

## **Management of Urban Parking Lot Energy Efficiency with the Application of Wind Turbine and LED lights**

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### **Abstract**

*A study of a parking lot lighting of a large manufacturing company in Iowa was implemented to evaluate monthly energy consumption. Mercury light bulbs with 227W ratings on the light poles were replaced with low power energy efficient LEDs to increase the overall efficiency. Additionally, a small scale wind turbine was installed to supply power to experimental light poles. Migration from the current gas bulbs to the LED light results yielded about 60% energy savings, while capital gains due to the generation of wind energy returned about 80% savings per month which recovered initial investments on the assets. The environmental impact of this study cannot be neglected and it also provided opportunity for STEM education in colleges and wind energy awareness in the society in Iowa by showing benefits from current experiments. Details of the methods and analyses should be particularly useful to urban planners because they show how standard references on investment in automobile parking should be modified to include efficient energy management. The authors proposed new way to limit the cost of energy consumptions and environmental pollution on wildlife and human health. Research implications are discussed in terms of the impact of natural features in urban areas for reduction of green house gas emissions and promoting alternative energy sources.*

Keywords: Mercury light, energy consumption, LED, STEM education, environmental pollution

### **1. Introduction**

Residential, commercial and industrial buildings as airports, roads, parking lots require lighting technologies. Outdoor lighting continues to expand as more infrastructures are built. The conventional parking lot lighting of a large manufacturing company in the Midwest were based on the technology that has been using mercury lamps of 227W rating per lamp in order to meet the parking lot lighting standard. The advent of high lumen efficiency light emitting diodes (LED) has revolutionized the lighting technology not only by reducing the required power, hence the energy, but also by increasing the operational life of the systems. The optical efficacy of LED has been proved to save energy about 50% as compared to mercury lamps widely used in parking lots<sup>1</sup>. Furthermore, updated legislation which demands consideration of the environmental effect of a product makes LED the ideal candidate for an environmentally – friendly light source.

Free or underpriced curb parking creates a classic commons problem in large cities. Researchers have found that 8 to 74% of cars were cruising in search of curb parking which took around 3 to 14 minutes to locate one<sup>1</sup>. In this regard, cruising vehicle in congested traffic of urban areas are contributing to air pollution. Priced parking spaces can yield 5 to 8% of the total rent in a city and more revenue than the property tax in some neighborhoods<sup>1</sup>. However, the concern of the environmental effect of the urban parking lighting on wildlife, human health and stellar cannot be neglected and residual light pollution should be limited too. The authors of this study have performed wind powered energy saving and green house gas (GHG) emission analyses on comparison between conventional parking lot lightings that use gas or mercury lamps and the new LEDs.

## 2. Energy Saving Analysis of LED Lighting

In August 2005 a comparative study was conducted to analyze energy saving potentials of LED lamps with efficacy 45 lm/W to the conventional mercury lamps used for road lightings<sup>2</sup>. The researchers installed this luminary in a 7m wide city alley and tilted the lamp 30 degrees on 5.5 m tall pole. Using the constant powered input the study resulted that the high – power LED with 100W rating has the same efficacy as conventional lamps (~70 lm/w). However, the study also showed that the light directedness of LED can hit the road surface while only 40-50% of light output from the conventional lighting fixture can hit the road surface<sup>2</sup>. They provided energy saving analysis of LED lighting compared to sodium lamp and mercury lamp as illustrated below in Table 1.

Table 1. Energy saving, LED vs. Sodium and Mercury lamp. (Modified from Wu et al., 2012<sup>2</sup>)

Brand new performance	Sodium	Mercury	LED
Lamp Efficacy (lm/W)	120	65	72
Lighting to target effectiveness	0.4	0.85	0.85
Overall lighting efficiency	28.6	15.5	44.2
luminary maintenance factor	0.7	0.7	0.8
Lifetime decayed luminance	0.4	0.4	0.7
lifetime year	3	3	10
Lifetime average overall lighting efficiency	14	7.6	30.1
Lifetime power consumption	0.071	0.132	0.033

**Lifetime energy saving**  
 LED saves 53.5% energy compared to Sodium Lamp  
 LED saves 74.8% energy compared to Mercury Lamp

One of the major causes that LED can reduce the energy consumption is due to its lighting to target, with 110° light emission angle effectiveness compared to 360° which also needs a reflector to direct the light beam to the target, and low light decay in lifetime<sup>2</sup>. Therefore LEDs have highly lighting-to-target efficiency. Based on the power consumption per net luminance to target, the researchers of the same study have concluded that LED can save 35.4 % and 65.0% energy consumption compared to sodium lamp and mercury lamp respectively in brand new performance (Table 1). Potential of LEDs in energy efficiency achieves about 50% of the theoretical maximum which raises the LED to the status of the “star of the industry”<sup>3</sup>.

Light emitting diode (LED) is a type of semiconductor diode. In 1980s, LED designers started to use GaAsP (gallium arsenide phosphide) and GaP(gallium phosphide) to create new types of LEDs. Usage development of new materials such as GaAlAs (gallium aluminum arsenide) and InGaAlP (indium gallium aluminum phosphide) helped to produce different output colors of LEDs. Figure 1a and Figure 1b show that high pressure sodium (HPS) lights are typically are about 120 lumens per watt, LED lights are about 72 lumens per watt, and mercury lights are about 65 lumens per watt and overall lighting efficiency of LEDs 74% higher than Mercury and HPSs.

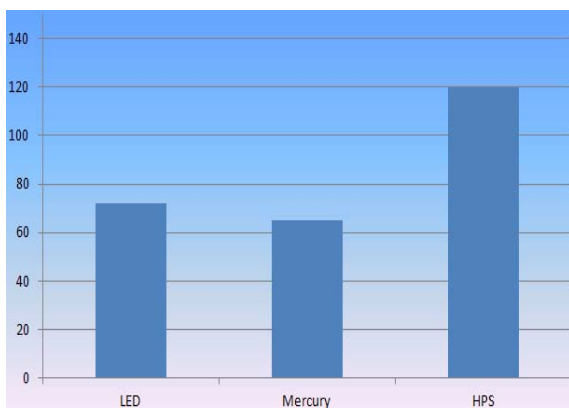


Figure 1a. Lumen per watt comparison

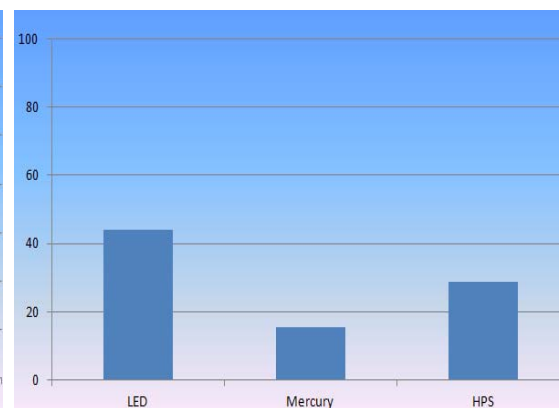


Figure 1b. Overall lighting efficiency (W/lm).

### 3. Environmental Impact of Power Plants

U.S. Department of Energy estimates that the electricity consumption in the United States will increase by 41% between 2005 and 2030. Despite the increased attraction to renewable sources, the share of electricity production in the United States from fossil – fuel power plants is forecast to increase during this period from 71 % to 74%. Power plants in the United States use over one billion tons of coal annually (over 650,000 tons per generator due to the fact that coal based electricity generation priced \$1.54 per million Btu compare to \$ 6.44 for fueled oil and \$ 8.21 for natural gas per million Btu<sup>4</sup>. However, coal plants tend to emit higher levels of pollutants and have other differential impacts on local community. In 2005, power plants in the United States emitted 2500 million metric tons of carbon dioxide (CO<sub>2</sub>), 10 million metric tons of sulfur dioxide (SO<sub>2</sub>) and 4 million metric tons of nitrogen oxides (NO<sub>x</sub>)<sup>4</sup>. In addition to this, coal burned power plants cause traffic around the neighborhood since coal plants receive coal by train, truck or barge. Carbon dioxide is associated with climate change and sulfur dioxide is associated with acid rain. Number of studies show that CO<sub>2</sub> and SO<sub>2</sub> emissions by power plants can be limited by number of different ways. Limitation of environmental pollution by power plants requires not only “how” the lighting is arranged, but also by preferential use of light sources with spectral characteristics that have the least impact on human and wildlife health, while still maintaining a given degree of visibility in areas that need artificial lighting. Typically, some studies proposed limiting the growth rates of installed flux in each city to reduce the environmental impact or to limit the average density of installed light flux per hectare or acre.

Another local externality from power plants is fossil fuel residue. Coal power plants produce 120 million tons of residues annually, according to National Research Council (2006)<sup>5</sup>, and the U.S. Environmental Protection Agency (2008)<sup>6</sup> includes fly ash, bottom ash, boiler slag, and flue gas desulfurization sludge<sup>5</sup>. Many plants landfill these residues on site; however, if managed improperly, particles can be picked up by wind or stream and transported locally or even enter drinking water supplies and be dangerous for health. According to the U.S. Bureau of Labor Statistics (2008)<sup>7</sup>, in 2006 there were 35,000 power plant operators in the United States.

### 4. Proposed Parking lot System Diagram

Installation of wind turbine with 50kw power output capacity is proposed to be installed on the parking lot of a large manufacturing company. Based on the annual and monthly readings of wind velocity outputs from Iowa Energy Center (IEC), the installed wind turbine is capable of producing 159, 127 kwh energy annually and 43,983 kwh electrical energy during the winter season (December, January and February) as shown below in Figure 2.

Proposed 50 kW Endurance E-3120 wind turbine is estimated to produce 159, 127 kWh of electrical energy annually with the average wind speed 14.46 mph. The maximum amount of power output can be seen during the first four months of the year when wind velocity is high ranging from 15.29 mph in February to 16.25 mph in April. Moreover, due to the shorter sun light during these four months the parking lot lighting may be utilized more than the average 12 hours daily.

Conventional system at the proposed parking lot draws 326.88 kWh electrical energy for 12- hour working period daily which is estimated as \$12,421 for 30 poles with 4 mercury lamps in each pole. Replacement of the conventional mercury lamps with proposed LED lamps results in the total savings of \$887 for the 12-hour working period. In this regard, total amount of electrical energy drawn by the conventional system results in 29, 419 kWh for the winter season. Figure 1 shows that for the winter season estimated power output by the proposed wind turbine can produce almost a double amount of electrical energy than the current system can utilize.

Figure 3 shows the average AC power output (watts) of a PV array as a function of time of day and month per installed 1kw-AC under ambient temperature 25<sup>o</sup>C on the collector of 1000 W/sq.m. Although solar energy is not efficiently produced by solar panels during the first four months of the year, months from April to August can generate enough electrical energy when the wind turbine energy production is lower compared to the winter season. In addition, power generation from solar panels, in this case 2095 kWh \* 50 = 104,750 kWh may be directed to the facility buildings.

Period	Average Speed (mph)	Air Density *	Average Wind Power Density (W/m <sup>2</sup> )	Capacity Factor (%)	Estimated Output for Period (kWh)
Annual	14.46	1.230	277	36.48	159,127
Jan	15.61	1.292	334	44.22	15,596
Feb	15.29	1.287	330	42.21	13,497
Mar	16.08	1.253	358	44.94	16,345
Apr	16.25	1.223	383	43.91	15,833
May	14.49	1.194	267	35.57	13,575
Jun	13.55	1.175	214	30.79	11,553
Jul	12.34	1.164	152	24.46	9,575
Aug	12.00	1.169	137	22.68	8,841
Sep	12.96	1.184	178	27.96	10,413
Oct	14.19	1.217	238	34.89	13,064
Nov	15.25	1.253	335	40.60	14,288
Dec	15.27	1.286	332	42.02	14,890

**City: Waterloo Turbine: Endurance E-3120 50kW; 50 kW  
Loss Factor (%): 12 Tower Height: 165 feet**

Figure 2. Proposed wind turbine output results. (Modified from IEC, 2013)<sup>8</sup>

Month	Output by time of day (CST in 2-hour periods)											24hr Avg (watts)	Total kWh	
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22			22-24
Jan	0	0	0	0	348	522	542	478	95	0	0	0	165	123
Feb	0	0	0	68	477	621	618	463	132	0	0	0	198	133
Mar	0	0	0	184	447	610	706	543	283	0	0	0	231	172
Apr	0	0	6	453	643	687	629	529	307	32	0	0	274	197
May	0	0	129	476	642	700	687	588	432	126	0	0	315	234
Jun	0	0	176	568	776	862	791	720	578	179	0	0	388	279
Jul	0	0	120	451	599	642	680	665	528	148	0	0	319	238
Aug	0	0	32	308	503	640	644	551	402	85	0	0	264	196
Sep	0	0	0	366	568	643	668	606	383	0	0	0	270	194
Oct	0	0	0	223	581	630	621	498	141	0	0	0	224	167
Nov	0	0	0	40	266	374	377	251	1	0	0	0	109	79
Dec	0	0	0	0	271	422	408	228	0	0	0	0	111	82
Yr. Avg.	0	0	39	261	510	613	614	510	274	48	0	0	239	2095

Figure 3. Proposed solar power output results (50kw –AC output). (Modified from IEC, 2013)<sup>8</sup>

Wind turbine installation on the parking lot should be carefully examined before any excavation works can take place. Authors proposed southern-east side of the parking lot for 50kW Endurance E-3120 wind turbine installation and north – center of parking lot for the proposed array of solar panels. Sketched view on MS Visio and the Satellite view of the current parking lot of the manufacturing company and proposed wind turbine solar panel hybrid diagram are shown below in Figures 4a and 4b. Installation of 50kw wind turbine on the southern-east side of the parking lot is considered to be optimal due to the open area with no buildings around. Furthermore, this location of wind turbine may decrease the cost of cabling and other underground works.

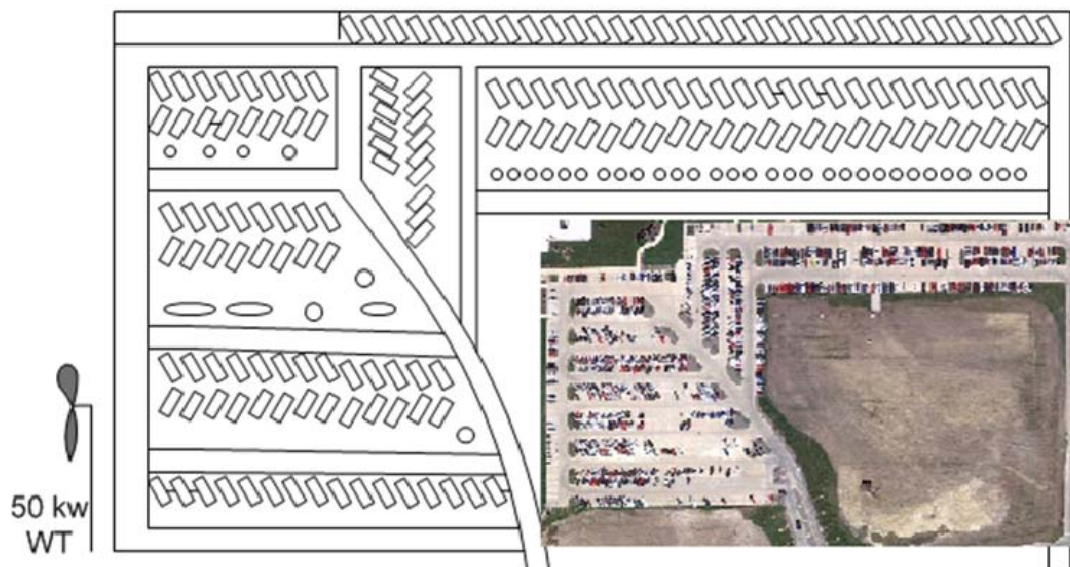


Figure 4a. Proposed wind turbine location. (Modified from Google maps, 2013)<sup>9</sup>

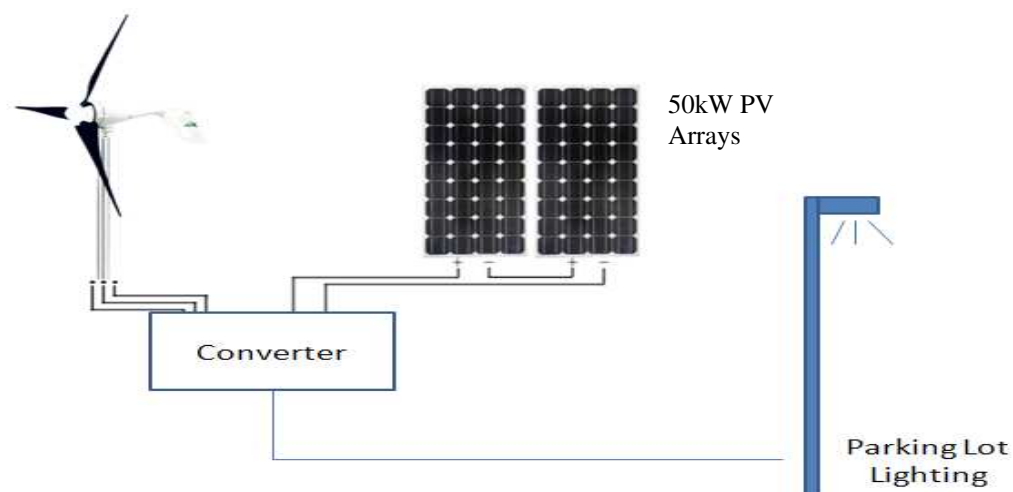


Figure 4b. Proposed solar-wind hybrid system installation diagram

Proposed project also offers to build a lab facility for a university's Electrical Engineering Technology (EET) and Environmental Studies students. Proposed lab facility's goals as follows:

- To show a complex interrelated real world system that provides actual data in order to analyze the hybrid power system.
- To provide wired and wireless sensors communication systems that is completely different than conventional electrical labs.
- To show and study real-world power issues such as AC/DC power interaction and power quality.
- To promote renewable energy technologies since there is clean energy production concerns.

The proposed lab facility will allow STEM teachers to do workshops in order to educate students and increase awareness on renewable energy and environmental issues. This project also will

provide a hands-on laboratory opportunity for STEM teachers and students. The intended outcomes of the proposed project include the following lab activities.

- To collect annual average hourly, daily, and monthly energy production by using LabView and NI FPGA data acquisition module.
- AC and DC bus measurements.
- Monitoring wind speed, solar radiation, and data storage.
- Rate of return and cost analysis of the renewable energy system.
- Voltage, current, power, and system efficiency measurements.

## 5. Conclusion

Conventional parking lot lighting in a large manufacturing company in Iowa was studied. Study results showed that current parking lot lighting system is no longer the most optimal way of enlightening during dark hours. More energy efficient light emitting diodes were proposed to replace current mercury lamps. Moreover, wind-solar hybrid system is proposed to be installed to provide parking with renewable energy. Replacement of mercury lamps to LEDs and installation of small scale wind turbine connected to an array of solar panels may decrease overall cost on electricity<sup>10</sup>. Renewable way of generating power from solar – wind hybrid system may decrease GHG emission and increase the awareness of renewable energy sources in the local community. This project and lab activities will motivate students' learning by introducing renewable energy fundamentals, economic, and environmental concerns. Renewable energy applications and programs in STEM education include basic mathematics, electrical circuits and design, analog and digital electronics, and conventional and renewable energy fundamentals.

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