Reducing Energy Consumption and Light Pollution by Redirecting Light

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Research and Background

Artificial lighting is one of the most essential uses of electricity in everyday life. However, inefficient usage of this lighting leads to a substantial waste of energy, and has many harmful environmental impacts. The team's goal for this project is to create an adjustable and cost-effective fixture out of repurposed materials in order to redirect light to only where it is needed, thus saving money and electricity, and reducing light pollution.

In 2017, 66 billion dollars were spent on lighting in the United States alone, accounting for approximately 17 percent of total US electricity consumption. Of that, 32 percent was used for outdoor lighting. 30 percent of all outdoor nighttime lighting was emitted into the sky, translating to more than 6.3 billion dollars and 23 billion pounds of carbon dioxide wasted [1]. With the prices for traditional processes of energy production climbing due to high demand and low availability, the number of funds wasted will keep increasing.

Wasted energy in the form of unnecessary light also has harmful effects on the environment. Greenhouse gases emitted during electricity production are large contributors to global warming, resulting in the emission of over 1.55 billion metric tons of carbon dioxide into the atmosphere in 2020. [2]. Lighting alone is responsible for at least one-fourth of all electricity consumption worldwide, and a significant amount of that is wasted. [3]

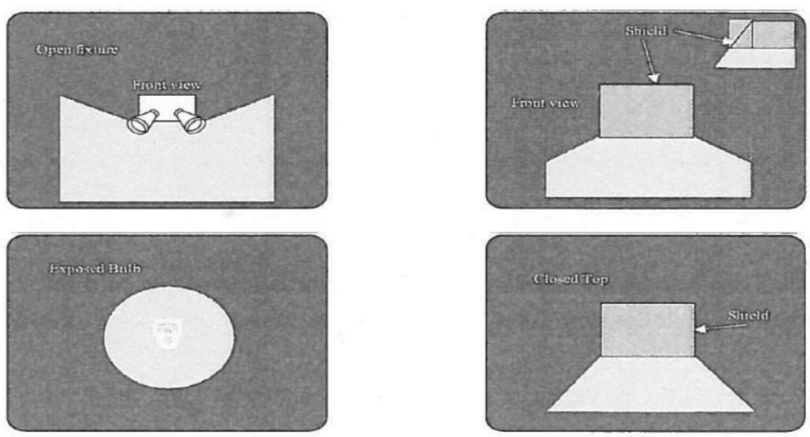
Light pollution is caused by inefficient light fixtures that allow about a third of all outdoor artificial light to be emitted into the sky. This growing issue has alarming impacts such as harmful physical effects on animals, insects, and humans, in addition to interference with astrological studies, Department of Energy (DOE), and Department of Defense (DOD) activities.

The natural world is set to the sun's pattern of light, and when light pollution alters the natural light patterns, countless processes are interrupted. Light pollution is linked to disruptions in the physiological patterns of animals due to artificial light's interference in the natural rhythms of nocturnal and diurnal life. This can ultimately put entire species at risk. [4]. On top of negatively affecting animals, artificial night light also leads to harmful health effects on humans, including increased occurrence of metabolic syndromes and cancer, reduced immunity, and abnormal circadian behavior [5]. Light pollution also interferes with photosynthesis in plants, which in and of itself causes a variety of issues in the ecosystem [6].

In addition to harming the environment, light pollution impedes astronomical research and causes difficulties for amateur and professional astronomers alike . Sky glow, the brightness in the sky caused by city lights, obscures the night sky, preventing astronomers from being able to observe celestial objects [7]. City lights emit light spectrums that interfere with those emitted from celestial bodies, making the observation of astronomical objects increasingly difficult; scientists have to go through a process of separating the emitted light spectrums of domestic lights from those originating in space [8]. Light pollution causes views of the Milky Way to be obstructed to 80 percent of Americans, and 99 percent of people in the United States and Europe live beneath light-polluted skies [9].

New Mexico is home to many DOE and DOD organizations. Nighttime lights from cities have been found to interfere with activities they may perform at night, such as military training, night vision equipment use, and combat simulations [10]. In 2019, The Compatible Lands Foundation paid over half a millions dollars to the State Land Office of New Mexico in order to restrict use of the land around Fort Bliss. This was done for the express purpose of avoiding the problems caused by light pollution [11]. DOD astronomers from White Sands Missile Range expressed concern about light pollution in 1991. One of their proposed solutions was shielding outdoor lights at the missile range [12]. Another example is the Magdalena Observatory, which had its location chosen specifically due to the low amount of light pollution in the area. The Magdalena ridge itself offered a defense against light from cities and other human activities. However, future human encroachment could degrade the telescope's viewing abilities. [13]

There are currently regulations in place to protect the night sky. For example, the New Mexico Night Sky Protection Act is in place to maintain an ideal environment by minimizing the amount of light pollution. The New Mexico Night Sky Protection Act says, “The area of illumination should be restrained to the area judged necessary”[14]. This project will allow for lights to be adapted for this purpose, allowing residents to adjust the direction of light without purchasing a new fixture. At least 18 other states, as well as the District of Columbia and Puerto Rico, have implemented similar protection acts, showing that this is an issue affecting more than just New Mexicans [10].



Examples of unacceptable vs acceptable wall-mounted light fixtures under Rio Rancho, NM outdoor lighting regulations [15].

Current solutions

Light pollution and the costs of energy waste affect many people, yet there are very few convenient solutions. Current options include dimmers and lower wattage light bulbs. The team went through extensive research to find where each of these possible solutions fall short in terms of light- and energy-saving techniques.While modern dimmers can save energy, they are not compatible with all lights, and any energy saved comes at the expense of brightness. In addition, for some lights, such as incandescents, using a dimmer to decrease the brightness of the light actually does not significantly decrease the amount of energy used, so the amount of energy that is actually saved is negligible [16]. Lower-wattage light bulbs save energy, which is why LEDs are so efficient; they are able to provide the same brightness as other types of lights using less energy [17]. However, even with both of these solutions, much of the light is still being wasted. Few light fixtures are designed with the intent of maximizing light efficiency, and those that do exist are often without reflective surfaces, absorbing much of the light rather than reflecting. After careful consideration, the team came up with a prototype that met many aspects that the modern solutions were lacking.

Constraints/Scalability

The constraints placed upon this project are largely due to the processing of raw non-recyclable materials, and the time it takes to do so. Using reclaimed aluminized mylar food wrappers requires them to be collected, cleaned, and processed. For production on a larger scale, collection of the appropriate materials would provide its own set of challenges. The processing of the aluminized bags proved to be a tedious and time-consuming undertaking.

The unique shape of various light fixtures made it difficult to create a single solution. The expansion of the accordion-style prototype can be a limiting factor depending on the possible variations in shape of different light fixtures. Additionally, for outdoor lighting, the repurposed material used must be able to withstand weather and outside conditions for extended periods of time.

Main Goal

The main goal of this project is to create a cost-effective solution to save energy and reduce the effects of light pollution by redirecting light downward to only illuminate areas of priority. Thus, the wattage of the bulb can be decreased, providing the same amount of light for less energy.

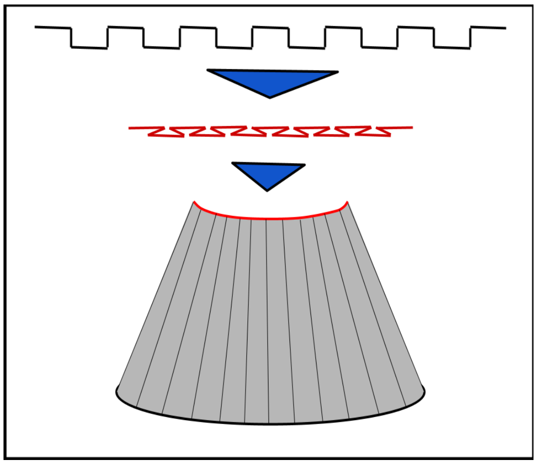
Various Ideas

When coming up with this project, the team wanted to address an issue that is often overlooked but has major consequences. Upon first-hand observation of the effects of light waste, the team began researching possible ways to minimize outdoor light pollution. After some brainstorming, the team changed focus to include indoor lighting. The team noticed how half of the bright classroom lights were pointed straight at the ceiling, which resulted in significant amounts of light and money being wasted. This led to the idea of creating an adaptable shield to direct light downward to usable areas. The team created several prototypes of different materials, shapes, and sizes to test for optimal brightness and efficiency.

Selected Approach

Through much deliberation, the team decided that the ideal approach to alleviate light pollution and to conserve energy is to simply redirect the light. Many light fixtures waste light by illuminating unnecessary areas such as ceilings and the sky, a problem that could be solved simply by reflecting the light downward. However, due to the fact that there are many different shapes and sizes of lights, the design needed to be adaptable. To address this, the accordion design allows for the necessary adaptability and efficiency, allowing the prototype to conform to any type of light fixture. Since the design is composed of weather resistant recycled materials, it can be used both indoors and outdoors. Instead of wasting valuable energy and negatively affecting the natural environment, this simple solution will effectively combat light pollution and energy waste.

Model or Prototype



Materials:
- LED light bulbs: ($1.56)
- Fluorescent lights: ($5.33)
- Cardboard: Recycled
- Mylar balloons: ($9.99)
- Paper: ($19.99)
- Lamp: ($11.99)
- Light meter: ($34.99)
- Chip bags: ($5.56)
- Tape: Donated ($6.38)
- Rulers: ($2.96)
- Tripod:($17.99)

Total: $117.74

Prototype Plan

In fabricating a prototype, the first thing the team considered was the processing of the reclaimed materials. All materials were thoroughly cleaned for use in the prototype. After sanitization, the raw reclaimed materials had to be cut from the packaging into the desired sheets to construct the final prototype. Reclaimed aluminized mylar packaging (such as wrappers from chips, granola bars, and balloons) was then folded into an accordion-inspired geometric pattern. This pattern, from a side profile, has characteristics of a square wave in which the wavelength is 4 times that of the amplitude. By enabling the prototype to collapse and expand like an accordion, the prototype is easily conformed to irregular light fixtures. A thin wire frame will allow the prototype to “fan out” from its accordion formation and hold its shape directing the light with the proper angle which will fill the desired area. Using this design idea, the same prototype could be used for a spherical bulb-type light (such as an LED light bulb) as well as a rod-style light (such as a long fluorescent light). Aluminum, and similar materials, are able to withstand the elements, allowing the possibility of use outdoors. For non-metal light fixtures, the use of velcro will ensure an easily installable and securely attached installation method. For metallic light fixtures, thin flexible strip magnets will ensure a strong mechanical connection that is also easily adaptable.

Safety and Protocol

The testing process occurred in the darkest possible testing environment, a small room with no light from any outside sources. All members of the testing process had an unobstructed testing area. Although light from outside sources was minimized, the experiment itself also produced light, meaning members were rarely forced to move about in the dark. The bulbs used were safe meaning no members could be burned, cut, electrocuted, or harmed in any way. Members worked together so no one was left alone in the testing environment.

Test Model and Evaluations

Troubleshooting and Testing

The testing environment consisted of a small room with a table in the center. A black canvas was laid on the table to prevent the reflection of excess light upward from the experiment. To quantify light amount, the team used a light meter made by Dr.meter to measure the luminous flux per unit area (lux) of the light at set distances from the light bulb. Measurements were taken in three spots: directly beneath the light, 6 inches from the center, and 12 inches from the center. This gave an illustration of how effective each prototype was by showing how well each reflected light and how focused the light was. For each type of light bulb, the team tested three different materials: aluminum foil, aluminized mylar, and black paper; and three different angles: flat-180°, 135°, and 90°. Both of the bulbs were measured without any prototype as a constant, and validation was done by doing multiple measurements at each trial

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Strengths and Weaknesses

One factor to consider when evaluating the effectiveness of the prototype, is the wide variability in shapes and sizes of both indoor and outdoor fixtures. However, this ended up becoming a strength for the project as the team adapted for the scalability by creating an adjustable prototype through the use of accordion folding. The ability to create various shapes to fit various light fixtures allows for optimal adjustability of the project.

Future Areas of Improvement

A large contributor of light pollution is blue light. The most efficient LEDs are also very rich in blue light. Blue light itself has harmful health effects and contributes to light pollution due to its increased glare [18]. A possibility for this project in the future is the integration of a blue-light filter into the design for use on LED light bulbs.

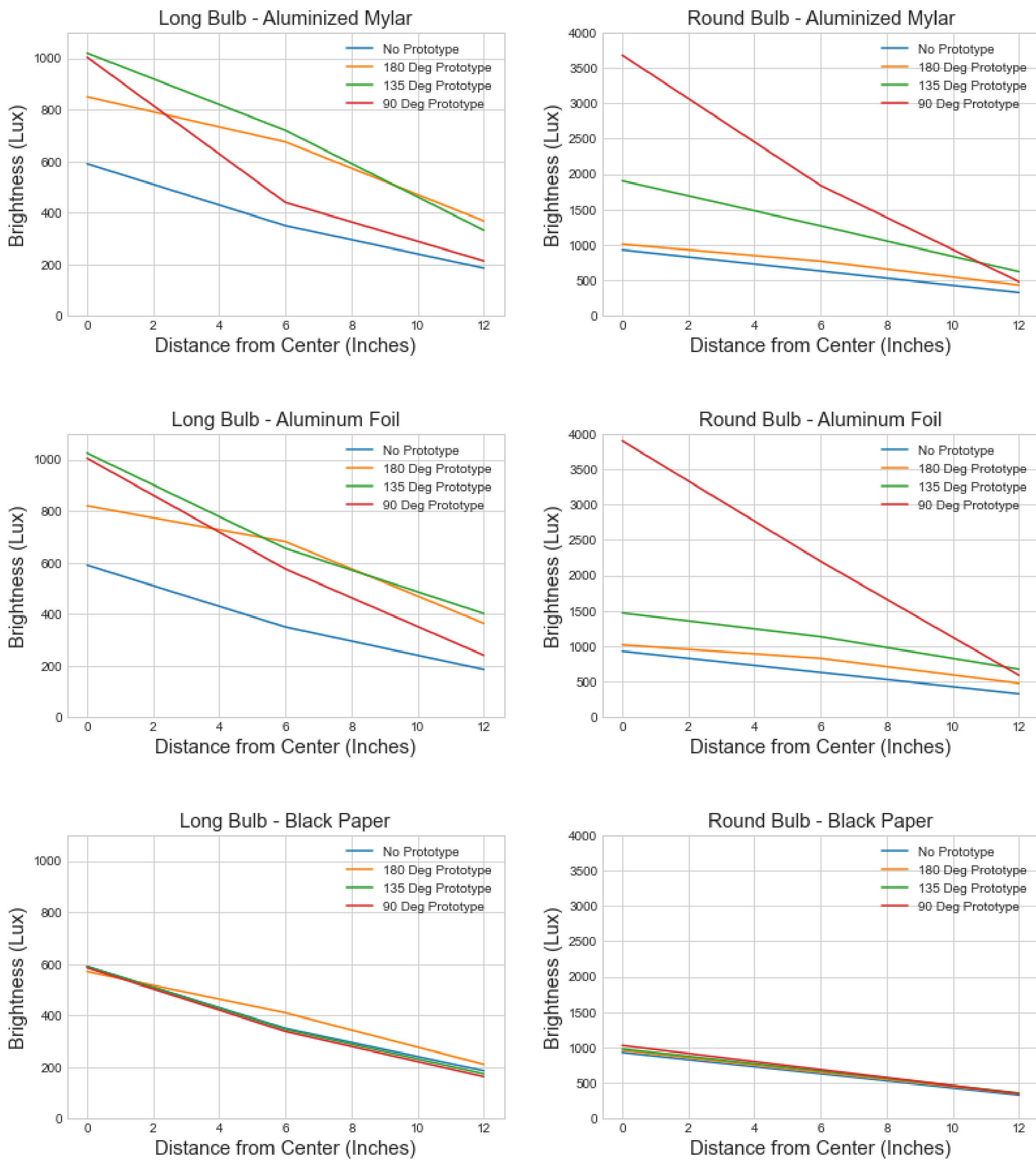
Modifications of Design

In order to engineer the optimal prototype, the team came up with a design that utilized available light, some of the original designs involved a myriad of recycled materials, including recycled chip bags, aluminum foil, and aluminized mylar. The aluminized mylar from chip bags was appealing because it provided the opportunity to repurpose non-recyclable chip bags. However, the team questioned whether aluminum foil or mylar would perform better. Aluminum foil was less appealing as a material because while it is fully recyclable, it is also very fragile. The results from testing revealed no significant difference between the effectiveness of the two materials, so the team decided to use aluminized mylar for the final design.

Test Results

Table 1: Experimental Results

Bulb Type	**Material Used**	**Horizontal Distance from light source center (in)**	**Light (lux)**			
			No Prototype	**180° (Flat)**	**135°**	**90°**
Long 17 Watts	Aluminized Mylar	0	590	850	1020	1004
		6	350	675	720	440
		12	185	368	332	213
Long	Aluminum Foil	0	590	820	1025	1005
		6	350	681	655	575
		12	185	364	402	240
Long	Black Paper	0	590	570	590	585
		6	350	410	346	338
		12	185	210	173	162
Round 8.5 Watts (LED)	Aluminized Mylar	0	930	1010	1905	3680
		6	630	770	1270	1840
		12	330	434	622	480
Round	Aluminum Foil	0	930	1020	1470	3900
		6	630	830	1135	2200
		12	330	477	676	590
Round	Black Paper	0	930	960	980	1030
		6	630	650	670	690
		12	330	350	360	350



The distances measured were: directly under the light bulb, 6 inches away, and a foot away. For longer light fixtures, often found in classrooms, businesses, and more, the best solution was a long piece of cardboard 11 inches wide, bent in the middle at a 135 degree angle. For rounder light fixtures, the cone coated with mylar at a 90 degree angle produced the brightest result directly below the light, but the cone at 135 degrees was brighter over greater surface area. Depending on the particular application, the user could decide how focused the light should be. The great difference between our reflective prototypes and black paper show how great of a difference the reflective material makes, meaning our prototype could be easily implemented to light fixtures that already have basic shields (often made of the same black or dark materials that the fixture is made out of).

Table 2: Costs

Source	**# of kWh used per year for lighting**	**# of kWh saved**	**Amount of money saved ($)**
Average Household	990	198	25.76
Average Business	6,550	1,310	160.0
New Mexico	2,032,000,000	406,400,000	36,535,360
United States	219,000,000,000	43,800,000,000	4,616,520,000

*Sourced from U.S. Energy Information Administration 2010-2020 data [19,20].

The best design for the long light fixtures resulted in an average of 55% more intense light. Despite the adjustable design, the product cannot be applied to every light fixture, such as recessed light fixtures. However, even just a 20% decrease in electricity consumption (the lower limit of the recorded results) by using this prototype would result in significant savings.

<u>**Collaboration**</u>

The team met multiple times a week after school with additional meetings in the morning and on other days of the week as needed. The team had a very thorough brainstorming process for several weeks, and examined each global issue that came to mind. After careful consideration, the team decided to combine the issues of energy waste and light pollution and create a design to combat both of these problems. After much research and deliberation on the various approaches to find a solution to the problem, the team decided upon an approach that would be applicable to many different aspects of the problem. The team then began compiling research and materials. The team built the prototype together and tested it. The team worked as a collective at every opportunity in order to allow for input on every front.

Contributions

- **Peyton Casey**: Assisted in researching light pollution and its effects on astronomy and the environment, organizing the bibliography, and editing the written plan.
- **Elijah Griego**: Created accordion prototype. Worked on Model and Prototype as well as Constraints on the Written Plan. Also contributed to data collection and translation.
- **Isabella Hendricks**: Assisted in researching DOE and DOD effects and writing said section, as well as researching the different protection acts, editing the written plan, and assisted in building the prototype.
- **Eliana Juarez**: Assisted in conducting the experiment, data analysis, experimental design, the written plan, and general project planning.
- **Josiah Phillips**: Assisted in researching current solutions, effects of light pollution, and experimental testing and design.

- **Graciela Rodríguez**: Helped with research on light pollution and energy usage, experimental design, assembly of testing environment and materials, testing, and writing the written plan.
- **Devonie Thompson**: Helped with testing during the experimental process, gathered data, and edited the written plan, helped format the executive summary.
- **Jacob Trappett**: Assisted in researching light pollution and helped assemble the experimenting area.
- **Victoria Shaner**: Assisted in researching light pollution and its effects as well as helping with the experiment, and writing the environmental section and other statistics in the written plan.

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