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WPI Energy Efficiency Lighting Study

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Abstract

This project determined the feasibility of reducing WPI’s total carbon footprint and energy usage costs through the modification of light sources and technology. By conducting an inventory of light bulbs in various on-campus buildings and determining the utilization of each type of light bulb in each building, the team calculated payback periods, annual rates of return and reduction in carbon footprint for various replacement light bulbs. The most cost efficient method of replacing the light bulbs is to first replace all remaining incandescent bulbs with compact fluorescent bulbs. Second, any halogen bulbs should be changed to LED bulbs. Third, motion sensors should be checked for functionality and replaced or added where none exist. Finally, short fluorescent bulbs, followed by long fluorescent bulbs, should be changed to LED bulbs as the fluorescent ones burn out due to the high cost of the LED bulbs. If implemented, these recommendations will reduce WPIs total carbon footprint by about 4%, while also reducing annual campus energy costs for lighting by about 3%.

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Executive Summary

As instances of extreme weather phenomena and temperatures increase so does the public's awareness of greenhouse gas emissions and global warming. WPI has demonstrated its interest in the benefits of environmentally friendly alternatives and while WPI has not committed to the American College & University Presidents' Climate Commitment, it has shown a desire to move towards more sustainable technologies.

In 2009, WPI used approximately 25 million kilowatt-hours of electricity, at a cost of over $1.8 million. Using approximately 15-25% of the electricity consumed at universities, lighting represents one of the major consumers of energy on campuses. In 2009, WPI used about 4.3 million kilowatt-hours of electricity on lighting and spent roughly $330,000.

To develop a representative lighting usage profile of WPI, this project group generated specific recommendations for how to reduce both the energy bill and carbon footprint of WPI through improving the energy efficiency of lighting on campus. The team first set a sample group to survey that could be expanded upon the entire campus. This sample group included Daniels Hall, Harrington Auditorium, Higgins Laboratories, the Bartlett Center, and Exterior lighting. The team then began collecting data by counting how many lights were on at set intervals during the day. This data was then extrapolated to calculate the average number of lights on at any point in the day. The lights being replaced are two foot long and four foot long fluorescent bulbs, incandescent bulbs, and halogen bulbs.

The team used the light utilization data to calculate payback periods, annual rates of return and savings in greenhouse gases for various replacement light bulbs. LED replacements for incandescent bulbs and for compact fluorescent bulbs are not viable choices as CFLs have much higher rates of return and shorter payback period. The rates of return for the replacement light bulbs are competitive for all other replacement light bulbs, though. The lowest rate of return is 0.72 percent in the Bartlett Center which the team expected as it is a relatively low used, LEED certified building.

The lower rates of return can be mitigated by how much greenhouse gases are conserved. For example, while replacing the long fluorescent bulbs in Higgins Laboratories yields a rate of return of about three percent, it saves about 600 thousand pounds of carbon dioxide over the lifetime of the bulbs. That converts to about 35 tons of carbon a year. The savings produced by replacing old light bulbs with newer technology will not only help reduce WPI's greenhouse gas emissions, but also its electricity bill. The following chart outlines the replacement plan developed by our group and shows the cost, return over the lifetime of the bulbs and annual rate of return of the light bulbs.

Step	Action	Number of Bulbs	Cost	Return Over Lifetime	Annual Rate of Return
1	**Incandescent to CFL**	2,300	$18,000	$206,000	270%
2	**Halogen to LED**	180	$14,000	$119,000	50%
3	**Motion Sensors**	N/A	N/A	N/A	N/A
4	**Short Fluorescent to LED**	6,000	$270,000	$404,000	3.3%
5	**Long Fluorescent to LED**	10,000	$630,000	$785,000	0.90%
	TOTAL	19,000	$930,000	$1,500,000	4.08%

The team's replacement plan is to first replace any incandescent bulbs with compact fluorescent bulbs which have an annual rate of return of about 270 percent. After that is completed, we recommend replacing the few halogen light bulbs with LED versions of halogens which have an annual rate of return of about 50 percent. Next, motion sensor checking and, in some cases, installation is a necessary step in saving energy usage when areas are unoccupied. It is difficult to accurately calculate returns for motion sensors without having data on building usage, so motion sensors were neglected from the calculations. Finally, the short and long fluorescent bulbs, in that order, should be replaced with LED fluorescents as they have rates of return of about 3.3 percent and 0.9 percent respectively.[we note that this is the largest and most expensive of the recommended steps].

All replacement light bulbs outlined in this project at least pay for themselves over their lifetime, and often have a competitive annual rate of return. If implemented, these recommendations will reduce WPI's total carbon footprint by about 4%, while also reducing annual campus energy costs for lighting by about 3%. If all bulbs are replaced on campus, the total project would cost approximately $930 thousand and save about $1.5 million over the lifetime of the bulbs. Replacing the out of date light bulbs at WPI will save money, greenhouse gas emissions, and help WPI move towards a more sustainable future.

1.0 Introduction

The top three global fuel sources currently being used include oil, coal, and natural gas. Together they comprise nearly 85% of the world's fuel. Fossil fuels are practical because the infrastructure to utilize them already exists and because they have a high energy density. Substances with a high energy density contain high amounts of energy per unit volume. Such substances are desirable for transport and storage because less of the substance is needed while maintaining high energy potential. This contrasts with substances such as biomass, which require larger volumes to maintain the same energy output.

Although fossil fuels are widely used for their high energy potential, over the past decades there has been a rising global concern over their use. Fossil fuels, when burned, release large amounts of carbon dioxide into the air. A carbon footprint is the measure of carbon dioxide created by a person or organization. As a result of centuries of burning fossil fuels, negative environmental effects have ensued. Global temperatures have started to rise. Consequently, the polar ice caps have been melting, which has also caused a general rise in the ocean level. Changes in temperature also affect climate zones and ocean currents. According to the United State Energy Information Administration, the world energy consumption is predicted to grow by 49 percent from 2007 to 2035 (Summary Statistics for the United States 2010). As global energy needs continue to increase, there will be a positive trend in the use of fossil fuels to fulfill this growing need.

Energy use in the United States can be analyzed in terms of four sectors including residential, commercial, industrial, and transportation. Industrial and transportation sectors account for 30% and 29% of the energy consumed in the United States respectively. The residential sector accounts for 22% and the commercial sector accounts for the remaining 19% of the energy consumed in the United States. Within the residential sector, electricity normally accounts for about half of the energy consumption. Furthermore, of the total electricity used by residential areas in the United States, lighting constitutes one of the largest percentages with 15.4%. Over the past decade, the average retail price of electricity in Massachusetts has risen from 8.24 cents per kilowatt-hour in 2000 to 15.18 cents per kilowatt-hour in 2010 for residential consumer, an 84% increase. Thus, lighting contributes to a substantially rising portion of electricity costs (Trends in Massachusetts' Electricity Retail Prices Fact Sheet 2010).

Worcester Polytechnic Institute (WPI) spends between 2 million and 4 million dollars on electricity every year. Fluctuations in the cost of electricity in previous years can be attributed to new buildings being erected on campus. Considering that lighting contributes to approximately 15-20% of electricity, this means that WPI spends somewhere between $200,000 and $600,000 on lighting electricity costs. As the cost of electricity continues to rise, WPI's expenditures on electricity to light the campus will continue to rise as well. Increased electricity usage for lighting will also increase the carbon footprint of the campus thereby expanding WPI's contribution to negative global consequences.

The group conducted a study of WPI lighting technologies and utilization patterns. We investigated alternatives for the purpose of developing a set of recommendations for changes in the WPI lighting infrastructure that can be implemented to significantly reduce the institution's carbon footprint in a financially sustainable and attractive manner.

2.0 Background

2.1 Energy Concerns

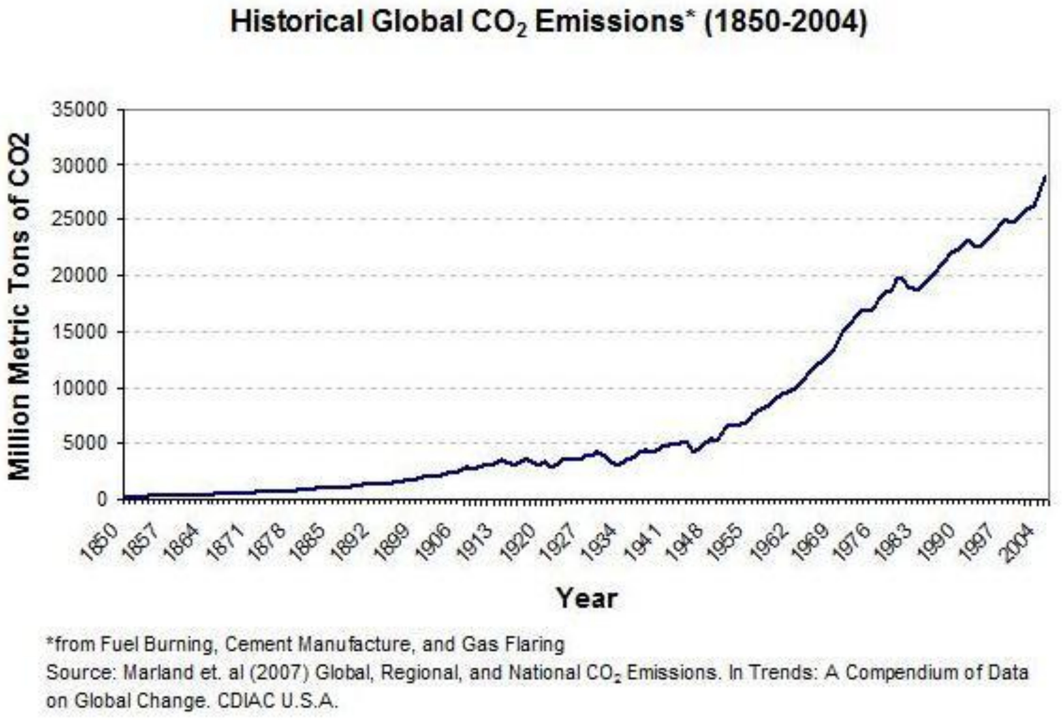
Considering that global energy consumption is predicted to grow by 49% from 2007 to 2035 and that energy costs have increased by 84% in Massachusetts over the past 10 years, there has been a growing concern over the use of fossil fuels (Summary Statistics for the United States 2010). Issues linked to the debate over the use of fossil fuels include concerns over negative environmental consequences as well as fossil fuel depletion, since fossil fuels are nonrenewable resources.

2.1.1 Environmental Factors

According to the National Climatic Data Center, the combustion of natural gas, oil, and coal has led to increased carbon dioxide levels in the atmosphere. Since the Industrial Revolution, global carbon dioxide levels have increased from 280 parts per million by volume (ppmv) to 280 ppmv. Global carbon dioxide levels have been increasing 1.9 parts per million per year since 2000 (Global Warming Frequently Asked Questions 2008).

The U.S. Energy Information Administration (EIA) is part of the Department of Energy that provides independent statistics and analysis on many energy topics. In March of 2010 the EIA released a report of the 2008 summary statistics of electricity generation individually by state. In the report for Massachusetts, data for the three main byproducts from electricity generation are shown as 2.3 pounds per megawatt-hour for sulfur dioxide, 1.0 pound per megawatt-hour for nitrogen oxide, and finally 1,154 pounds per megawatt-hour for carbon dioxide (Summary Statistics for the United States 2010). Although much more carbon dioxide is produced per megawatt-hour, sulfur dioxide and nitrogen oxide are toxic at lower levels.

As Figure 1 shows, global carbon dioxide emissions have been drastically increasing.



Historical Global CO_2 Emissions* (1850-2004)

*from Fuel Burning, Cement Manufacture, and Gas Flaring

Source: Marland et. al (2007) Global, Regional, and National CO_2 Emissions. In Trends: A Compendium of Data on Global Change. CDIAC U.S.A.

Figure 1: Historical Global CO2 Emissions (National Climatic Data Center)

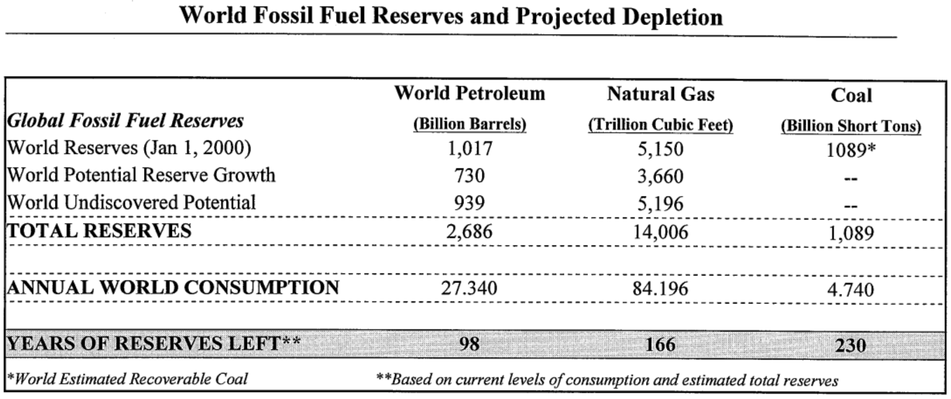
As a result of increasing levels of carbon dioxide in the atmosphere, global surface temperatures have increased .74°C since the late 19^{th} Century. The National Climatic Data Center confirms that there has been a linear trend of 0.13°C ± 0.03°C per decade for the last 50 years. The planet has also experienced 7 of the 8 warmest years on record since 2001 (Global Warming Frequently Asked Questions 2008). According to data from NASA, as an outcome of increased global temperatures, Arctic perennial sea ice has been increasing at a rate of 9% per decade. Consequently, the sea level has been rising at an average rate of 1.7 mm/year ± 0.5 mm over the past 100 years (NASA 2003).

2.1.2 Fossil Fuel Depletion

According to the United States Department of Energy, “Fossil fuels – coal, oil and natural gas – currently provide more than 85% of all the energy consumed in the United States, nearly two-thirds of our electricity, and virtually all of our transportation fuels” (DOE 2010). Data from the EIA confirms that in 2008, coal produced 21.03% of electricity, petroleum produced 1.12%

of electricity, and natural gas produced 21.03% of electricity. Combined, the three major fossil fuels produced a total of 70.36% of United States electricity production.

The Colorado River Commission of Nevada published a report in March 2002 on the world's fossil fuel reserves and the projected depletion. The results are "based on current levels of consumption and estimated total reserves." As shown in Figure 2, the commission concluded that there was tentatively 98 years left of petroleum, 166 years of natural gas, and 230 years of coal (World Fossil Fuel Reserves and Projected Depletion 2002).



World Fossil Fuel Reserves and Projected Depletion

Global Fossil Fuel Reserves	World Petroleum (Billion Barrels)	Natural Gas (Trillion Cubic Feet)	Coal (Billion Short Tons)
World Reserves (Jan 1, 2000)	1,017	5,150	1089*
World Potential Reserve Growth	730	3,660	--
World Undiscovered Potential	939	5,196	--
TOTAL RESERVES	2,686	14,006	1,089
ANNUAL WORLD CONSUMPTION	27.340	84.196	4.740
YEARS OF RESERVES LEFT**	**98**	**166**	**230**

**World Estimated Recoverable Coal* ***Based on current levels of consumption and estimated total reserves*

Figure 2: World Fossil Fuel Reserves and Projected Depletion (World Fossil Fuel Reserves and Projected Depletion)

Other such studies conclude that petroleum reserves will reach depletion between 2050 and 2100. One such study conducted by L.F. Ivanhoe, a geologist with 50 years of experience in petroleum exploration, claims that petroleum reserves may have peaked in 2000 and they will continue to fluctuate until they eventually decline around 2050 (Ivanhoe 1995). Similarly, J.H. Walsh, an energy advisor, calculated that petroleum will be depleted by the year 2075 (Walsh 2000). Overall, these studies disagree only on the date, not the fact, of the exhaustion of petroleum reserves.

2.2 Certification Systems

Several companies have created systems for measuring the sustainability of a building or institution. There are two major scales for this measurement: LEED (Leadership in Environmental and Energy Design) and STARS (Sustainability Tracking Assessment and Rating System). LEED focuses on the design and construction of a single building, while STARS focuses more on the ideology of an entire institution. While design has some ties to the ideology of an entire institution, it is a much smaller aspect of STARS compared to LEED. Finally, while there are other certification systems, these two are the easiest to use because they enable anyone to self-evaluate a building based on clearly defined rules in their handbooks.

2.2.1 LEED

Quickly after formation in 1993, the United States Green Building Council (USGBC) “realized that the sustainable building industry needed a system to define and measure ‘green buildings’” (USGBC 2009, xi). After several years of discussion and planning, in August 1998, the pilot program for Leadership in Environmental and Energy Design, or LEED for short was unveiled. After heavy modifications LEED Green Building Rating System Version 2.0 was released in March 2000. As LEED has grown and matured, so have its initiatives and goals. Now there are eight different LEED rating systems devoted to different types of development and maintenance issues: LEED for Core & Shell, LEED for New Construction, LEED for Schools, LEED for Neighborhood Development, LEED for Retail, LEED for Healthcare, LEED for Homes, and LEED for Commercial Interiors.

LEED is a point based system that seeks to encourage healthy and sustainable construction and design aspects of a building while discouraging wasteful construction and implementation by-products. In this scale there are 100 base points and 10 more points based on innovation in design and regional priority. There are four main awards when it comes to LEED certification; Certified (40-49 points), Silver (50-59 points), Gold (60-79 points), and Platinum (80 points and above).

LEED for Schools mentions lighting very often and it is included in much of their scoring, both directly and indirectly. LEED for schools grants one point for light pollution reduction, one point for the controllability of the systems, and one to three points for using daylight efficiently, all out of the possible 110 points. Another section of LEED for schools is based on the energy used in the entire building. To become certified, buildings must follow much of this section, but there are also up to 19 points available for optimized energy performance. Lighting is included in these sections and is difficult to differentiate lighting from the rest of the energy being used.

There are three main sections in the LEED system that relate to lighting; reduction of light pollution, controllability of energy use, and maximizing daylight's contribution to meet needs in building design. Light pollution is related very directly to light energy usage; it is energy that is not being used for its intended purpose. In the winter, this energy may help provide heat to buildings but in the summer that heat must be extracted from the building. For interior lighting there are two options for reducing light pollution according to the LEED 2009 for Schools checklist. Option one includes: "Reduce the input power (by automatic device) of all nonemergency interior luminaires with a direct line of sight to any openings in the envelope (translucent or transparent) by at least 50% between 11 p.m. and 5 a.m. After-hours override may be provided by a manual or occupant-sensing device provided the override lasts no more than 30 minutes" (LEED, 18). Option two is essentially to shield all openings to the exterior so that less than 10% of light is let through between 11 p.m. and 5 a.m. Option two will be disregarded as it is an option more for buildings that must be lit throughout the night. Exterior lighting is also taken into account for this section of LEED but will also be disregarded as it deals with the amount of light directed upwards, not the usage of light, which is more difficult to measure. Finally, sports field lighting is another aspect of this section of the certification. "All sports lighting must be automatically controlled to shut off no later than 11 p.m. Manual override must be provided to avoid disruption of school sponsored sporting events" (US Green Building Council 2009, 19).

Next, light is accounted for in the controllability of systems. The main goal of this one point section is to provide users with control of the lighting for their own comfort and well-being. This section says that in administrative offices and other regularly occupied spaces, 90% of the buildings occupants must be able to control the lighting in order to suit their individual needs. Also, classrooms must have controls to operate in both general illumination and A/V modes. A/V mode adjusts the light so that it is focused on the front of the classroom for lectures and presentations.

The final section dealing with lighting is the most valuable, according to LEED's points system: daylight. To receive the full three points of this section, the building must provide 90% of the classroom spaces with day lighting and 75% of all other regularly occupied spaces. There are four different options that can be used to prove that a building has the appropriate day lighting including computer simulations. Essentially, a 10 foot grid in the least day lit portion of the room must measure at least 25 foot-candles.

2.2.2 STARS

STARS focuses on the ideology behind sustainability, energy efficiency, and harmful emissions. STARS was created by the Association for the Advancement of Sustainability in Higher Education (AASHE). AASHE was awarded the US Green Building Council Leadership Award for Non-Government Organizations in 2009 for its part in launching the American College and University Presidents' Climate Commitment. Drafts of the STARS technical manual have been available since 2007. However, the STARS system is less well known because the first full version of their technical manual was not published until June 2010. STARS is a voluntary, self-assessment tool that provides colleges and universities a guide to developing a green institution. “It provides a tool for looking at all facets of our institutions—curriculum and research, campus operations, planning and institutional capacity – with the goal of aiding strategic planning, fostering cross-sector dialogue about sustainability on campus, and stimulating conversations and learning between institutions” (AASHE 2010, iv). Also, AASHE was awarded the US Green Building Council Leadership Award for Non-Government Organizations in 2009 for its part in launching the American College and University Presidents' Climate Commitment.

Scoring is broken up into three sections; Education and Research category, Planning, Administration and Engagement category, and Operations category. The final score is based on the average percent of points scored in each section. For example, if a university scores a 30% in Education and Research, a 40% in Planning, Administration and Engagement, and a 50% in Operations, their final score would be a 40%. Finally, there are four main rating levels: Bronze (25%), Silver (45%), Gold (65%), and Platinum (85%). An institution can be seen as a “STARS reporter” if they submit data publically but do not pursue a rating.

Lighting is broken into two “Tier Two” parts in the Operations category, under the energy subcategory. Each part is worth 0.25 points out of the 16.5 total possible points in the energy subcategory. The criterion for the first 0.25 points is “Institution uses motion, infrared, and/or light sensors to reduce energy use for lighting in at least one building” (AASHE 2010, 127). The second 0.25 points available is simply for the use of LED lighting technology in at least one application and exit signs and remote controls do not count for this section. STARS mentions lighting very little and lighting has very little effect on the final score of the institution.

2.3 Public Policy

The government has a strong hand in the U.S. marketplace that is often times underused. Dr. Marilyn Brown, Professor of Energy Policy at Georgia Institute of Technology, argues for greater Federal government involvement in the energy marketplace: “Often the technical solutions to societal problems already exist; all that blocks their usage are market imperfections than can be eliminated by simply updating public policies” (Sovacool and Brown 2007, 23). By enforcing bans, like the banning of incandescent bulbs in Europe, or by encouraging the public to make better choices, like tax refunds for upgraded windows, a government can change a society’s perspective in favor of “correct” environmental decisions. “The fact is, the U.S. government and industry have invested a fraction of what has been needed to develop solutions to the nation’s energy problems, and local, state, and federal policies and initiatives have been inadequate” (Sovacool and Brown 2007, 23). Brown acknowledges that part of the problem constraining public support for proactive energy policies has to with the consumer’s experience of energy price shocks: “marketplace manipulation has been a common accusation by those who claim that today’s energy crisis is a hoax” (Sovacool and Brown 2007, 23). Despite criticism by those who do not believe in the energy crisis many governments and institutions within the United States and beyond have started to take steps towards policies advocating a more sustainable world and a cleaner environment.

2.3.1 United States

In August 2005, President George W. Bush signed into law the Energy Policy Act (EPAct). “The EPAct calls for $14.5 billion of additional tax incentives over the 10-year period covered by the act to bring a variety of new energy supplies and infrastructure on line” (Sovacool and Brown 2007, 44). Some policy provisions included legislation for new efficiency standards on twelve residential and five commercial products and the creation of tax credits for builders of high efficiency homes.

Not all American energy policy initiatives, however, originate at the federal level. For example, in 2007, the New York Education Department decided that its lights would be shut off from 11 p.m. to 5 a.m. every day. This decision was instigated by a report done by the New York

Daily news, which found that “lights in city buildings burned throughout the night, wasting power and money. When we asked Mayor Bloomberg about it, he admitted the city was messing up - and vowed to fix the problem” (Belenkaya and Moore 2007). The Daily News continued to investigate and found that many public buildings were found to have lights on throughout the night despite the fact that they were not in use. A spokesperson for the Department of Citywide Administrative Services, which controls 53 municipal buildings, said that it would start a building by building survey in order to determine where more energy efficient lighting, motion sensors, and timers could be implemented to save electricity.

2.3.2 Europe

Paul Waide, an employee of the Energy Efficiency and Environment Division of the International Energy Agency since 2004, has made several presentations across the world on public policy and what should be changed to make a more energy efficient world. Waide has supported the G8 countries in developing their plans of action for climate change, clean energy and sustainable development. Before joining the International Energy Agency, he worked as an international energy efficiency consultant for fourteen years where he was involved in developing energy efficiency programs in over sixty countries. Wade states that if incandescent lamps were replaced by compact florescent lamps that about 5% of the world’s electricity demand and about 16% of the world’s cars carbon dioxide emissions would be avoided. This task is non-trivial; without a well implemented policy, no change will occur. Starting with the 2006 G8 summit, Europe began the process of phasing out incandescent lamps in favor of energy-efficient alternatives. It was decided by members of the G8 that a mix of regulatory and market building measures were needed. Since then, many countries in Europe, including the United Kingdom, Ireland, Belgium and Portugal, have announced plans to phase out incandescent lighting through a mix of financial and fiscal incentives and disincentives but much of this plan has been completed through the help of the European Lamp Companies Federation (ELC). On March 1, 2007 the ELC “announced a first-ever joint industry commitment to support a government shift to more efficient lighting products for the home” (Waide 2007). The final plan was to phase out all incandescent and move to more energy efficient lighting within 10 years. The ELC estimated a 63,000 GWh drop in energy usage and a 60% savings in carbon dioxide emissions with their plan by 2015. Led by European public policy, much of the world has begun to move towards phasing out incandescent lamps.

2.4 Lighting Energy Use

Many companies have done research to determine what the largest uses of energy in a typical building. Energy Star, one of the foremost companies on energy efficient technologies, wrote an extensive article on the importance of lighting and ways to save money and energy in 2006. “Lighting takes a larger share of a [commercial] building's electricity use than any other single end use—more than 35 percent” (Energy Star 2006). The Florida Solar Energy Center did a study on the energy savings of occupancy sensors. They discovered that at Fellsmere Elementary School “metered lighting energy use has averaged about 17% of total facility energy consumption” (Floyd, Parker, Sherwin 1995). In 2008, the U.S. Energy Information Administration determined that lighting was 15.4% of all electricity used in residential homes. According to the U.S. Energy Information Administration, lighting was the third biggest single category behind space cooling and “other”.

Green Energy Payback, a company that specializes in energy use and analysis buildings of every type, analyzed multiple different types of buildings and shown that, in general, heating and cooling uses the majority of the energy. One of the building types that Green Energy Payback investigated was school buildings, which included preschools, elementary schools, middle or junior high schools, high schools, vocational schools, and college or university classrooms.

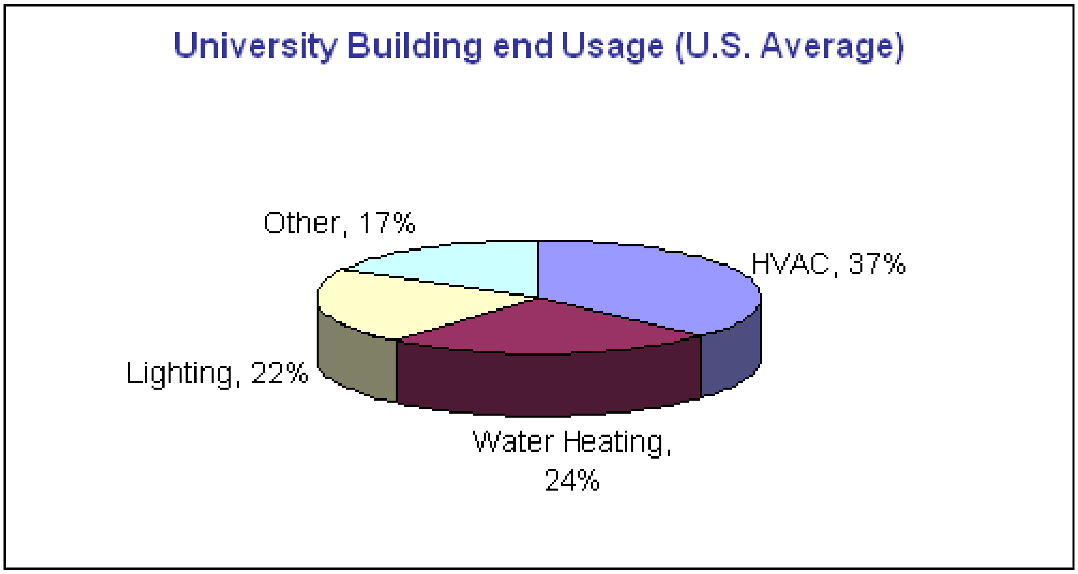


Figure 3: University Energy Usage (Green Energy Payback LLC)

In Figure 3, Green Energy Payback accepts what several other companies have stated: lighting generally uses about 15-25 percent of all energy in a building.

Sections 2.4.1 and 2.4.2 show several case studies, varying from public schools to colleges to street lights, throughout the world that have tried to reduce the effect of lighting on the total energy used in a building. All of these case studies have different and important attributes that relate to the WPI campus and the plan to light it.

2.4.1 Street Lights

Exterior lighting has been upgraded in several communities in Europe. First, in Banyeres de Mariola Alicante, Spain the street lights were updated to Lighting Science Group's PROLIFIC Series Street lights from the old, out of date HID street lights. Struggling with the rising cost of energy in Europe, this community updated their street lights to these new ones that are "50% more efficient, provide more uniform light distribution, increase light levels and will save Banyeres de Mariola Alicante thousands of dollars in energy cost over the life of the fixtures" (Lighting Science 2010). These maintenance free LED street lights also eliminate some of the hidden costs of HID street lights: re-lamping and re-ballasting. Fairchild Semiconductor is another lighting company, based out of China that has taken big steps towards more efficient street lighting. Their new LED street lights provide "high efficiency and outstanding thermal performance - as well as high reliability - to increase the lifetime of street lamps" (Fairchild Semiconductor's 2010). There are many companies in the world that have recognized the problems with out of date street lighting technology.

2.4.2 Schools and Universities

Many schools have attempted and succeeded in taking on energy efficient and sustainable renovations. The Baker City High School is just one of the many examples of schools trying to reduce their energy bill while also gain publicity. As of 2006, the school had replaced all of the 250 watt metal halide lights in the gym with T5 lams and electronic ballasts. Just the project in the gym alone is expected to save 41,190 kilowatt-hours and $2,400 per year (Oregon Department of Energy 2006). The gym project cost Baker High School $20,000 but there was much funding from the Williams Oil Settlement and Oregon Department of Energy's Business Energy Tax Credit Program. The next step in the lighting upgrade is to work on the rest of the 90,000 square foot school, which is expected to cost $60,000. This final upgrade is expected to save an additional 63,100 kilowatt-hours and $5,000 per year (Oregon Department of Energy 2006).

Many colleges and universities have also joined in the pursuit of higher energy efficient campuses. In 2003 Carnegie Mellon University opened the doors of America’s first “Green” Dormitory. This $12.5 million residence hall earned the LEED Silver Certification. It boasts 18 inch exterior walls for better insulation and carpet made from recycled yarn. “‘Carnegie Mellon's adoption of sustainable or 'green' building principles demonstrates its commitment to the health and well-being of young people today and in the future. This is really about the next generation,’ said Rebecca Flora, executive director of Pittsburgh's Green Building Alliance and board member of the U.S. Green Building Council” (Pittsburgh’s Carnegie Mellon 2003). Carnegie Mellon University took one of the first major steps in turning American colleges and universities towards the energy efficient path.

In 2002, The Biosphere 2 Center, Columbia University’s 250-acre campus near Tucson, Arizona, also took a big step towards being energy efficient. Earth Savers, an energy conservation services company, helped the center with a massive retrofit to replace all standard fluorescent bulbs with more than 2,300 new 30-watt ultra-fluorescent bulbs. “The replacement bulbs will reduce energy consumption by 60 percent, said Randy Decker, chief executive officer of Earth Savers, a Tucson energy conservation company working on the retrofit. The total cost of the project, including parts and labor, was about $138,000, GE said” (Gerdel 2002). This renovation is expected to save about $45,000 a year and therefore have a payback period of just over three years, neglecting the cost of the light bulbs being replaced.

In 2004, the University at Buffalo completed a $10.7 million project to upgrade the Goodyear Hall dormitory to be more energy efficient. The project upgrades were broken into three phases; heating system, new windows, and lighting, water conservation and air ventilation. The final phase cost $2.3 million and the light upgrades included mainly motion sensors. This entire project is expected to reduce greenhouse emissions by 650 tons per year.

Finally, several projects have been completed at Kwantlen Polytechnic University in Canada relating to lighting upgrades on campus. First, they found that “at Kwantlen’s Langley campus just 40 parking lot fixtures represented almost 5% of our total electrical consumption (all exterior lighting uses almost 17% of our total electrical consumption)" (Kwantlen). In order to address this problem, they simply reduced the power of their bulbs from 400 W to 250 W. This reduction in power brought lowered lighting levels closer to a recommended brightness. The total project cost to relamp and reballast all of the fixtures was $10,000 with a simple payback period of just under seven years. They chose to implement these changes all at once instead of over time to save travel and set up costs, as well as the cost of renting a lift. Next, Kwantlen replaced all incandescent light bulbs over exterior doorways and covered walkways connecting some of the buildings with compact fluorescent bulbs. This project also cost about $10,000 but was paid for by their electrical utility (BC Hydro). Simply replacing these light bulbs had a payback period of two years and reduced the annual maintenance cost by $3,500 due to the increased lifetime of the bulbs.

2.5 Worcester Polytechnic Institute

According to the WPI Sustainability website, "Worcester Polytechnic Institute strives to comply with all environmental laws and regulations while also incorporating the values of sustainability into the daily operation of the University" (WPI 2010a). So what is the degree of WPI's demonstrated commitment to sustainable energy decision-making? WPI consistently scores high on the STARS system and also enacts several programs and policies to ensure a movement towards energy efficiency.

2.5.1 WPI's Electricity Usage

If we accept that lighting is between 15% and 25% of overall residential electricity usage, then the average household's reported total 2008 consumption of 11,040 kWh of electricity translates into approximately 2,000 kWh of lighting usage per private home (EIA 2008). In comparison, WPI had an annual electricity usage of about 25.5 million kWh in 2008. Thus, in 2008, WPI's annual electricity usage was about equal to 2300 average households. Energy usage at other colleges varies but remains similar. Consequently, colleges and universities use a vast portion of electricity in the United States.

In 2009, WPI used about 23.8 million kWh and spent over $1.8 million. Since lighting translates to 15-25 percent of electricity, WPI used roughly 4.3 million kWh on lighting and spent roughly $330,000 on lighting. As energy costs continue to rise and new buildings bring new lighting needs, costs and electricity usage will continue to follow. It would be advantageous to take steps to reduce the amount of electricity used to light WPI. Figure 4 shows the linear trend of the annual electricity consumption at WPI.

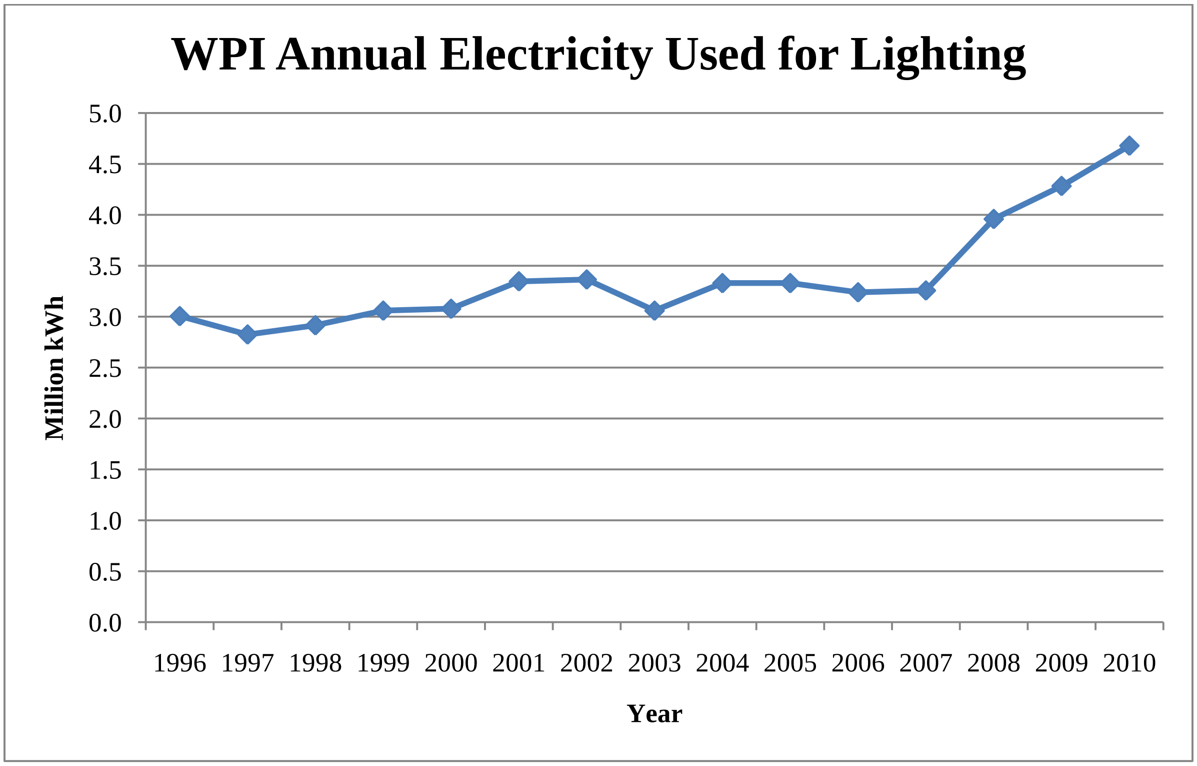


Figure 4: WPI Annual Electricity Consumption Used for Lighting

2.5.2 Formal Policy

The President's Task Force on Sustainability is an organization set up at WPI to handle the energy efficient renovations on campus. Their mission statement is as follows:

> The purpose of the President's Task Force on Sustainability is to provide leadership and coordination for WPI's campus-wide efforts in energy and resource conservation and reduction in the harmful environmental impacts of our operations, all directed toward enhancing the long-term sustainability of WPI's activities and the environment of which we are a part. We are an educational institution; thus, these goals are the impacts and behavioral changes, as well as in conducting research in the reduction of environmental impacts and in methods of enhancing sustainability (WPI 2010b).

The President's Task Force currently has a policy that all future buildings constructed on campus must be environmentally friendly and LEED certified. According to members of the President's Task Force, no formal policy exists for energy efficient lighting. However the organization has a goal to increase energy efficiency in lighting whenever renovations are conducted. This includes the addition of occupancy sensors, LED lighting, and more efficient ballasts and fluorescent lamps.

According to WPI President Dennis D. Berkey, WPI will continue to look very seriously at cost benefit analyses to make sure the University is aggressively adopting energy efficient technologies. Berkey states that green outcomes will result from effective energy cost reductions. However, he shares concerns that sometimes the more sophisticated the technology, the more temperamental (Berkey Interview 2010). For instance, East Hall, the most energy efficient of WPI's dormitory buildings, has been currently experiencing problems with their sophisticated climate control system as a result of students opening windows. Applied technology must work on a consistent basis and residents need to be educated as to how to properly use the technology.

2.5.3 Recent Projects

WPI's most recently completed main campus project was the building of East Hall equipped with maximized day lighting, motion sensor lighting, and Worcester's first vegetative roof. Other buildings recently constructed on campus, including the Bartlett Center and Gateway Park, have maximized day lighting and energy efficient systems installed. The new Recreation Center is currently ongoing construction and will have these systems installed as well. Energy efficient technologies currently in many classrooms on campus include energy management systems to regulate temperature based on occupancy hours, LED lighting, recycling programs, EP-certified desktops, and LCD monitors. Keeping with the Task Force's goal of increasing energy efficient lighting during renovations, Perreault Hall has been recently renovated and retrofitted with LED lighting.

2.6 Energy Efficient Technologies in Lighting

2.6.1 Lighting Technology Vocabulary

The amount of light a bulb gives off is measured in lumens. A higher number means a brighter light. Lumens are classified as initial lumens, or how bright the brand new light is, and average lumens, the average brightness over the whole lifetime of the bulb. Bulbs slowly get dimmer as time goes by. Some bulbs have ratings of lumens per watt, with lower lumens per watt being more efficient. Calculating lumens per watt is a good way to measure efficiency (Eartheasy).

Color temperature is another variable to take into consideration. Color temperature is used to classify light color relative to white and is measured in kelvins, with most CFLs being between 2700K and 6500K. Lower temperature rating is warmer light, while higher temperature is cooler light. 5000K is approximately the color of direct sunlight at noon (EHow CFL).

CRI means color rendering index. It is the quality of light and how faithfully the bulb renders colors. The scale goes from 1-100, with 1 being terrible and 100 being perfect. The ideal light has a CRI of 100, but most lights are between 85 and 90 (Eartheasy).

2.6.2 CFLs

CFLs, or compact fluorescent lights, are mini fluorescents that look like incandescent bulbs. They are much more efficient than incandescent, and last much longer, but are more expensive. However, the price is outweighed by the low power usage. The light they give off is also warmer than large fluorescents, and they do not flicker or hum. They come in many shapes and sizes, so they can be used anywhere. However, they are not as efficient in places with high on/off cycling, like closets, and low temperatures reduce light levels, so they are not great for outdoor use. They are best for large area lighting. However, CFLs contain a small amount of mercury that can be released if broken. Special “Alto” bulbs have been developed that use less mercury, but if WPI disposes of its own bulbs that is something that should be taken into consideration (Eartheasy).

One of the biggest problems with using CFLs is that they contain mercury. It is necessary in the bulb, and if the bulb stays intact there is nothing to worry about, but if the bulb is broken every precaution must be taken not to expose oneself to the mercury powder inside (Harris CFL).

2.6.3 LEDs

LEDs, or light emitting diodes, are extremely energy efficient. They do not have a filament, but are instead a solid bulb, which makes them very durable. Since they are very bright, there are new bulbs with diffusers for home use. LEDs are a relatively new technology for use in homes. They are often used as Christmas lights, but now they can be clustered with a diffuser lens to create a larger “bulb” to light more space. LEDs can last up to 10 times as long as CFLs, use even less power, and do not heat up. However, their solid state makeup and recent development as a viable lighting technology makes them more expensive than CFLs. Recently, Perdue University has developed a way to use silicon instead of sapphire in the bulbs to reduce cost, but they are still not cheap. LEDs are excellent to use with solar panels because they use so little wattage. They come in many different colors, from red to green, and many warm and cool whites. Amber LEDs are especially good outside because they do not attract bugs (Eartheasy).

The semiconductor within the LED is tiny, only a few microns wide, but the materials inside are chosen for their high refraction. The semiconductor is a tiny plate with the wires attached to each side that are used to connect it to a circuit, and the entire thing is encased in plastic to protect it. The plastic shell and lack of filament make the LED very durable, able to withstand a lot of beating, unlike a CFL or incandescent (Harris LED).

2.6.4 Fluorescents

Fluorescent lamps are long thin tubes that are the second most popular kind of lamp after incandescent. Fluorescents are very similar to CFLs, only the tubes are straight and not curled. They light up more area because of their size, but are very bright. Direct view must be minimized because of their brightness, but there are diffuser lenses over most fluorescent lamps. Newer thinner tubes are more diffuse for better optical performance, but still too bright to look at directly. They last much longer than incandescent, but not quite as long as CFL or LEDs. However, fluorescents are so popular because they are very cheap. They are very easy to make, with simple glass tubes and some electronics, and are made so often that the process has been streamlined to be as fast as possible. They are less expensive than both CFLs and LEDs (Harris fluorescent).

One of the biggest disadvantages of fluorescents is that they flicker and hum, and contain mercury. Flickering lights can sometimes distract people and make them irritable. The humming can also mix with the humming of another electronic device, like a computer, which can make a dissident chord and can affect people’s mood, making them sad or angry. Often people do not even notice, but their brain notices. Also, the mercury inside a fluorescent, if broken, can be very dangerous to anyone exposed to it. Care must be taken when disposing of fluorescent bulbs (Nelson). However, there are also ‘Alto’ fluorescent bulbs, which is what WPI uses. This is important because coal plants emit mercury while producing electricity, but the lower wattage bulbs require less electricity so there is less mercury being emitted by the plants, which offsets the mercury inside the bulbs. Since WPI uses the low mercury bulbs, the mercury is lowered all together.

2.6.5 Motion Sensors

Motion sensors work in a few different ways. Some use radar and send out radio waves and wait for the waves to be reflected and come back. When a person moves into the waves it bounces back differently, so it sets the sensor off. Other motion sensors use light and photo sensors. The beam of light is sent across the doorway into the photo sensor. When the beam is interrupted by a person walking through the door, it senses the lack of light and is triggered. Others detect the infrared light coming from a human being. Humans have an average skin temperature of 93 degrees, which is a wavelength of between 9 and 10 micrometers, so most of these sensors (called pyroelectric sensors) detect between 8 and 12 micrometers. When the light hits the surface it sets off the sensor. This sensor only 'sees' a person if they are moving around, because it is looking for a rapid change in infrared energy, and not a slight change like the sidewalk cooling down at night. Most motion detectors cost between $25 and $100, with some outliers. The easiest for the rooms in WPI would be the radar motion sensors. They are simple and effective, and not as expensive as the photo sensors or pyroelectric sensors (HSW motion).

2.6.6 Other Technologies

There are many other kinds of lamps available, but they are not as energy efficient as the ones listed above. The most popular and oldest of these is the incandescent bulb. It is a glass bulb filled with argon or nitrogen, with a tungsten filament in the middle. Electricity heats up the tungsten, which makes it glow white hot and therefore emits light. Compared to newer bulb technologies, these do not last as long, and much of the potential energy is released as heat (Nelson).

Another available lamp is the halogen lamp, which is very similar to incandescent, but instead of glass surrounding the filament it has quartz. The quartz “envelope” is much closer to the filament than normal lights, so if it was glass it would melt. Inside of the envelope, instead of nitrogen or argon, is a gas from the halogen group, which is able to combine with tungsten vapor. The tungsten filament gets so hot, the gases combine with the tungsten atoms as they evaporate and then redeposit them on the filament, which makes it last longer. However, halogen lights are also extremely hot, even hotter than incandescent because the quartz is so close to the filament, so a lot of energy is lost (HWS halogen).

3.0 Methodology

3.1 Goals and Objectives

The goal of our IQP group was to study WPI's lighting technologies, and find ways to change the current lighting to reduce electricity usage and WPI's carbon footprint. The group gathered data on light technologies by doing a full inspection of the types of lights used in a specific collection of buildings, then surveying the utilization for the campus to find out when the lights are being used and when they are not needed to be on. The team also investigated alternatives for the current bulbs in use, attempting to find other technologies that would increase energy efficiency on campus, as well as reducing WPI's electricity bill. This data was then analyzed to find the rate of return for each possible change, as well as finding the optimum choice for cost efficiency and maximum carbon footprint reduction.

3.2 Study of Current Light Technology

3.2.1 Building Sample

Instead of gathering data on every building on campus, the group chose specific buildings to represent the campus as a whole to increase the efficiency of the study. The team analyzed the buildings on campus and felt the main types of buildings were dormitories, academic buildings, administrative buildings, athletic facilities, and exterior lights. The campus center and library are also important buildings on the campus, but observations based upon the unique usage patterns of these two buildings cannot be extrapolated to any other building, so they were not included in this investigation.

To represent dormitories on campus, we chose Daniels Hall. It is very close to campus and the lights are easy to see from the outside. It is one of the main three housing options on the campus and it is an average size building in comparison to the other dormitories. Daniels Hall has not been renovated recently, so there are still incandescent bulbs in use. Dormitories require lighting of good quality and color because people spend a lot of time there, often times doing hours of work, so there generally needs to be a lot of light throughout the building.

To represent administrative buildings on campus, we chose the Bartlett Center. We wanted to compare the lighting of a newer building to that of the older buildings on campus. The Bartlett Center is one of the newest buildings on campus. It is LEED certified, so most of the lighting is already energy efficient and it makes good use of day lighting. Administrative buildings require a lot of light as well, but not for the entire day. People work in them during the day, but when the work day ends the buildings is empty. Thus, there needs to be plenty of light during building operating hours, but during the night, the lights should be turned off.

To represent the athletic facilities, we chose Harrington Auditorium over Alumni Gym. Harrington Auditorium is newer than Alumni Gym and there are also plans to renovate Alumni in the next few years. Harrington is relatively old so it has not been renovated since it was built in the 1960's. As a result, most of the lights are fluorescent. Athletic buildings need a lot of light to make sure that any students exercising have enough light to see well, but when the building closes, all the lights should be turned off.

To represent the many academic buildings on campus, we chose Higgins because it is open 24 hours a day. It is full of classrooms and offices, and the hallways are full of fluorescent lights. Since it is open 24 hours a day, the lights need to be on all the time, especially in the computer labs. The office lights can turn off when the professors go home and lock the door, as can most of the normal classrooms. However, the hallways and lab lights need to stay on all the time to make sure students can continue working. The lighting in Higgins is mostly up to date, with few incandescent bulbs, but the building is very large. There are a very large number of lights which leaves much room for improvement. Academic buildings need a lot of light in the rooms so students can study and learn effectively. The color quality also has to be optimal because it promotes emotional well-being. Especially in the 24 hour buildings, the lights have to be on at all hours of the day, so they do not really need to turn off often, but when there is no one using the room they should be turned off.

We also surveyed the exterior lighting throughout the campus because there are a lot of lights outdoors, and they are important for safety. New England winters are very dark and cold, so having good lighting outside is very important, especially for a 24 hour campus. There are students coming and leaving the campus at all hours, so the lights need to be bright enough to illuminate their way. They also need to be an amber color so as not to attract bugs in the summer. Moreover, exterior lighting is only needed when the sun sets, so it can be turned off during the day while the sun is up.

3.2.2 Inventory

The first step to gathering light data was to take an inventory of the building sample. This was accomplished by surveying the interior of the buildings. The group kept a detailed checklist of every visible light outlet. The most common bulbs used in buildings on campus include CFLs, fluorescent, and incandescent.

Concerning exterior lighting, the group decided to focus on the fixtures located on the main campus. This includes all the light fixtures powered by the main electric meter at 183 West Street. Due to the large extent of exterior light fixtures on campus, we took an initial survey to decide which types constituted the majority of electricity usage on campus. We then plotted the different fixtures on a campus map and took an inventory of these fixtures. The majority of exterior fixture bulbs consisted of halogen, metal halide, and floodlights. Figure 5 illustrates the main light fixtures plotted on a campus map.

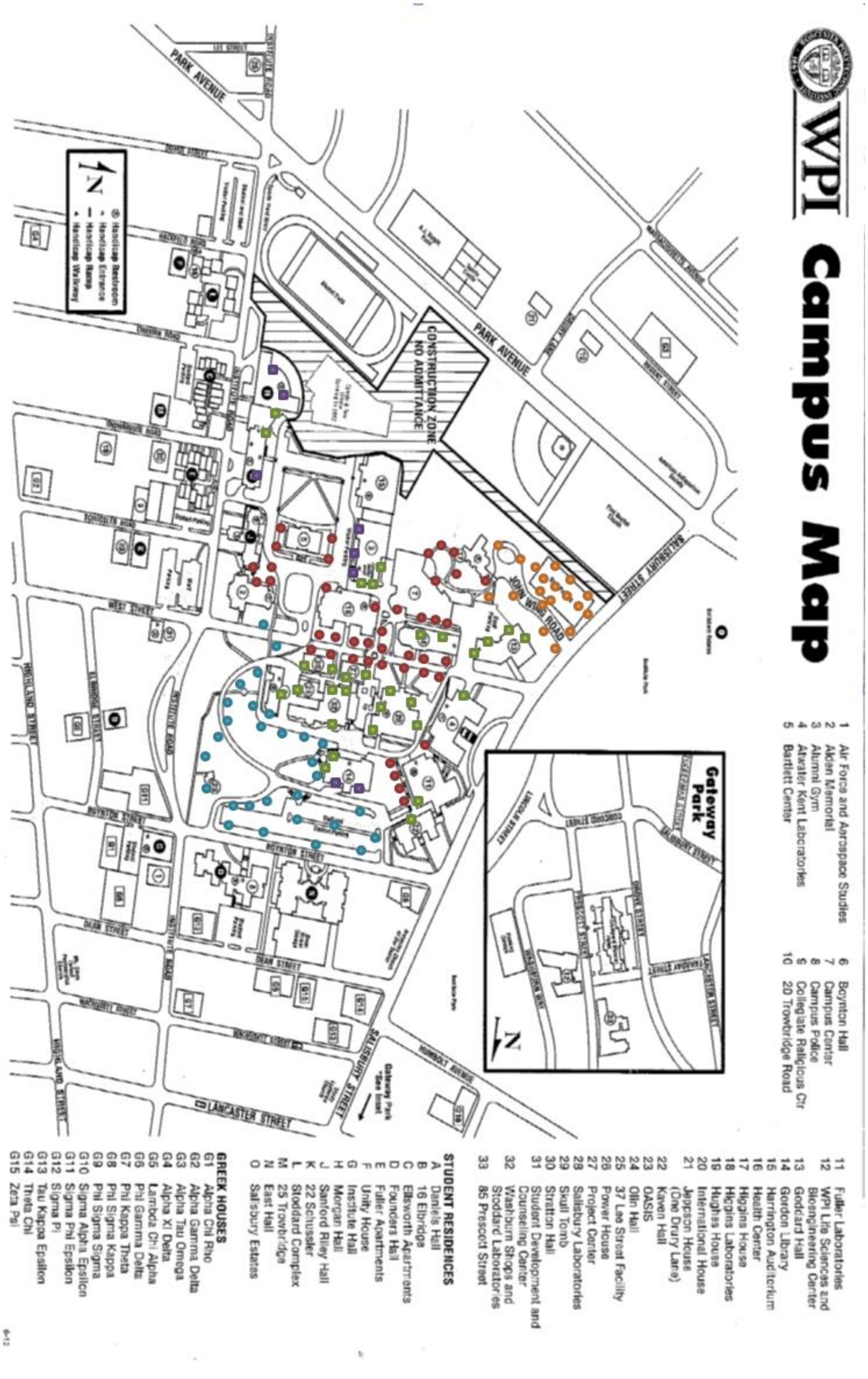


Figure 5: WPI Exterior Lighting Map

3.3 Tools for Data Analysis

3.3.1 Gathering Utilization Data

After collecting inventory data from our building sample, the group needed to gather relevant lighting utilization data in order to determine the amount of electricity used. Initially the group ran a trial run of Daniels Hall and Morgan Hall to discover the most efficient way to gather utilization information. We concluded that simply counting the number of lights that were on based on the inventory checklist would be the most efficient method.

3.3.2 Utilization Schedule

Gathering data samples of utilization behavior in any particular moment only tests small bits of the big picture. To draw valid conclusions from these data points required the group to translate the discrete moments into a representative sample of continuous daily, weekly, and annual energy usage. We therefore designed our sampling technique and schedule in terms that would incorporate the widest range of utilization behaviors. The first concern was that the group needed to ensure that the data included different time intervals throughout the day to best represent the fluctuations of lighting use. We decided to count the number of lights that were on at 9am, 1pm, 6pm, 10pm, and 2am. We felt that these times represented key intervals throughout the day. 9am represents the time when the day starts, as classes begin and the populace arrives on campus. 1pm represents midday when building use is at its height. 6pm represents the time when classes are ending and the populace departs campus. 10pm represents the time when building use is slowing. Finally, 2am represents the time when building use should be at its lowest point. By taking an average of these times, as represented in Equation 1, we were able to calculate more accurate utilization data for an average day.

Please note that each equation represented in this section describes the calculations necessary to determine the yearly percentage for a single light type.

Equation 1: Average Number of Lights by Day

$$Average\ Number\ of\ Lights\ by\ Day = \frac{(\#\ Lights\ 9am + \#\ Lights\ 1pm + \#\ Lights\ 10pm + \#\ Lights\ 2am)}{5}$$

The second concern was that we needed to select days that could accurately represent a week's worth of utilization data. Our solution was to gather data on Tuesday, Thursday, Friday, and Sunday. We took an average of Tuesday and Thursday to generate the average weekday utilization (Equation 2). Similarly, we took an average of Friday and Sunday to generate the average weekend utilization (Equation 3). To calculate a week's worth of utilization data we applied the weekday average to days Monday through Thursday, as well as applied the weekend average to days Friday through Sunday (Equation 4).

Equation 2: Weekday Average

$$Weekday\ Average = \frac{Average\ \#\ Lights\ Tuesday + Average\ \#\ Lights\ Thursday}{2}$$

Equation 3: Weekend Average

$$Weekend\ Average = \frac{Average\ \#\ Lights\ Friday + Average\ \#\ Lights\ Sunday}{2}$$

Equation 4: Week Average

$$Week\ Average = \frac{4}{7} Weekday\ Average + \frac{3}{7} Weekend\ Average$$

The group then divided the week average by the total number of the given light as indicated in the inventory (Equation 5). The result represents the percentage of each light that is on at any given time.

Equation 5: Week Utilization Percentage

$$Week\ Utilization\ Percentage = \frac{Week\ Average}{Total\ Number\ of\ Light\ Type}$$

The final concern was that WPI's lighting utilization differs between school days and vacation days. To solve this problem, the group gathered lighting utilization data for two weeks, including one week while WPI was in session during November and a second week while WPI was on vacation in early January. For each week, the group calculated the week utilization percentage as expressed above in Equation 5. According to the WPI Undergraduate Calendar, WPI is in session roughly 31 weeks of 52. Assuming that the second week of data represents light utilization during vacation days year round, the group applied the first week of data to 31 weeks, as well as applied the second week of data to the remaining 21 weeks. Consequently, the group managed to calculate more accurate utilization data for the course of a year, as expressed in Equation 6.

Equation 6: Yearly Utilization Percentage

$$Yearly\ Utilization\ Percentage = \frac{31}{52} Week\ 1\ Utilization\ Percentage + \frac{21}{52} Week\ 2\ Utilization\ Percentage$$

The utilization percentage for the exterior portion of our sample was calculated in a different manner. The group observed that fixtures across WPI's main campus have differed running times with concern to how long they run during daylight hours. However, during nighttime hours, all fixtures are on. Thus, the group decided to use the hours of darkness to represent the light utilization of the fixtures. The average hours of darkness in a day are around 12 hours. Therefore, considering that 100% of exterior fixtures run for at least 12 hours, each fixture runs about 50% of the day.

3.3.3 Equations Employed for Computing Cost Savings and Carbon Reduction

After obtaining the estimated number of lights based on our utilization schedule, an average was taken to represent the light utilization for the course of a year. This average can be assumed to be the number of lights that were on at any specified time throughout the year. Therefore, using the inventory of total lights and their wattages, the average percentage of power being used for each type of light bulb in each building could be calculated. Different buildings were not averaged together because each building was chosen as a representative for the six main types of buildings on the campus.

The team then researched replacement lights. Lights were chosen by the team based on several factors including wattage, lifetime, and cost. It was difficult to research every light bulb so the team chose companies that seemed reputable and reliable as a baseline.

The following three equations show how to calculate the total return on investment, or the total amount the replacement bulb will pay back, the adjusted lifetime, or how long the light bulb will last taking into account how long the bulb is on, and the adjusted payback period, or the amount of time it will take the bulb to save how much it costs. All of these values can be calculated by knowing the wattage of the bulb being replaced (original wattage), the wattage of the replacement bulb (replacement wattage), the lifetime, and the percentage of time the light is on.

Equation 7: Total Return on Investment

$$\begin{aligned} &Total\ Return\ on\ Investment(\$) \\ &\qquad = Lifetime(hrs) \\ &\qquad \times \big(Original\ Wattage(kW) - Replacement\ Wattage(kW)\big) \\ &\qquad \times Cost\ of\ Energy \end{aligned}$$

Equation 8: Adjusted Lifetime

$$Adjusted\ Lifetime\ (yrs) = \frac{Lifetime(yrs)}{Percentage\ of\ Time\ Light\ is\ On}$$

Equation 9: Adjusted Payback Period

$$\begin{aligned} &Adjusted\ Payback\ Period(yrs) \\ &\qquad = \frac{Initial\ Cost\ of\ lightbulb(\$)}{Total\ return\ on\ investment\ (\$)} \times Adjusted\ Lifetime(yrs) \end{aligned}$$

After the lights were chosen by the team, we performed several calculations in order to determine the simple payback period and emissions savings over the lifetimes of the replacement bulbs. In order to simplify the calculations, factors such as inflation and the shorter lifetimes of the bulbs being replaced were not taken into account by the team. We used a cost of $0.15 per kilowatt-hour as an average because it was approximately the cost per kilowatt-hour for commercial enterprises in 2010 in Massachusetts according to the U.S. Energy Information Administration. Payback period of a light bulb is simply the amount of time it would take a light bulb to recover the initial cost of investment. In order to calculate the payback period, the total payback and adjusted lifetime must first be calculated. Total return on investment is simply the lifetime of the replacement light bulb times the change in wattage from old to new light bulb times the cost of energy as shown in equation 7. Adjusted lifetime is the lifetime divided by the percentage of time the bulb is expected to be on, as shown in equation 8. The adjusted payback period is calculated by dividing the initial cost of the light bulb by the total return on investment and multiplying that quantity by the estimated lifetime of the bulb divided by the percentage of time the light is on as shown in equation 9.

Equation 10: Adjusted Annual Rate of Return

$$Adjusted\ Annual\ Rate\ of\ Return(\%) = \frac{(Total\ Payback - Initial\ Cost)/(Total\ return\ on\ investment)}{Adjusted\ Lifetime}$$

The annual rate of return is the next important step in determining if a light bulb is worth investing in. Through this calculation, it can be determined whether it is more profitable to invest in installing new light bulbs or in other investments, such as savings accounts or the stock market. The adjusted annual rate of return is the total percentage of money made over a bulbs lifetime divided by the adjusted lifetime as shown in equation 10. This number is approximately the amount of the initial cost the bulb will pay back annually, over its lifetime.

Equation 11: Greenhouse Gas Emissions Saved

$$Greenhouse\ Gas\ Emissions\ Saved(lbs) = Factor\ of\ greenhouse\ gas\ \left(\frac{lb}{MWhr}\right) \times Savings\ in\ energy(MWhr)$$

Finally, the greenhouse gases are calculated to determine how environmentally friendly each light bulb is. First, the savings in energy must be calculated by subtracting the wattage of the replacement bulb from the wattage of bulb being replaced. Next, the appropriate factor (pounds per megawatt-hour) must be found for the greenhouse gas being calculated, which can be found on the U.S. Energy Information Administration website for individual states. This factor does not include the greenhouse gases involved in the manufacturing of each type of bulb.

Finally, the greenhouse gas emissions saved can be calculated by multiplying the factor of the greenhouse gas times the savings in energy.

3.3.4 Expansion of Analysis

To find the significance of each section, or main type of building on campus, the team determined how much energy due to lighting needs each type of building uses in comparison to other. The team determined which buildings on campus were included in which sections. From there the buildings were broken down into numbers of floors. The team determined number of floors by estimation while taking into consideration the floor size and number of floors compared to the specific building being surveyed in that section. Wattage per building must then be calculated by summing the total number of lights multiplied by their individual wattage and also multiplied by their usage (found during survey). Then, the wattage per floor can be calculated by taking the total wattage of the building being surveyed and dividing it by how many floors there are. Finally, the team found total wattage per section by multiplying the total number of floors by the wattage per floor. These numbers can then be compared as percentages.

As another approximation, the amount of energy used by lighting was obtained using the on-campus energy usage per year. Approximately 20% of the total energy used on campus is assumed to go toward lighting, as explained in section 4.4. This was used as a rough estimate of the entire campus and to compare to the gathered data. Wattage per building type was calculated by the team through the same process as described in the previous section. The total wattage of each section was added together and multiplied by 24 hours and 365 days, as percentage of time was already calculated, to find the total kilowatt hours used by lighting in these sections. Equation 12 shows how to calculate the total amount saved per year in dollars per year.

Equation 12: Total Amount Saved per Year

$$Total\ Amount\ Saved\ per\ Year(\frac{\$}{yr}) = \frac{Total\ Return\ (\$) - Total\ Costs(\$)}{Maximum\ Adjusted\ lifetime}$$

Finally, to compare our collected data to the known electricity usage, we calculated an average for total cost and total return for each building type. A weighted average was used to find the total return and total costs for the entire campus. This weighted average was calculated based on the same principles as used for finding the significance of each building type. Equation

12 shows how to calculate the total amount saved per year. The calculated total amount saved per year was combined with the cost of electricity for WPI in 2010 to find the reduction in energy costs for lighting in a percentage. The same process was used to calculate the approximate reduction in carbon footprint. A weighted average of the total carbon reduction from each building type was taken then compared to the total carbon footprint. The total carbon footprint of the campus was calculated using equation 11, knowing the total kilowatt-hours used by WPI.

4.0 Results

4.1 Significance of Each Building Type

Figure 6 shows the light usage, including the usage calculated during surveying, as a percentage of each building type as calculated in section 3.3.4. Each building in its corresponding section was broken down into number of floors and data from the building being surveyed was expanded upon the other buildings. Administrative buildings include Bartlett Center and Boynton Hall. Dormitories include Daniels Hall, Founders Hall, Morgan Hall, Sanford-Riley Hall, 16 Elbridge, Ellsworth Apartments, Unity House, Institute Hall, Fuller Apartments, 22 Schussler, Stoddard Complex, 25 Trowbridge, and East Hall. Athletic Buildings include Alumni Gym and Harrington Auditorium. Classrooms include Atwater Kent Laboratories, Fuller Laboratories, Higgins Laboratories, Kaven Hall, Olin Hall, Salisbury Labs, Stratton Hall, and Washburn Shops. The number of floors per building is shown in appendix B. There are 2 administrative buildings, 13 Dormitories, 2 athletic buildings, 10 Classroom buildings, and the exterior lights.

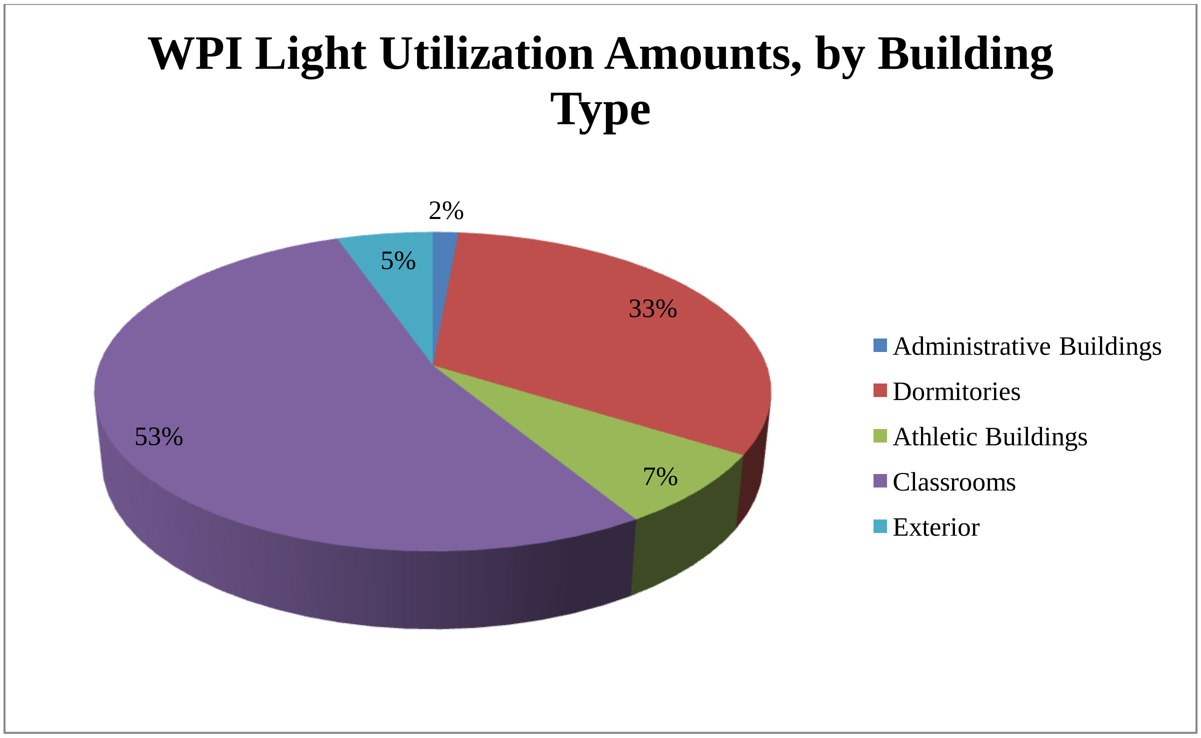


Figure 6: Significance of Each Building Type

Figure 6 shows that dormitories and classrooms use about 86% of the total energy, in terms of lighting the campus. This is in part due to the fact that Dormitories and classrooms are the most numerous building types represented on the campus. The exterior lighting section takes up the second smallest percentage of the total campus wattage. The smallest percentage is the administrative buildings, but this is expected as the building being surveyed is one of the most energy efficient buildings on campus.

4.2 Inventory and Light Utilization Data

Figure 8 shows the inventory data gathered by the group.

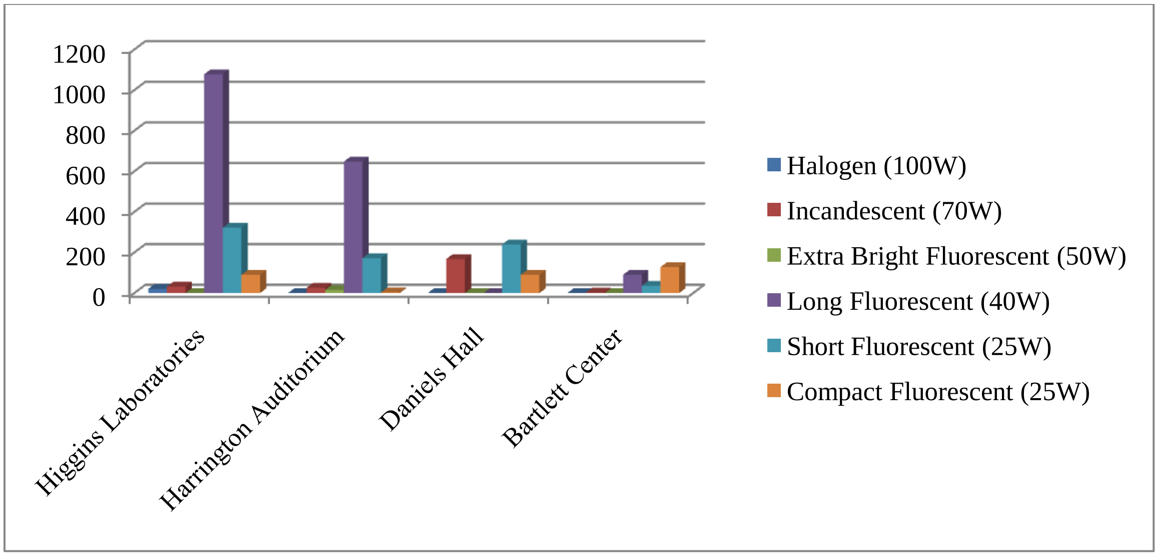


Figure 7: Inventory Data of Building Sample

Higgins Laboratories and Harrington Auditorium boast the largest number of lights in our sample, while Daniels Hall and the Bartlett Center have relatively fewer. Moreover, the three most common light types in our building sample include long fluorescent, short fluorescent, and compact fluorescent. Halogen, incandescent, and extra bright fluorescent are the least numerous bulbs types currently in use at WPI. As mentioned in Section 4.5, replacement bulbs for compact fluorescents yield the lowest savings. However, replacement bulbs for long fluorescents and short fluorescents yield greater savings of about 25 watts and 12 watts respectively. Therefore, inventory data suggests that Higgins and Harrington would benefit the most from lighting improvements as both buildings have high number of long fluorescent and short fluorescent bulbs. The Bartlett Center would benefit the least from lighting improvements as it has the fewest number of bulbs and most of the bulbs are compact fluorescents. Although Daniels Hall also has a fewer number of lights, it has the highest number of incandescent bulbs. Since replacing incandescent bulbs with LED incandescent bulbs yield the most savings, it would be very beneficial to replace the incandescent bulbs in Daniels Hall.

Figure 9 shows the light utilization data gathered from our sample. The graph illustrates the average percentage of each light type that is on at any given time. These Figures were calculated as specified in Section 3.2.4.

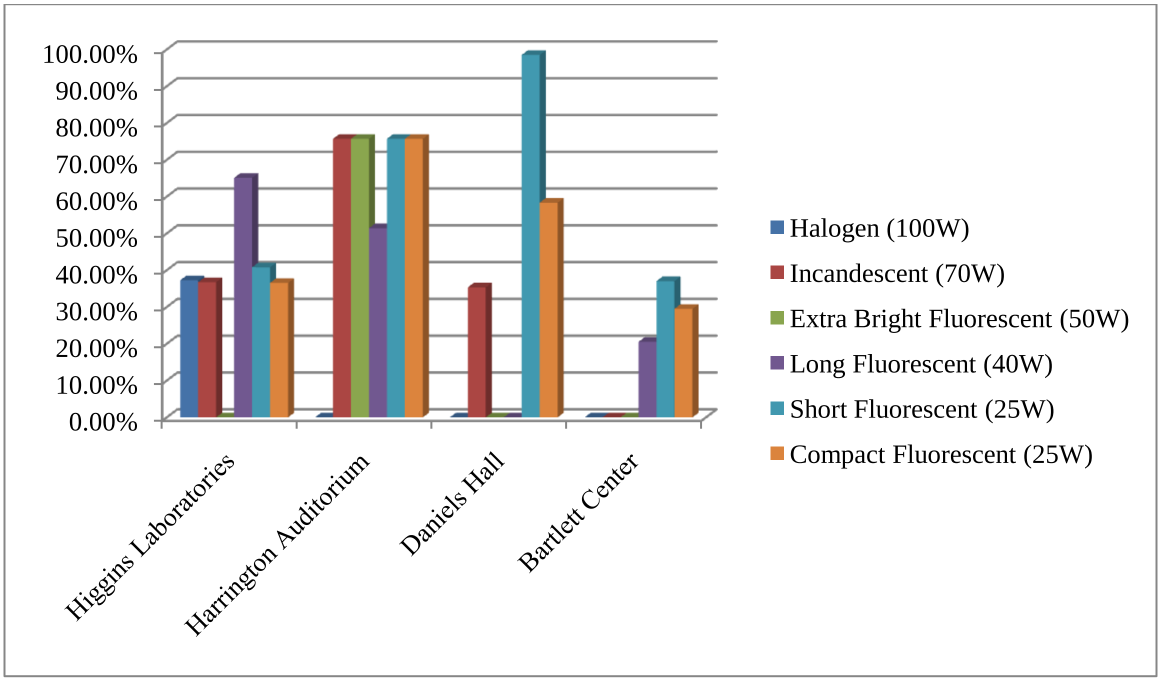


Figure 8: Light Utilization Data of Building Sample

Of the buildings in our sample, current light utilization is the highest at Harrington Auditorium at around 75%. High light utilization at Harrington can be attributed to almost all lights being on during operational hours. Current light utilization of Higgins Laboratories is about 40%, which is proportional to the number of classrooms and offices in use. One striking figure is the high light utilization of short fluorescent bulbs in Daniels Hall. Short fluorescent bulbs are used in the hallways of Daniels and are kept on during all hours of the day. The current light utilization of the Bartlett Center is the lowest at around 30%.

Considering these Figures along with the inventory data, the group can conclude that the Bartlett Center has a low priority for light replacement because it has the least number of lights as well as the lowest light utilization. Moreover, most bulbs in the Bartlett Center are already energy efficient compact fluorescent. Harrington Auditorium and Higgins Laboratories have a high priority because they have a large number of lights as well as a high light utilization. Although Daniels Hall has a high light utilization, it also has a much fewer number of lights than Higgins and Harrington. Improvements still need to be considered because small fluorescent bulbs have almost a 100% light utilization and there are a large number of incandescent bulbs.

4.3 Replacement Lights

In order to find suitable replacement light bulbs, the team researched several types of replacement light bulbs and chose bulbs from companies that seemed reliable and bulbs that seemed to represent an average replacement light bulb in terms of lifetime and wattage and price, as there are hundreds of companies competing for the “best” product. Table 1 shows the different lights and their part numbers. Short Fluorescent light bulbs in this report are classified as two foot long bulbs while long fluorescent bulbs are three feet long.

Table 1: Replacement Bulbs

Original Bulb	**Original Wattage**	**Replacement Bulb**	**Replacement Wattage**	**Company**	**Name/Product Code**	**Energy Savings (W)**	**Initial Cost**	**Lifetime (Hrs)**
Halogen	100	LED Halogen	8.7	LC-LED	PAR30-100W	91	$81.00	50,000
Incandescent	75	CFL Incandescent	26	Sylvania	DULUX EL	49	$7.58	12,000
		LED Incandescent	13	EarthLED	EvoLux	62	$49.99	50,000
Extra Bright Fluorescent	50	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Long Fluorescent	25	Long LED Fluorescent	15	EarthLED	DirectLED FL	10	$59.99	50,000
Short Fluorescent	17	Short LED Fluorescent	8	EarthLED	DirectLED FL	9	$44.99	50,000
Compact Fluorescent	26	LED Incandescent	13	EarthLED	EvoLux	13	$49.99	50,000

Table 1 shows that LED Halogen bulbs promises the greatest savings in energy, but it also has the greatest cost which is due to the still developing technology . The compact LED incandescent replacement for the compact fluorescent provided the lowest savings in energy because the compact fluorescent is already a very energy efficient light bulb.

Table 2 shows the total return on investment, payback period, and annual rate of return for each light bulb. These calculations were done assuming the light bulbs were on 24 hours a day, 365 days a year, and using equations 7, 9, and 10 in section 3.3.3.

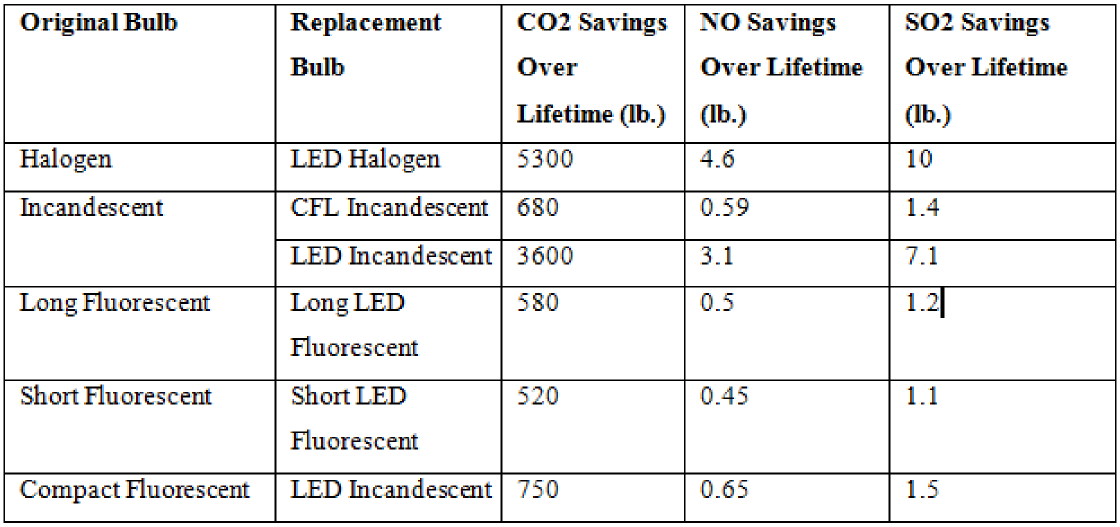
Table 2: Replacement Returns

Original Bulb	Replacement Bulb	Total Return on Investment($)	Payback Period (Yrs)	Annual Rate of Return
Halogen	LED Halogen	$685.00	0.68	130.59%
Incandescent	CFL Incandescent	$88.00	0.12	780 %
	LED Incandescent	$465.00	0.61	150%
Extra Bright Fluorescent	N/A	N/A	N/A	N/A
Long Fluorescent	Long LED Fluorescent	$75.00	4.6	4.4%
Short Fluorescent	Short LED Fluorescent	$67.50	3.8	8.4%
Compact Fluorescent	LED Incandescent for CFL	$97.50	2.9	17%

As shown in table 2, CFL replacements for incandescent light bulbs have the shortest payback period and highest annual rate of return, while having the lowest total return on investment. The low total return on investment is because compact fluorescents have lower initial costs for the reason that they have been in the market for longer, causing manufacturing cost to drop. The annual rates of return for these light bulbs are all either higher or comparable to various other forms of investment. The average rate of return for stocks, treasury bills and treasury bonds in 2010 was 14.86 percent, 0.13 percent and 8.46 percent respectively. However, the geometric average, which takes into account large losses or gains in the market, for 2001-2010 for the average rate of return for stocks, treasury bills and treasury bonds in 2010 was 1.38 percent, 2.16 percent and 5.49 percent respectively (Damodaran 2011).

Table 3 shows the total savings of the three main gases that contribute to global warming, Carbon Dioxide (CO_2), Nitrous Oxide (NO), and Sulfur Dioxide (SO_2). These are all calculated for the lifetime of the replacement light bulb and do not include the any gases created during the manufacture of the light bulbs.

Table 3: Greenhouse Gas Emissions Saved



Original Bulb	**Replacement Bulb**	**CO2 Savings Over Lifetime (lb.)**	**NO Savings Over Lifetime (lb.)**	**SO2 Savings Over Lifetime (lb.)**
Halogen	LED Halogen	5300	4.6	10
Incandescent	CFL Incandescent	680	0.59	1.4
	LED Incandescent	3600	3.1	7.1
Long Fluorescent	Long LED Fluorescent	580	0.5	1.2
Short Fluorescent	Short LED Fluorescent	520	0.45	1.1
Compact Fluorescent	LED Incandescent	750	0.65	1.5

Table 3 shows that the gases emitted are directly related to the amount of energy each bulb saves. These numbers were calculated using factors according to how much of each gas is emitted per megawatt-hour from power plants in Massachusetts and using equation 11 of section 3.3. All of the factors outlined in this section, with the addition of how often each light is in use, must be taken into account in order to determine which light bulb to choose because how often each light is in use affects the lifetime.

Finally, Figure 7 shows another way of comparing the replacement bulbs: dollars per pound of carbon dioxide. This is a way to relate the cost of a bulb to the benefits of reducing carbon dioxide emissions and a way of relating the cost of the bulb to the cost of a carbon tax.

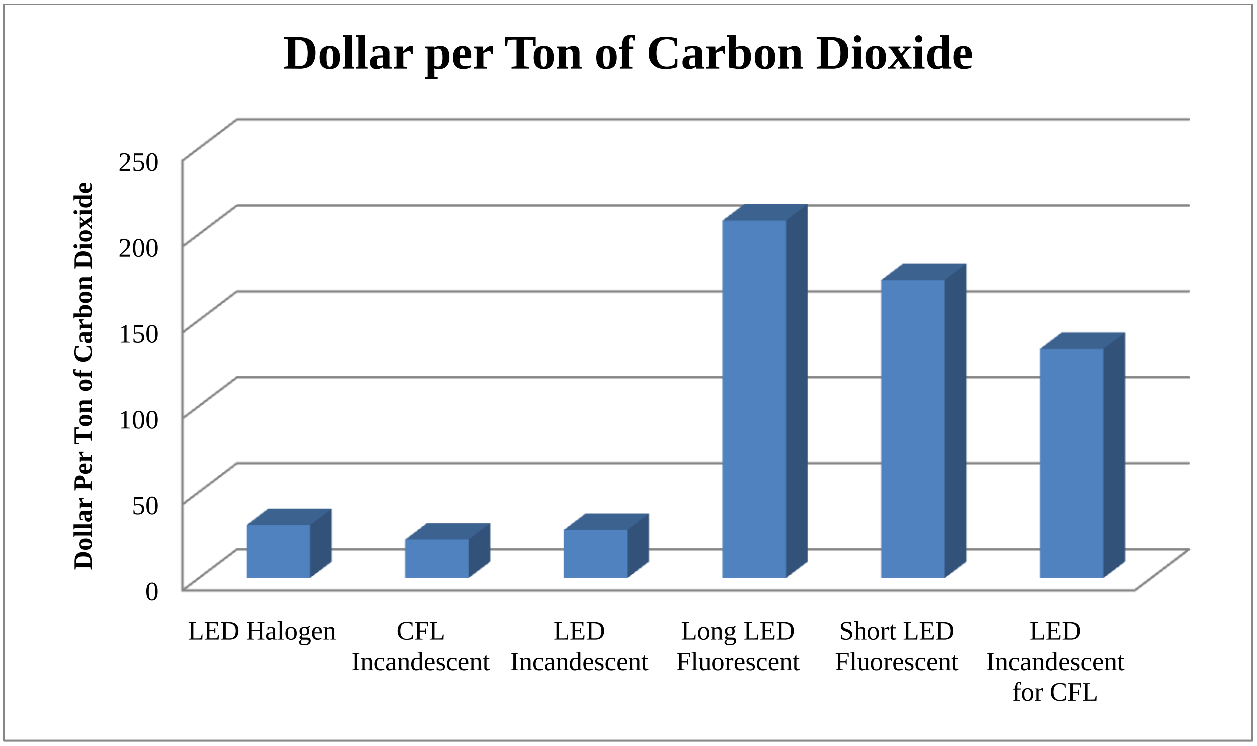


Figure 9: Dollar per Pound of Carbon Dioxide Reduced

Figure 7 shows that LED Halogen, CFL incandescent and LED incandescent bulbs lead the group in terms of dollars per pound of carbon dioxide at about $20 to $30 per ton of carbon dioxide. Therefore, the cheapest way to reduce the emission of greenhouse gases is to install Compact Fluorescent bulbs, while the most expensive way to save emissions is to install Long LED Fluorescents. LED Halogen, CFL incandescent and LED incandescent bulbs are all competitive in terms of dollars per ton when comparing to a carbon tax of up to about $50 per ton.

4.4 Anecdotes and Observations

Many interesting things were noted during the inspection of each building. The lights were on very often when there was no one around in every building. The group also talked to people in some of the buildings and asked what they thought about the lighting and how often lights are left on when no people are present.

When the group surveyed Higgins during the day, there were many lights on. Yet when classes ended and most people went home, the lights were left on in many classrooms. Some classrooms had a few people working in them, yet all lights were kept on. In several instances, the large lecture halls were found fully lit with only one student working in it. The computer labs were almost always full of people, so they needed to be on, but the classrooms did not have people in them very often so the lights do not need to be on. The lights in the hallways are also always on no matter how many people are in the building, and they have more lights than any other building we surveyed. However, late at night, every other light in the basement hallway turned off, so some energy is saved at that time.

In the Bartlett Center, the group questioned some people that worked there, who stated that they did not like the compact fluorescent bulbs because they take some time to warm up and turn on. They also stated that the bulbs are being replaced quite frequently. That being said, the lights were on more often than necessary during the day. Even when there were not many people in the building, many of the lights in the main foyer were all on. Since Bartlett makes good use of day lighting, the lights do not necessarily have to be on as often as they are.

In Daniels, the room lights were mostly off when no one was in them, but the hallways are always on, as are the bathroom lights. It is good that the residents turn the lights in the rooms off, but the bathrooms and hallways do not need to be on all day and all night. Even the residents said the lights are on too often. The hall lights are always on, but they are programmed to grow dim when no one is in the hallway. However, when someone walks through the hall they all turn back to full strength, then stay that way for a long time.

Harrington lights need to be on to light the building enough for students who are exercising or using the courts. However, when the building closes, they should all be turned off, which was not always the case. The windows on the top floor are also very large, so more use of day lighting could occur, which means fewer lights need to be on, especially the ones lighting the top floor.

Among all the campus lighting fixtures, the exterior lights are the best in terms of being on at the correct time. These lights do not turn on until dusk or close to it, so they are not on when they are not needed.

4.5 Analysis of Data

Tables 4-7 show the approximate total initial cost, adjusted lifetime, payback period and annual rate of return for Higgins Laboratories, Harrington Auditorium, Daniels Hall, and the

Bartlett Center. Adjusted lifetime, payback period and annual rate of return are calculated using equations 8, 9, and 10 and explained section 3.3.3.

Table 4: Higgins Laboratories Costs and Returns

Higgins Laboratories	Replacement Bulb	Total Initial Cost	Adjusted Lifetime (Yrs)	Payback Period (Yrs)	Annual Rate of Return
Halogen (100W)	LED	$1,700	15	1.8	49%
Incandescent (75W)	CFL	$245	3.7	0.32	290%
	LED	$1,600	16	1.7	54%
Long Fluorescent (25 W)	LED Fluorescent	$65,000	8.8	7.0	2.9%
Short Fluorescent (17 W)	LED Fluorescent	$14,500	14	9.3	3.6%
CFLs (25 W)	LED	$4,499.10	16	8.7	5.1%

Table 5: Harrington Auditorium Costs and Returns

Harrington Auditorium	Replacement Bulb	Total Initial Cost	Adjusted Lifetime (Yrs)	Payback Period (Yrs)	Annual Rate of Return
Incandescent (75W)	CFL	$200	1.8	0.16	590%
	LED	$1,300	7.5	0.81	110%
Long Fluorescent (25 W)	LED Fluorescent	$39,000	11	8.9	2.3%
Short Fluorescent (17 W)	LED Fluorescent	$7,700	7.5	5.0	6.6%
CFLs (25 W)	LED	$200	7.5	4.2	11%

Table 6: Daniels Hall Costs and Returns

Daniels Hall	Replacement Bulb	Total Initial Cost	Adjusted Lifetime (Yrs)	Payback Period (Yrs)	Annual Rate of Return
Incandescent (75W)	CFL	$1,300	3.9	0.33	24%
	LED	$8,400	16	1.7	5.5%
Short Fluorescent (17 W)	LED Fluorescent	$11,000	5.8	3.9	5.8%
CFLs (25 W)	LED	$4,500	9.8	5.4	4.6%

Table 7: Bartlett Center Costs and Returns

Bartlett Center	Replacement Bulb	Total Initial Cost	Adjusted Lifetime (Yrs)	Payback Period (Yrs)	Annual Rate of Return
Long Fluorescent (25 W)	LED Fluorescent	$5,500	28	22	0.72%
Short Fluorescent (17 W)	LED Fluorescent	$1,600	15	10	2.2%
CFLs (25 W)	LED	$6,400	19	11	2.3%

In tables 4-7 an important note to take is that all of the calculated values, from section 4.1 have decreased except for total return on investment when the light utilization data is taken into account. The best place to see where replacement lights are needed is where the highest rates of returns are. The Bartlett center has the lowest rates of return which coincides with its LEED certification and the fact that it is not a highly used building with respect to the other buildings in the survey. Harrington Auditorium and Higgins Laboratories, on the other hand, are very highly used, somewhat inefficient buildings. Excluding the Bartlett center, every replacement bulb has a rate of return higher than two percent, which is comparable to some five year CD rates. In terms of rate of return and initial cost, the best option for every building is the replacement of all incandescent bulbs with compact fluorescent bulbs. Next, in terms of rate of return, the best replacement options from highest to lowest savings include LED replacements for incandescent bulbs, LED replacements for CFL's, LED replacements for short fluorescents, and LED replacements for long fluorescents respectively. LED replacements for halogen bulbs are only in one building so it is difficult to compare how efficient they would be in other buildings, but they have the third highest rate of return in Higgins laboratories at about 49 percent.

Tables 8-11 show the potential greenhouse gas savings for Higgins Laboratories, Harrington Auditorium, Daniels Hall and the Bartlett Center over the lifetime of the replacement bulbs.

Table 8: Higgins Laboratories Greenhouse Gases Emissions Saved

Higgins Laboratories	Replacement Bulb	CO_2 Savings (lb)	NO Savings (lb)	SO_2 Savings (lb)
Halogen (100W)	LED	110,000	96	220
Incandescent (75W)	CFL	22,000	19	43
	LED	110,000	99	230
Long Fluorescent (25 W)	LED Fluorescent	620,000	540	1200
Short Fluorescent (17 W)	LED Fluorescent	170,000	145	330
CFLs (25 W)	LED	62,000	54	120

Table 9: Harrington Auditorium Greenhouse Gases Emissions Saved

Harrington Auditorium	Replacement Bulb	CO_2 Savings (lb)	NO Savings (lb)	SO_2 Savings (lb)
Incandescent (75W)	CFL	18,000	15	35
	LED	93,000	81	190
Long Fluorescent (25 W)	LED Fluorescent	370,000	320	750
Short Fluorescent (17 W)	LED Fluorescent	89,000	77	180
CFLs (25 W)	LED	2,800	2	6

Table 10: Daniels Hall Greenhouse Gases Emissions Saved

Daniels Hall	Replacement Bulb	CO_2 Savings (lb)	NO Savings (lb)	SO_2 Savings (lb)
Incandescent (75W)	CFL	110,000	99	230
	LED	601,000	520	1200
Short Fluorescent (17 W)	LED Fluorescent	125,000	110	250
CFLs (25 W)	LED	62,000	54	120

Table 11: Bartlett Center Greenhouse Gases Emissions Saved

Bartlett Center	Replacement Bulb	CO_2 Savings (lb)	NO Savings (lb)	SO_2 Savings (lb)
Long Fluorescent (25 W)	LED Fluorescent	53,000	46	105
Short Fluorescent (17 W)	LED Fluorescent	19,000	16	37
CFLs (25 W)	LED	89,000	77	180

One number that jumps out from a reading of tables 8-11 is the replacement of long fluorescent bulbs with LED's in Higgins Laboratories. Approximately 622,000 pounds of carbon dioxide, 539 pounds of Nitrous Oxide, and 1,200 pounds of Sulfur Dioxide are saved by replacing the long fluorescent bulbs in Higgins Laboratories over the lifetime of the replacement bulbs. It is more difficult to make general comparisons between buildings regarding greenhouse gases than it is to make comparisons regarding rate of return because the greenhouse gas calculations depend on the number of lights in a building. In general, however, LED fluorescent bulb replacements are among the best for savings in greenhouse gases due to the large percentage of fluorescent bulbs in most buildings.

4.5.1 Expansion of Analysis

Figure 10 shows the comparison of our surveying results and the calculated amount used by lighting on campus which is calculated in section 3.4.

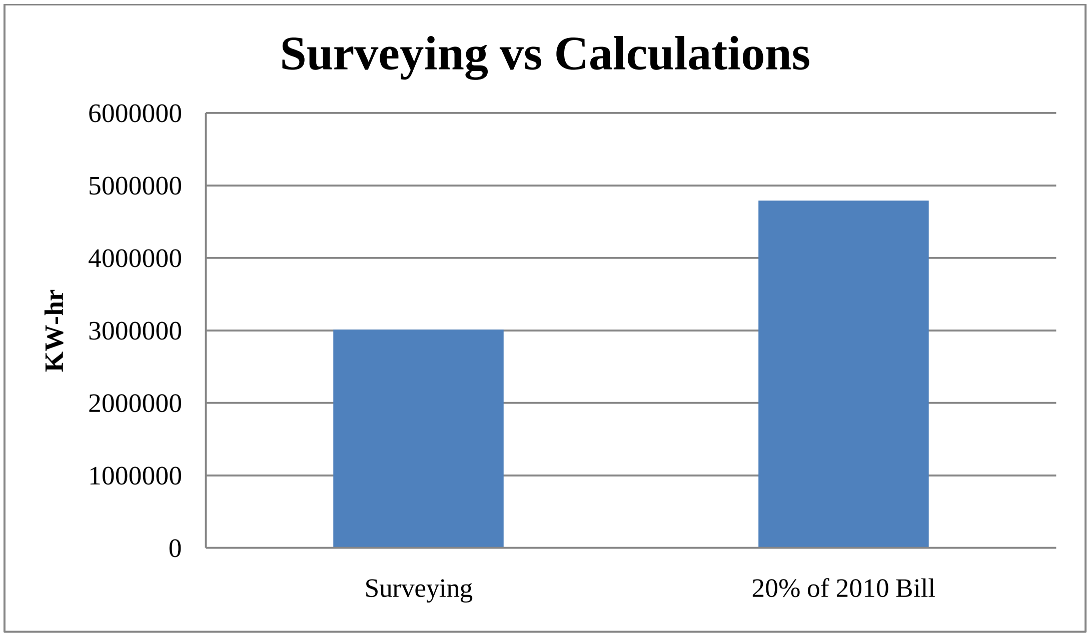


Figure 10: Approximation of Total Energy Usage of Lighting on Campus

Figure 10 shows that through our surveying and the calculated KW-hrs used by lighting on campus are on the same order of 3-5 million kilowatts. Surveying is approximately 63% of the calculated KW-hrs due to the fact that major contributors to lighting usage, such as the library, campus center, and parking garages were not taken into account. Also, it was a rough estimation of how much energy each individual building uses.

In order to further compare our calculated numbers to WPI's total electricity bill, as explained in section 3.3.4, the team found that if all bulbs are replaced as outlined in the recommendations, that it would reduce WPI's annual electricity bill by 3%, or $64,000, per year and its carbon footprint by almost 4%, or 1.1 million pounds of carbon, per year. The total project would cost about $1 million and have a total return of about $1.5 million. All of the numbers calculated here are for the entire campus, not just our survey group.

4.6 Caveats

Several points must be made in order to make certain ideas more clear. First of all the lights chosen may not be the best or the optimal choice because it is difficult to research every bulb on the market. The team found replacement bulbs that seemed to be close to the average for that type of bulb from companies that seemed reliable and reputable.

Also, it was difficult to find a replacement for the extra bright fluorescents, found in Harrington Auditorium, because they are very specialized light bulbs, unlike the short and long fluorescent bulbs. Therefore, we did not find a suitable replacement for the extra bright fluorescent light bulbs.

The cost of replacing bulbs that were not yet burnt out was not taken into account. Calculations were done assuming the all of the light bulbs had have of their life left, and therefore were worth half of their original cost. These calculations found that taking into account the cost of the bulbs being replaced is negligible and therefore could be ignored.

Finally, figure 6 shows that exterior lighting is the second smallest energy consumer, in terms of lighting, on campus. This combined with the fact that it is difficult to calculate accurate numbers for replacements because of the cost of implementation allows for this section to be neglected because it was so small. Administrative buildings are not being neglected because the Bartlett Center was taken as energy efficient, LEED certified building to compare our findings to. Therefore, it is being taken into account for comparison.

5.0 Recommendations

5.1 Dormitories

There are 9 separate dormitory buildings on campus, as well as 6 apartment-like buildings. The dormitories are all similar in their lighting needs, so the recommendations for Daniels can be extrapolated to all of them. The order of priority was decided to minimize initial cost at first, and have higher cost later.

The highest priority replacement would be to replace all the incandescent bulbs with CFL's. The initial cost would be low at $1300, with an annual rate of return of 24%. The payback period would be .33 years, or 4 months. The adjusted lifetime of the CFL's would be 4 years. LEDs are more expensive with a longer lifetime, but they are not necessary for dormitories because the CFL's would be a more cost effective change. The second priority would be to check the motion sensors in the hallways to see if they are working, and to install some more in the halls and in the bathrooms. The initial cost of simple motion sensors would be about $30 each, and the increase in bulb lifetime and energy savings would be very large. The last priority in changes to Daniels and other dormitories would be to replace the short fluorescent in the hallways to LED fluorescents. The initial cost would be $11,000, with a rate of return of 5.8%. Since it would be most efficient to replace the current bulbs as they die, LEDs with the same CRI would have to be bought to keep the color identical. The payback period would be 3.9 years, and the adjusted lifetime would be 5.8 years.

5.2 Classrooms

There are 9 academic buildings on campus. The recommendations for Higgins can be applied to all of them because the lighting needs are similar for every academic building. The priorities were chosen for maximum savings and smaller immediate cost.

The first priority of replacement would be to replace the incandescent bulbs with CFLs. The initial cost would be only $243, with a very high rate of return of 285% and a payback period of .32 years, or just less than 4 months. The adjusted lifetime would be 3.7 years. The second priority would be to replace the halogen bulbs with LEDs. The initial cost would be $1,700, with a large rate of return at 49%. The payback period would be 1.8 years, and the adjusted lifetime would be 15 years which is excellent. The third priority would be to check the motion sensors and install more in the halls and bathrooms. The fourth priority would be to replace the short fluorescent bulbs with LED fluorescents. The initial cost would be $14,000 with a rate of return of 3.6%. The payback period is long at 9.3 years, but the adjusted lifetime at 14 years is excellent. The final recommendation for Higgins and all academic buildings would be to replace the long fluorescent bulbs with LED fluorescents. Since there are so many, the initial cost is high at $65,000, with a rate of return of 2.9%. The payback period is 7 years, but the adjusted lifetime is 8.8 years. All bulbs should be allowed to burn out before replacement.

5.3 Athletic Buildings

There are two athletic buildings on campus, including Harrington Auditorium and Alumni Gymnasium. The lighting situation of both buildings is very similar so the recommendations made for Harrington could also be applied to Alumni. The order of priority for Harrington was selected by monetary savings. This includes recommendations with low initial costs, higher annual rates of return, and lower payback periods given higher priority.

The group recommends the replacement of all incandescent bulbs in Harrington with compact fluorescent bulbs as the first priority. As shown in Section 4.2, the replacement of incandescent bulbs with compact fluorescent bulbs has a very low initial cost of around $200 with a low payback period of 0.16 years, or about 2 months. Moreover, the annual rate of return is extremely high at 590%. The group recommends the second priority be to check the status of all motion sensors to ensure that they are in working condition. The group also advocates the install of additional motion sensors wherever necessary, including but not limited to, hallways and bathrooms. The group recommends the third priority be the replacement of the short fluorescent bulbs with LED fluorescent bulbs. This replacement has a higher initial cost of around $7,800 as well as a higher payback period of 5 years. However, the annual rate of return is very high at 6.6%, compared to CD rates of around 3%. The carbon savings is also very high at around 90,000 pounds of carbon dioxide saved over the course of the 7.5 years adjusted lifetime of the bulbs. The group recommends the last priority be the replacement of the long fluorescent bulbs with the LED fluorescent bulbs. The initial cost is very high at around $40,000 and the payback period is also high at 8.88 years. The annual rate of return is less than 3%, but in direct correlation to high cost, the carbon savings is exceedingly high at around 400,000 pounds of carbon dioxide saved during the adjusted lifetime of the bulbs. The savings of nitric oxide and sulfur dioxide are also very high at around 324 pounds and 745 pounds saved respectively.

5.4 Administrative Buildings

The Bartlett Center represents one of the most energy efficient buildings on campus. The replacement of the compact fluorescent bulbs, short fluorescent bulbs, and long fluorescent bulbs present in the Bartlett Center are estimated to yield low carbon savings at a higher cost. The replacement of long fluorescent bulbs with LED fluorescent bulbs have a high initial cost of around $5,500 with an every higher payback period of 22 years. The annual rate of return is miniscule at 0.72%. Moreover, the replacement of short fluorescent bulbs with LED fluorescent bulbs have a low initial cost of $1,600, yet a high payback period of 10 years and a low annual rate of return of around 2.2%. Lastly, the replacement of compact fluorescent bulbs with LEDs has a high initial cost of $6,400 with a high payback period of 10 years and a low annual rate of return of around 2.3%. The replacement of long and short fluorescent bulbs yields a low carbon savings of 53,000 pounds of carbon dioxide and 19,000 pounds of carbon dioxide respectively. The replacement of compact fluorescent bulbs with LEDs yields a much higher carbon savings of around 89,000 pounds of carbon dioxide, but the associated expenditures are not cost-effective. For these reasons, the group recommends no changes be made to the lighting of the Bartlett Center.

We cannot, however, make the same recommendations of all administrative buildings on campus. The Bartlett Center represents the energy efficient LEED certified buildings on campus more than it represents an administrative building. The other administrative buildings on campus have an older design, as well as older lighting technologies.

5.5 The Plan

Table 12 shows a more clear and broken down way of looking at our general recommendations. The totals were calculated by breaking down the buildings into floors and calculating the number of lights per floor per building. Therefore, we could expand our findings onto the whole campus. Annual rates of return were calculated using the maximum adjusted lifetime of each bulb. If the maximum lifetime was calculated from the Bartlett center it was neglected due to the fact that the Bartlett center is an energy efficient building.

Table 12: The Plan

Step	Action	Number of Bulbs	Cost	Return Over Lifetime	Annual Rate of Return
1	**Incandescent to CFL**	2,300	$18,000	$206,000	270%
2	**Halogen to LED**	180	$14,000	$119,000	50%
3	**Motion Sensors**	N/A	N/A	N/A	N/A
4	**Short Fluorescent to LED**	6,000	$270,000	$404,000	3.3%
5	**Long Fluorescent to LED**	10,000	$630,000	$785,000	0.90%
	TOTAL	19,000	$930,000	$1,500,000	4.08%

Table 12 shows that, in general, our plan is to first replace incandescent bulbs with CFLs. Second, replace halogen bulbs with LED bulbs. Third, check the functionality of motion sensors and replace or add sensors where needed. Finally, replace short and long fluorescent bulbs, in that order, as they have the lowest annual rate of return and the highest initial costs. the total cost of our plan, if fully put into action, is almost $1 million and returns about $1.5 million. The first two steps are easy ways to not only save money but also greenhouse gases with a relatively low cost of implementation. Motion sensors are difficult to calculate accurate returns for, so they were not included in the calculations.

6.0 Conclusion

The growing knowledge and acceptance of global warming has caused a need for a world with fewer emissions of greenhouse gases and other pollutants has become apparent. Scientists, engineers, and even politicians around the world have joined forces to develop and employ more energy efficient and sustainable technologies that reduce greenhouse gas emissions.

The need for greater energy efficiency has developed not only from global warming, but also from the awareness that the world's fossil fuel energy resources are non-renewable, and therefore finite. As oil and energy costs have risen, the general public has begun to realize that such resources are diminishing. As these resources diminish, so does the ease of obtaining energy.

The energy crisis is being approached from two sides. On the producer side, technologies such as wind and solar energy are on the rise, while power plants with high emissions have not been built in years. The producers of the energy realize that their source of energy is diminishing and are trying to develop other ways to produce the energy needed. On the consumer side, many technologies are moving towards being marketed as "green." The greatest problem with this marketing is that consumers cannot tell if a product is "green" due to greater energy efficiency, or "green" due to a change in the packaging.

As a technical university, Worcester Polytechnic Institute is producing many of the scientists and engineers that will go on to develop the technologies for a greener future. WPI has shown its interest in the benefits of environmentally friendly alternatives through classes such as Global Problems Seminar: Power the World, the President's Task Force on Sustainability, and the recent building of only LEED certified buildings. According to President Dennis D. Berkey, WPI will continue to look very seriously on cost benefit analyses to make sure the University is moving aggressively into energy efficient technologies. While WPI has not committed to the American College & University Presidents' Climate Commitment, it has shown a desire to move towards more sustainable technologies.

In 2009, WPI used approximately 25 million kilowatt-hours of electricity, at a cost of over $1.8 million. As lighting uses about 20 percent of the electricity at a university, it is a great place for the start of a change. In 2009, WPI used about 4.3 million kilowatt-hours of electrity on lighting which translated to roughly $330,000.

While collecting data on how often the lights are on in several buildings on campus, it was easy for the group to see there was a definite need for a change. In buildings that are open 24 hours, such as Higgins Laboratories, lights are unnecessarily left on while no one is nearby. In dormitories, such as Daniels Hall, lights in the hallways are often left on throughout the night and over breaks when very few people need them.

Figure 9 indicates the light utilization data gathered from our sample. The chart illustrates the average percentage of each light type that is on at any given time. Figure 9 shows that about half of the lights in these buildings are on more than half of the time. One number that is highly visible is that the short fluorescent bulbs in Daniels are on about 98 percent of the time; due to the fact that most of the short fluorescent bulbs are in the hallways, where they are hardly ever turned off. Some of these numbers cannot be changed because of the fact that the lights must be on, but the wattages these bulbs consume can be changed as easily as changing a light bulb.

The group analyzed the light utilization data and compared several replacement lights in order to calculate annual rates of return, payback period, and greenhouse gas reduction for the replacement bulbs. Chart 5 shows the replacement bulbs, total return on investment, payback period, and annual rate of return based on electricity costs of $0.15 per kilowatt-hour and assuming the lights are on at all times. As seen in Chart 5, all rates of return are comparatively high. CD rates generally do not exceed 3.5%, however, the geometric average for the average rate of return for stocks, treasury bills and treasury bonds between 2001and 2010 was 1.38 percent, 2.16 percent and 5.49 percent respectively (Damodaran 2011). When taking into account the light utilization data, the lowest rate of return is 0.72 percent, but this is in the Bartlett Center, which is LEED certified and quite energy efficient. Not only do these light bulbs save money, but they also save emissions.

Figure 7 shows the pounds of carbon dioxide save per dollar spent on the light bulb. It shows that CFL replacements for incandescent bulbs are the best at saving carbon emissions for their value, followed by LED replacements for incandescent bulbs and LED replacements for

Halogen bulbs. On the other hand, the most expensive way to save carbon dioxide emissions is to install LED replacements for long fluorescents.

With the replacement plan outlined in the recommendation section and analyzed in table 12, WPI will save money and reduce its carbon footprint. In general, our group's replacement plan is to first replace any incandescent bulbs with compact fluorescent bulbs which have an annual rate of return of about 270 percent. After that is completed, replace the few halogen light bulbs with LED versions of halogens which have an annual rate of return of 50%. Next, motion sensor checking and, in some cases, installation is a necessary step in saving energy usage when areas are unoccupied. Finally, the short and long fluorescents, in that order should be replaced with LED fluorescents as this is the largest and most expensive step which have a rate of return of 3.3 percent and 0.9 percent respectively. If all replacements are done as outlined in this report, it will reduce WPI's total electricity bill by about 3% a year, or about $64,000 a year and will reduce WPI's carbon footprint by about 4%, or about 550 tons of carbon per year.

In conclusion, there is a major opportunity for a change in the lighting policy at WPI. All replacement light bulbs, at the very least, pay for themselves in their lifetime and, in many cases, have a competitive annual rate of return. The total project, if the entire campus is taken into account would cost approximately $1 million and return about $1.5 million over the lifetime of the bulbs which is about a 5% return on investment. Replacing the out of date light bulbs at WPI will save money, greenhouse gas emissions, and help WPI move towards a more sustainable future.

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Appendices

Appendix A: Light Technologies (Continued)

CFLs

CFLs have an electrical circuit on the inside, which includes a transformer. The transformer works to increase the voltage sent through the bulb. The circuit it connected to tiny wires called electrodes, and when the electricity moves into the electrodes, electrons burst off the end and go shooting into the tubes on the end of a CFL. The electrons then collide with mercury atoms, which makes the mercury unstable and electrons move up in the orbital within the atoms. However, this makes the mercury unstable, so in order to become stable again the electron then goes back down in orbital, thereby releasing energy as photons. Photons in a CFL are ultraviolet light, which is not visible to the human eye. However, the tubes on the CFL are covered in white-colored chemicals called phosphors. When the electrons hit the phosphors, they also get excited by electrons just like the mercury, then have to release energy, only this time the photons are white, visible light (Woodford).

LEDs

Since LEDs are solid, the way they make light is a little complicated. The two sides of the diode are made of semiconductor material, usually either aluminum-gallium-phosphide or gallium-arsenide-phosphide. Alone, these compounds are stable, but when impurities are added, the electrons do not come together completely and it creates holes. The side with extra electrons is called the N-type material, because it is more negative, and the side with fewer electrons is called the P-type material, because it is positive. When the diode is inactive, the electrons move to fill in the holes and both sides are stable, but when a current is added the electrons will move to the positive side of the semiconductor, creating holes for electrons to move through. This is why a diode will only work when current is flowing one way. When the electrons move through the holes in the atoms, they have to expend energy and move down an orbital level within the atoms. This energy is released in the form of photons, the particle that makes up light. In normal diodes, the photons are invisible to the human eye, but in LEDs the light is at a frequency that we can see. Different compounds are added to the semiconductor to make the photons vibrate at different frequencies, and each frequency is a different color LED (LED Made).

Fluorescents

Fluorescents work exactly the same as CFLs, just on a larger scale. They have mercury and an inert gas (usually argon) inside sealed glass tubes, which are coated on the inside with a phosphor. When current is sent through the tube, it excites the mercury, which lets off ultraviolet light. That light excites the phosphor, which lets off white light. Unlike incandescent bulbs, fluorescents use electrons and photons to make light. An incandescent bulb gets it light from heat, as the filament gets very hot as current is sent through it. The fluorescent is much more efficient because it loses very little energy as heat, and turns most of it to light (Harris fluorescent).

Appendix B: Significance of Each Building Type

Administrative	**Floors**	**Dormitories**	**Floors**	**Athletic Buildings**	**Floors**	**Classrooms**	**Floors**
Bartlett Center	2	**Daniels Hall**	3	**Alumni Gym**	3	**Atwater Kent Laboratories**	4
Boynton Hall	4	**Founders Hall**	3	**Harrington Auditorium**	3	**Fuller Laboratories**	4
		Morgan Hall	3			**Goddard Hall**	4
		Sanford Riley Hall	4			**Higgins Laboratories**	4
		16 Elbridge	1			**Kaven Hall**	3
		Ellsworth Apartments	4			**Olin Hall**	4
		Unity House	1			**Salisbury Laboratories**	4
		Institute Hall	4			**Stratton Hall**	2
		Fuller Apartments	4			**Washburn Shops**	4
		22 Schussler	1				
		Stoddard Complex	3				
		25 Trowbridge	1				
		East Hall	4				
Total	**6**		**36**		**6**		**33**

	Administrative Buildings	**Dormitories**	**Athletic Buildings**	**Classrooms**	**Exterior**
Sample Kilowattage per Floor	3.156	6.31	7.32466667	9.7935	30.8
Number of floors	6	36	6	33	1
Total Section Killowattage	18.936	227.16	43.948	323.1855	30.8
Percentage of Total	0.02940238	0.352716762	0.06823911	0.501817852	0.0478239

Appendix C: Buildings Receiving Electricity from Main Meter at 183 West Street (Power House)

1. Alden Hall (Auditorium, Classrooms)
2. Alumni Gym (Gym, Offices, Pool)
3. Alumni Gym Extension (Locker Rooms, Offices)
4. Atwater Kent (Classrooms, Labs)
5. Bartlett Center (Admissions, Financial Aid)
6. Boynton Hall (Offices, Administration)
7. Campus Center (Offices, Meeting Rooms, Dining)
8. Daniels Hall (Residence Halls, Offices)
9. Fuller Labs (Classrooms, Auditorium)
10. Goddard Hall (Classrooms, Labs, Offices)
11. Gordon Library (Library, Meeting Rooms)
12. Harrington Auditorium (Gymnasium, Classrooms)
13. Higgins House (Offices, Food Service, Meeting Rooms)
14. Higgins House Garage (Storage, Offices)
15. Higgins Labs (Classrooms, Labs)
16. Kaven Hall (Classrooms, Labs)
17. Morgan Daniels Wedge (Meeting Rooms)
18. Morgan Hall (Residence Hall, Offices, Food Service)
19. Olin Hall (Classrooms)
20. Powerhouse (Boiler Room)
21. Project Center (Offices, Classrooms)
22. Salisbury Labs (Classrooms, Labs)
23. Sanford Riley Hall (Residence Hall, Administration)
24. Skull Tomb (Meeting Place)
25. Stratton Hall (Classrooms, Offices, Physical Plant Workshops, Storerooms)
26. Washburn (Classrooms, Labs)
27. Field House (Storage)
28. Football Field Garage (Storage)
29. Press Box / Bleachers (Press Box)

TOTAL: 29 Buildings / Properties

Appendix D: Buildings Receiving Steam from Central Heating Plant at 183 West Street (Power House)

1. Alden Hall (Auditorium, Classrooms)
2. Alumni Gym (Gym, Offices, Pool)
3. Alumni Gym Extension (Locker Rooms, Offices)
4. Atwater Kent (Classrooms, Labs)
5. Bartlett Center (Admissions, Financial Aid)
6. Boynton Hall (Offices, Administration)
7. Campus Center (Offices, Meeting Rooms, Dining)
8. Daniels Hall (Residence Halls, Offices)
9. Fuller Labs (Classrooms, Auditorium)
10. Goddard Hall (Classrooms, Labs, Offices)
11. Gordon Library (Library, Meeting Rooms)
12. Harrington Auditorium (Gymnasium, Classrooms)
13. Higgins Labs (Classrooms, Labs)
14. Kaven Hall (Classrooms, Labs)
15. Morgan Daniels Wedge (Meeting Rooms)
16. Morgan Hall (Residence Hall, Offices, Food Service)
17. Olin Hall (Classrooms)
18. Powerhouse (Boiler Room)
19. Project Center (Offices, Classrooms)
20. Salisbury Labs (Classrooms, Labs)
21. Sanford Riley Hall (Residence Hall, Administration)
22. Stratton Hall (Classrooms, Offices, Physical Plant Workshops, Storerooms)
23. Washburn (Classrooms, Labs)

TOTAL: 23 Buildings / Properties