Energy Efficiency: LED Lighting

An Online Continuing Education Course for Engineers

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Introduction

Lighting represents a significant portion of the total electrical energy consumption in the United States and Solid State Lighting (SSL) offers a way to reduce energy consumption. One form of solid state lights is LED lamps. An LED lamp is a solid-state lamp that uses light-emitting diodes (LEDs) as the source of light. The LEDs involved may be conventional semiconductor light-emitting diodes, organic LEDs (OLED), or polymer light-emitting diodes (PLED) devices, although PLED technologies are not currently commercially available.

It is estimated that switching to LED lighting over the next two decades could save $120 billion in energy costs, reduce the electricity consumption for lighting by 25%, and avoid 246 million metric tons of carbon emission.

Since the light output of individual light-emitting diodes is small compared to incandescent and compact fluorescent lamps, multiple diodes are often used together. In recent years, as diode technology has improved, high power light-emitting diodes with higher lumen output are making it possible to replace other lamps with LED lamps. One high power LED chip used in some commercial LED lights can emit 7,500 lumens for an electrical power consumption of 100 watts. LED lamps can be made interchangeable with other types of lamps.

Diodes use direct current (DC) electrical power; to use them from standard AC power they require internal or external rectifier circuits. LEDs are damaged by operating at high temperatures, so LED lamps typically include heat management elements such as heat sinks and cooling fins. LED lamps offer long service life and high energy efficiency, but initial costs are higher than those of fluorescent and incandescent lamps.

In this course we will look at the size of the U.S. lighting market, give an overview of the physics of lighting, the basics of LED lighting, and discuss how LED lamps may be used in residential and commercial applications. First, let's look at the lighting market.

Chapter 1

The Lighting Market

This chapter discusses the size of the U.S. lighting market, recent changes in the market and describes lighting intensities by sector (residential, commercial, industrial, and outdoor lighting).

The total energy consumption in the United States is about 100 quadrillion BTUs (quads) of primary energy. Roughly 39 percent of this energy is consumed for electricity use.

For the purposes of this course, the lighting industry is divided into four sections:

1. Residential
2. Commercial
3. Industrial
4. Outdoor Lighting

Data in this chapter is derived from the latest edition of the DOE report "U.S. Lighting Market Characterization."

The total amount of electricity consumed by lighting technologies is estimated to be 641,000 GWh of site energy, or 6.9 quads of primary energy. Thus, lighting accounts for 7 percent of the total energy and 18 percent of the total electricity consumed in the U.S.

The residential sector accounts for the overwhelming majority of installed lamps, at 71 percent of installed base of lighting. However, in terms of electricity consumption, the sector only consumes 149,000 GWh, or 23 percent of the total. Due to the relatively low efficacy of residential light sources (primarily incandescent), the residential sector only accounts for 8 percent of the lumens produced.

The commercial sector is the greatest energy consumer, accounting for half of the total lighting electricity consumption. In addition, the commercial sector represents the sector in which the greatest number of lumens is produced. This is largely due to the longer operating hours found in the commercial sector as compared to the residential sector. Both the industrial and outdoor sectors make up a relatively small portion of the total installed stock of lamps, each approximately two percent. However, the use of high lumen output lamps and high operating hours result in these sectors consisting of greater shares of total electricity consumption and lumen production.

Residences account for 71 percent of all lamp installations nationwide, at 6.2 billion lamps. The commercial buildings sector is the second largest sector with 24 percent of all installations and

2.1 billion lamps. The outdoor and industrial sectors are significantly smaller, each accounting for roughly 2 percent of all lamps installed, 170 million and 260 million lamps, respectively.

With regard to average daily operating hours, while lamps in the commercial, industrial, and outdoor sectors typically are used for half the day (working hours for commercial and industrial sector lamps and nighttime hours for outdoor lamps) residential lamps are only used a couple hours a day on average. As for the average wattage characteristics, the residential sector average wattage of 38 watts per lamp represents the mix of low wattage, high efficacy CFLs and higher wattage, lower efficacy incandescent lamps installed in the sector. The commercial, industrial and outdoor sector's average wattages are characteristic of the high installed base of fluorescent lamps and high wattage high-intensity discharge lamps. These inputs combined result in a total annual electricity use of U.S. lighting of 641,000 GWH, or approximately 18 percent of total U.S. electricity use.

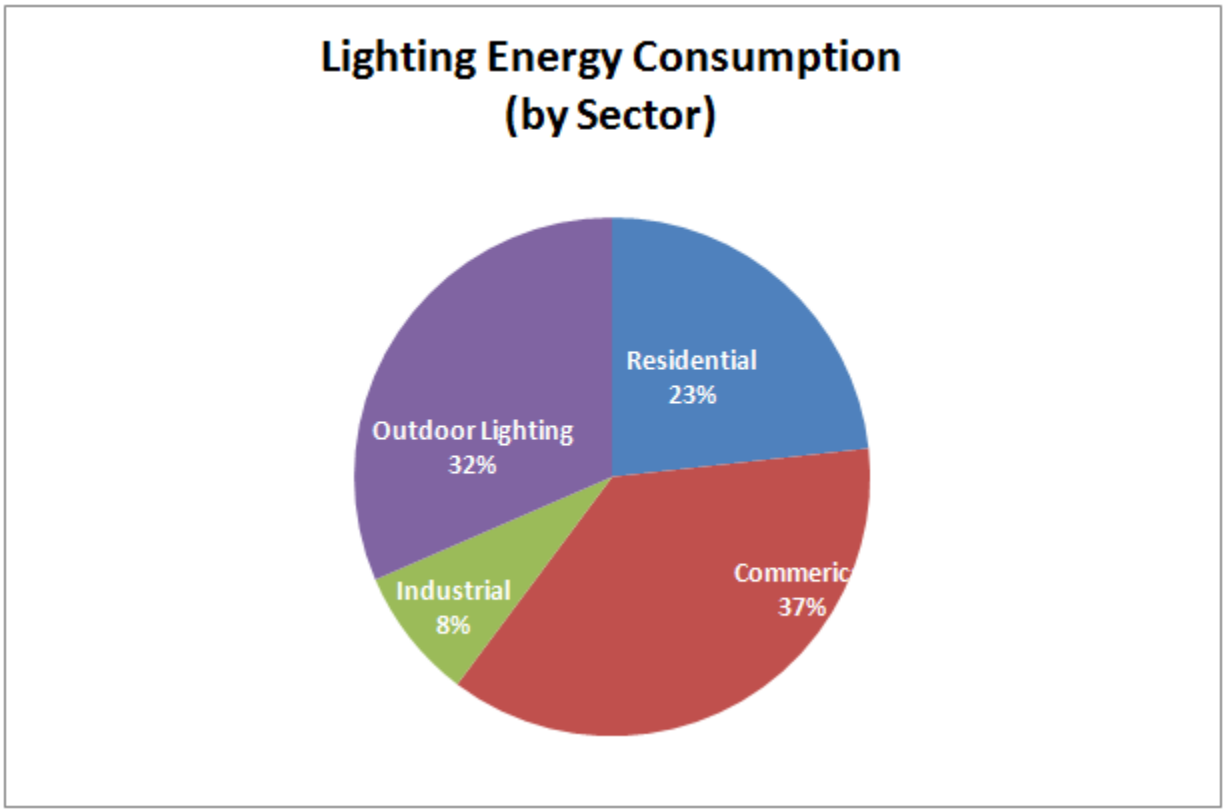

Figure 1

See Figure 1, we see that 37% of the lighting electricity is consumed in the commercial sector, which also represents the sector in which the majority of lumens are produced. This sector is dominated by linear fluorescent area lighting. Outdoor lighting follows at 32% and the residential sector, at 23%, is lower than past years due to CFLs and LED lighting though it still is responsible for 149,000 GWh per year.

The outdoor stationary sector accounts for the remainder of lamps not installed inside buildings. The outdoor subsectors are based on the application where the lamp is used. This includes lamps that may be associated with a specific commercial or industrial building but are installed on the exterior, such as parking lot lights or exterior wall packs.

Lighting Inventory and Energy Consumption Estimates

The light sources are grouped into six broad categories: incandescent, halogen, compact fluorescent, linear fluorescent, high-intensity discharge, and solid state/other. Within each of these are subgroups of commonly available lighting products (e.g., reflector lamps, T8 fluorescent tubes, metal halide lamps). In total, 28 lamp types are included.

The lamp technologies have been categorized as displayed below in Figure 2.

Figure 2

While LED lighting had previously been limited to mostly niche applications, such as traffic signal lighting and exit lights. In recent years LEDs penetration into general illumination applications in the building sectors has grown.

There have been significant changes in the lighting stock and energy consumption characteristics during the past decade. Two notable trends include:

- Increased demand for light. The total number of lamps installed in U.S. applications grew from just under 7 billion in 2001 to over 8.7 billion in 2015. The majority of the growth occurred in the residential sector, primarily due to the increase in number of households and the rise in the number of sockets per household, from 43 in 2001 to 52 in 2015.

- Push towards higher efficacy lighting. Investment in more energy-efficient technologies, lighting regulations, and public awareness campaigns has been effective in shifting the market towards more energy-efficient lighting technologies. Across all sectors the lighting stock has become more efficient, with the average system efficacy of installed lighting increasing from 45 lumens per watt in 2001 to 58 lumens per watt in 2015. This rise in efficacy is largely due to two major technology shifts; the move from incandescent to compact fluorescent lamps (CFLs) and LED's in the residential sector, and the move from T12 to T8 and T5 fluorescent lamps in the commercial and industrial sectors.

The total installed base of lamps in 2015 was est[illegible]n. This represents an overall growth of 17% in th[illegible] inventory growth has been in the residentia[illegible] number of lamps in the remaining sectors cor[illegible]commercial sectors have increased largely due [illegible]. In contrast, the industrial sector lamp [illegible]ostly due to a reduction in manufacturing floor[illegible]t technologies, such as HID. The outdoor sect[illegible]

In the residential sector, [illegible] service incandescent lamps (decreasing from [illegible]neral service CFLs (increasing from 2 perce[illegible]n significant movement toward directi[illegible] reflector, and halogen low voltage disp[illegible]ial installed base.

In the commercial sector, [illegible]escent lamps to T8 and T5 linear fluorescent lamp[illegible] less than 34 percent of the commercial installed base of linear fluo[illegible]mps, with the remaining base being overwhelmingly T12