Figure 10: Intensity of low wavelength light in lux.

The mean intensity of each of the light sources at the low wavelengths (400-500nm) in terms of lux is plotted against the corresponding measured color temperature in Figure 10.

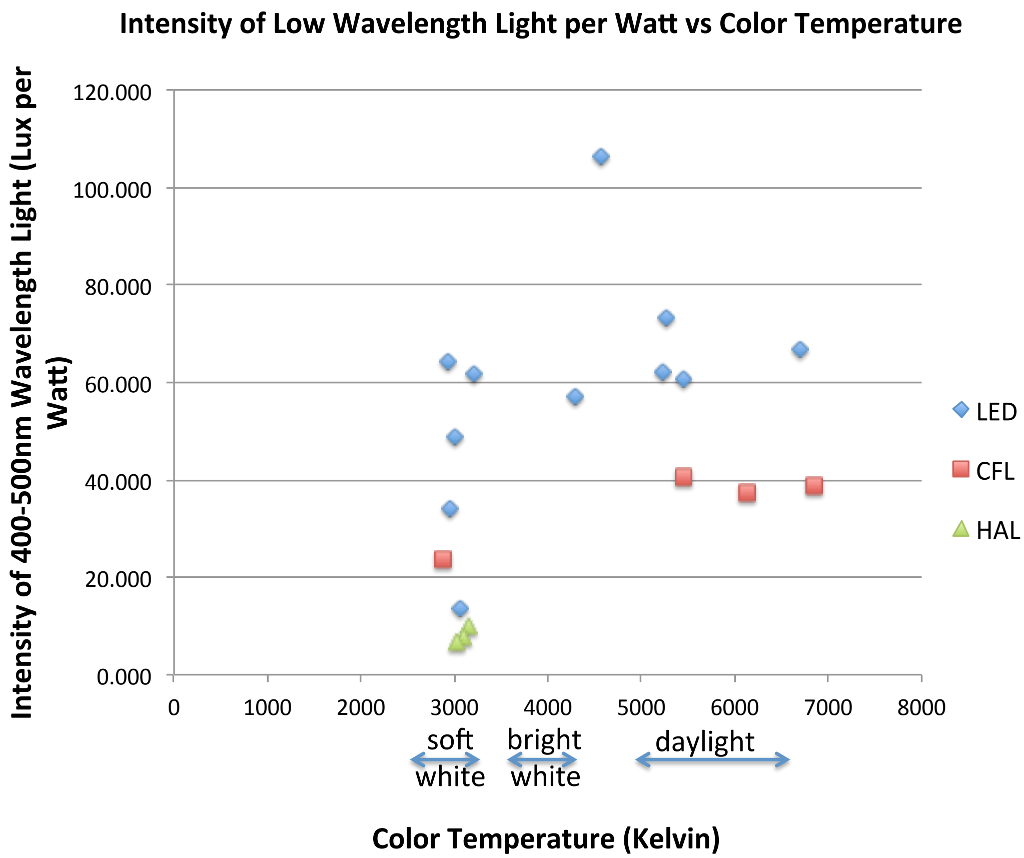

Figure 11: Intensity of low wavelength light in lux per watt.

The mean intensity of each of the light sources at the low wavelengths (400-500nm) per unit power consumed in lux per watt is plotted against the corresponding measured color temperature in Figure 11.

Results

The mean ratio of intensity of low wavelength light to that of the total spectrum for natural light in a room (control) is calculated to be 0.36 and is shown by the "X" mark in Figure 9. This metric is also the highest (0.462) for the iPhone in the normal mode. As expected, the iPhone with the night shift mode turned on has a lower value for this metric (0.388). Along with the iPhone, 3 CFL light sources above 5000K have a higher value for this metric compared to the natural sunlight in a room. This metric is also low for halogen bulbs. The values of this metric for the halogen and the LED bulbs are below that for the control.

Figure 10 shows that among bulbs that have about the same color temperature and are of the same type (LED, CFL, halogen), the intensity of low wavelength light produced in lux increases as their power rating increases. For example, LED bulbs around the color temperature of 3000K produce increasing intensities of low wavelength light as their power rating increases from 5.5W through 15W. This can be because bulbs with higher power rating produce higher light intensities across the visible spectrum, and hence a higher intensity of low wavelength light as well. Also, for bulbs of a specific type, say LED, and the same power rating, the intensity of low wavelength light increases as the color temperature increases. The two 9W LED bulbs and the two 12W LED bulbs above 5000K in Figure 10 demonstrate this trend. Even though the iPhone produces higher relative intensity of low wavelength light in the normal mode as shown in Figure 9, Figure 10 shows that it produces much less total intensity of low wavelength light compared to other light sources. This is because it produces much less overall light intensity across the visible spectrum.

The data in Figure 11 indicates that high efficiency bulbs produce higher intensities of low wavelength light at any given color temperature, since they produce higher overall light intensities per unit watt of power consumed. Since LED sources are more efficient than CFL or halogen sources, they tend to produce higher intensities of low wavelength light across all color temperatures, followed by CFL and halogen sources.

In summary, LED light sources above 8.5W, CFL light sources at or above 14W and with a color temperature higher than 5000K, and halogen sources above 53W, produce higher intensities of low wavelength light than that in a normal well-lit room.

Conclusion

The objective of this experiment is to identify which type of light sources commonly used at homes produce a large amount of low wavelength (400-500nm) light. The hypothesis was that daylight LED bulbs produce the maximum amount of low wavelength light. This hypothesis is proven correct in general. From Figure 10, it is seen that **the highest intensity of low wavelength light is produced by a 16W LED bulb at a color temperature of 5262K**. In the group of bulbs above 5000K, 2 LED bulbs produce higher intensities of low wavelength light than the rest. However, it is also found that LED bulbs at color temperatures below 5000K can also produce significant intensities of low wavelength light at high power ratings. The 10W LED bulb at 4572K and the 15W LED bulb at 3202K are the sources producing the next highest intensities of low wavelength light. These high intensities are followed by a group of 3 bulbs, a 12W LED bulb at 6700K, a 19W CFL bulb at 5450K, and a 12W LED bulb at 5456K. The light sources mentioned so far are those that are to be definitely avoided around nighttime since they produce much higher intensities of low wavelength light compared to natural light in a room during the day. There are group of 4 LED bulbs, 2 CFL bulbs and 2 halogen bulbs across color temperatures that produce low wavelength light intensities in the 500-600 lux range which is close to natural light in a room (459 lux). These bulbs are preferably avoided during nighttime. However, for reading and other activities during late afternoons, the 9W LED bulb with a color temperature of 5225K and 561lux low wavelength output is recommended as it comes closest to natural light output in terms of both relative and absolute intensities of low wavelength light produced.

Results from Figure 11 show that on a per watt basis, daylight LED bulbs produce the most amount of low wavelength light, followed closely by daylight CFL bulbs. This result can be explained by the nature of construction of the LED and CFL light bulbs. The daylight variety of both these types of bulbs most likely have phosphor coatings that are designed to filter light at low wavelengths only to a small degree in order for them to have a whitish or bluish tint.

In conclusion, LED bulbs of higher power ratings, and CFL bulbs of higher power ratings and color temperatures above 5000K are the types of bulbs to avoid in the bedrooms of residences, especially at nighttime, to prevent them from affecting sleep since they produce higher intensities of low wavelength light compared to light in residences illuminated by sunlight through windows during a normal day.

Suggestions for Further Research

This experiment can be used on more light sources used in home such as laptop screens and televisions to find the intensity of low wavelength light they produce. This research can also be extended to identify the types of light sources that can benefit growth of different varieties of plants.

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References

Gunnars, K. (2017, June 04). How Blocking Blue Light at Night Can Transform Your Sleep. Retrieved October 22, 2017, from https://www.healthline.com/nutrition/block-blue-light-to-sleep-better

Han, T., Vaganov, V., Cao, S., Li, Q., Ling, L., Cheng, X., … Tu, M. (2017). Improving "color rendering" of LED lighting for the growth of lettuce. Scientific Reports, 7, 45944. http://doi.org/10.1038/srep45944

Jabr, F. (2016, November 1). Blue LEDs Light Up Your Brain. Scientific American, Retrieved October 22, 2017 from https://www.scientificamerican.com/article/blue-leds-light-up-your-brain/

Prospero, M. (2017, October 16). Light Bulb Guide: LED vs. CFL vs. Halogen. Retrieved October 22, 2017, from https://www.tomsguide.com/us/light-bulb-guide,review-1986.html

Street Lighting and Blue Light – Frequently Asked Questions, https://energy.gov/sites/prod/files/2017/02/f34/Street%20Lighting%20and%20Blue%20Light%20FAQs.pdf

University of Haifa. (2017, August 22). Blue light emitted by screens damages our sleep, study suggests. ScienceDaily. Retrieved October 22, 2017 from www.sciencedaily.com/releases/2017/08/170822103434.htm