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Original Research Paper

# Cost effectiveness of new roadway lighting systems

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ABSTRACT

Appropriate and adequate lighting at select locations on roadways is essential for roadway safety. As the lighting technologies advance, many types of new lighting devices have been developed for roadway lightings. The most promising new lighting technologies for roadway lighting include light emitting diode, induction, plasma, and metal halide lighting systems. A study was conducted to compare the new systems with the conventional high pressure sodium systems that are currently used on the Indiana roadway systems. In this study, the engineering issues, were analyzed such as illuminance, color rendering, power usage, cost effectiveness, and approval procedures for new roadway lighting systems. This paper, however, presents only the study findings related to cost effectiveness of the evaluated roadway lighting systems. Illustrated in this paper are the main features of the roadway lighting systems under evaluations, installations of the new lighting systems, measurements of power consumptions, and life cycle cost analyses of the lighting systems. Through this study, experience and knowledge have been obtained on the installations, power measurements, and cost effectiveness of the new types of the roadway lighting devices. The actual power values of various luminaires were obtained by measuring the electric current with a multi-meter. It was found that the differences between the rated and measured power values could be significant. The results of the life cycle cost analysis indicate that the lower life cycle costs of some of the alternative lighting devices are attributed to their relatively lower electricity usages and longer lamp/emitter replacement cycles.



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## 1. Introduction

Appropriate and adequate lighting at select locations on roadways is essential for roadway safety. As the lighting technologies advance, many types of new lighting devices have been developed for roadway lightings. The most promising new lighting technologies for roadway lighting include light emitting diode (LED), induction, plasma, and metal halide (MH) lighting systems. Currently, the high pressure sodium (HPS) lighting systems are the only type of light source adopted by the Indiana Department of Transportation (INDOT) for its roadway lighting. The usages of the new lighting systems in Indiana are only limited to the lights for urban streets, residential streets, walkways, and other non highway applications. It was therefore desired for INDOT to determine if the new lighting systems could be utilized on Indiana's roadway systems. Therefore, a study was conducted to compare the new systems with the conventional HPS systems that are currently used on the Indiana roadway systems. The objectives of this study were to evaluate if the new lighting systems meet the required light output and if they are cost effective.

The study was performed through field measurements and evaluations on the new lighting systems in comparison with the conventional HPS lighting devices. In this study, the engineering issues were analyzed such as illuminance, color rendering, power usage, cost effectiveness, and approval procedures for new roadway lighting systems. This paper, however, presents only the study findings related to cost effectiveness of the evaluated roadway lighting systems. Other issues addressed in the study can be found in the technical report (Li et al., 2013). Illustrated in this paper are the main features of the roadway lighting systems under evaluations, installations of the new lighting systems, measurements of power consumptions, and life cycle cost analyses of the lighting systems. The new roadway lighting systems evaluated in this study include several types of LED, induction, plasma, and MH lighting systems.

## 2. Overview of roadway lighting systems

There are three types of lighting sources that have been widely used for indoor and outdoor lighting applications: incandescent, fluorescent, and high intensity discharge (HID) lights. For roadway facilities, lighting is commonly provided at interchanges, rest areas, weight stations, tunnels, parking lots, and signage boards. Traditionally, HID lighting systems have been widely used for roadway lighting. The HID light source family consists mainly of four members, including mercury vapor (MV), low-pressure sodium (LPS), HPS, and MH lights. Among these HID lighting systems, HPS lights are most commonly used for conventional and high mast roadway lighting due to their excellent luminous efficiency, power usage, and long life (INDOT, 2012).

An HPS lamp commonly consists of four basic components, including a sealed, translucent, ceramic arc tube, main electrodes, an outer bulb, and a base (Halonen et al., 2010; USDOE, 2010). An HPS lamp requires an inductive ballast to regulate the arc current flow and deliver the proper voltage to the arc. An HPS lamp is powered by an alternating current (AC) source. When the HPS lamp is turned on, the voltage is applied across the main electrodes and the xenon gas is easily ionized. The ionized xenon gas strikes the arc and generates heat. The heat then vaporizes the mercury and sodium. The resultant mercury vapor raises the gas pressure and operating voltage to a point so that the sodium vapor produces golden light. Similar to other HID lamps, a standard MH lamp consists of four basic components, including a quartz arc tube, main electrodes, outer bulb, and base. The operation of MH is similar to HPS lamps in that they produce light by way of an arc tube contained within a glass bulb. Inductive ballast is also used to regulate the current and the voltage to the lamp.

LED lighting is a type of solid-state lighting. It is a semiconducting device that produces light when an electrical current passes through it. Multiple LEDs can be combined into LED arrays. An LED lamp is defined as a lighting device with an integrated driver and a standardized base that is designed to connect to the branch circuit via a standardized lamp holder/socket (IESNA, 2008). A basic LED lamp consists of three groups of components, including optical, electrical, and mechanical and thermal components (Halonen et al., 2010; USDOE, 2008). When an LED is energized, the electrical current flows from one end of the diode to the other. Charge carriers are known as electrons and holes flow into the diode in the direction of the current flow. When an electron meets a hole, the electron falls into a lower energy state and releases a particle known as a photon, where is the visible light comes from. A heat sink is needed to draw the heat away from the LED array to cool them and prevent premature failure. The heat sink is typically integrated right into the outer housing of the fixture to maximize heat dissipation.

Plasma, formally known as lighting emitting plasma (LEP), is an ionized gas with equal number of positive and negative charges. Radio frequency waves are used to excite plasma within the bulb. A plasma lamp typically consists of four basic components, lightron, waveguide, cavity resonator and bulb assembly (LUXIM, 2014). When a plasma lamp is powered, radio frequency waves or microwaves are produced. Radio frequency waves are guided toward the bulb to energize the plasma gas inside the bulb. The gas (usually a noble gas) becomes ionized causing some electrons excited and collide with the gas and metal particles inside brought some electrons to a higher energy state. When the electrons return to their original state they emit a photon that gives off visible light.

An induction lamp consists of three major components, ballast, power coupler, and lamp bulb (ETC, 2014; LL, 2013). The ballast contains an oscillator and the preconditioning and filtering circuits. The power coupler contains an antenna that is made of a primary induction coil and ferrite core. It transfers energy from the ballast to the discharge inside the lamp bulb. The lamp bulb is a sealed glass bulb containing a low pressure inert gas with a small amount of mercury vapor. When an induction lamp is powered, the ballast generates a current. The current is sent through the electromagnet and a strong magnetic field is generated. The energy is transferred from the magnet to the mercury in the tube via the antenna