MODELING U.S. INDUSTRIAL LIGHTING ENERGY CONSUMPTION AND SAVINGS POTENTIAL

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INTRODUCTION

In the industrial sector, potential savings in building energy consumption are smaller than those attainable from increases in process energy-efficiency. Nevertheless, efficiency gains in lighting, space conditioning, and the building envelope present industry with significant savings opportunities and are receiving increasing attention. One early survey of work aimed directly at assessing non-process energy use in industrial buildings concluded that, although the studies surveyed addressed a range of different objectives and situations, "they all pointed to the importance of non-process energy use in industry as an area of potential conservation[1]." Savings potential may be especially large in "high-tech" industries, such as computer hardware and software manufacturing, where most energy consumption is for lighting and air conditioning.

In an attempt to more precisely quantify this incipient source of energy savings, Lawrence Berkeley Laboratory (LBL) has undertaken a preliminary study of industrial sector lighting. Working with Regional Economic Research, Inc. (RER), LBL has been able to synthesize two key industrial energy use data sources (MECS and XENCAP, described below) and incorporate them into an enhanced version of the energy forecast modeling program, COMMEND 4.0 . This paper discusses these data sources and gives an overview of the forecasting model used for this new analysis. Discussion is restricted to the largest industrial sub-sector, manufacturing (SIC 20-39), which accounts for roughly 78% of all energy consumed by U.S. industry.

It is hoped that in presenting this material now—even as it remains a work in progress—the authors will focus attention on potential gains in industrial lighting efficiency. Additional analysis and forecast results will be presented at the 1995 ACEEE Summer Study.

DATA SOURCES

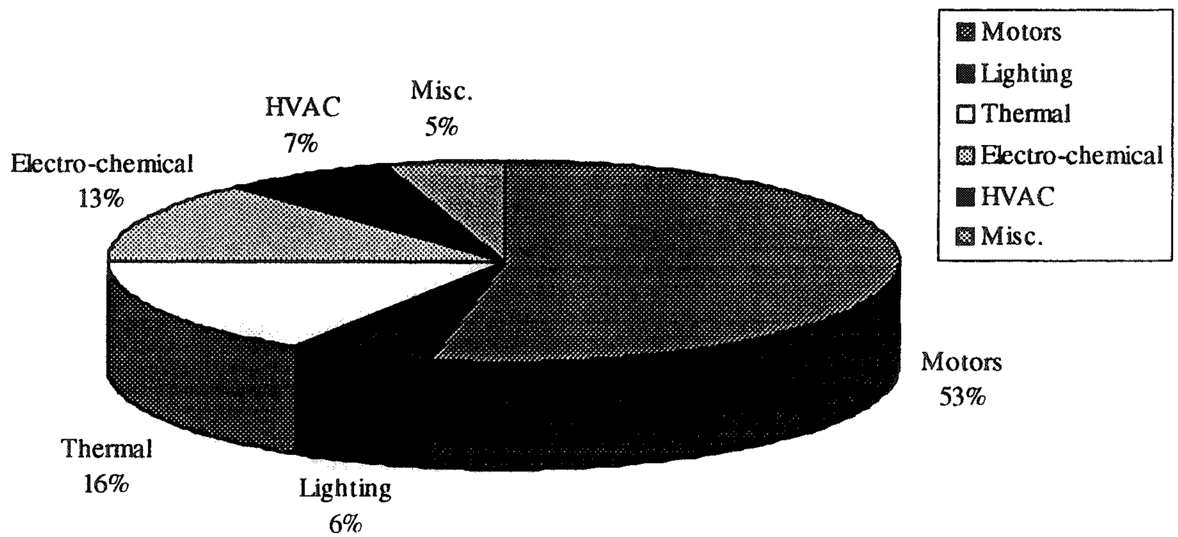
Unlike industrial process energy use, consumption from industrial building end uses may be analyzed using tools similar to those for the commercial sector. First, however, features unique to the industrial sector (here specifically manufacturing) must be included in the baseline from which energy savings are calculated. In addition, the lighting technologies and building stock must be well understood and described. In this latter process, interior and exterior lighting must be analyzed separately.

End-Use Composition of U.S. Manufacturing Electricity Consumption: MECS

A fundamental first step in the LBL analysis has been to assess past lighting electricity consumption for the U.S. manufacturing sector. Until recently, only limited work had been done in this area because of the lack of national-level end-use data. This analysis benefited from the first national industrial survey to provide data about end-use energy consumption, the *1991 Manufacturing Energy Consumption Survey* (MECS) published by the Department of Energy (EIA/DOE, 1994).

According to MECS, U.S. manufacturing consumed an estimated 820 billion kWh of electricity in 1991. This total includes purchases, onsite generation and net transfers in. Although industrial electricity rates can vary greatly, this level of industrial electricity consumption costs over $39 billion at the 1991 average industrial rate of $0.048/kWh.[2] The end-use composition of electricity consumption is presented below in Figure 1.

Figure 1. End-Use Share of 1991 U.S. Manufacturing Electricity Consumption



As indicated in Figure 1:

- Thermal processes, which include process heating, process cooling and refrigeration, boilers and other process uses are found throughout the industrial sector. Together, these processes account for 16% of electricity use, or about 127 billion kWh.
- Electro-chemical processes are concentrated in Primary Metals Production (SIC 33) and Chemical and Allied Products (SIC 28). These processes account for about 13% of industrial electricity use, or about 106 billion kWh.
- Facility heating, cooling and ventilation (HVAC) account for 7% of electricity use, or 60 billion kWh.
- Lighting (interior and exterior) accounts for about 6% of electricity use, which represents electricity consumption of 51 billion kWh.
- Miscellaneous uses, which include facility support, on-site transportation and other non-process uses account for 5% of industrial electricity use, or about 42 billion kWh.

To enhance the end-use energy estimates presented in MECS with information on lighting technologies and building stock, existing energy audit data were sought and incorporated via the Xenergy XENCAP data set.

Lighting Technologies and Building Stock: XENCAP

For the LBL model, energy audits of industrial buildings are a primary source of lighting data. Lighting technologies and their market penetration in industrial buildings have been characterized using data compiled by Xenergy and processed by LBL. To protect confidential utility data, the Xenergy data were taken from the XENCAP database of energy audits from 2,700 industrial buildings, but presented to LBL in an aggregated form (by 3-digit SIC code and zip code). LBL analyzed audits performed in the years 1990 - 1995 as a first approximation to the existing lighting stock. The percentage of delivered lighting provided by these major technology types was calculated: high intensity discharge (metal halide, high pressure sodium, and mercury vapor), fluorescent (four-foot, eight-foot, eight-foot high output, and other), incandescent, and compact fluorescent. Lighting operating hours were also obtained for each of these technologies, and footcandle levels (lumens per square foot) were estimated. Saturations of lighting equipment for new construction and renovated lighting systems were projected by LBL using Bureau of Census data trends, research by the Lighting Research Institute, information from industry, and analysis by Regional Economic Research (RER).

From these sources it is clear that both fluorescent and high intensity discharge (HID) lighting are used extensively. Fluorescent systems tend to be used in areas with relatively low ceilings (low bay) where people are working, such as electronics assembly spaces. Fluorescent is also used in support spaces such as offices, employee areas, and restrooms. HID sources are used in areas with high ceilings (high bay). Metal halide is becoming increasingly popular for mixed-use areas, including spaces with machinery. High pressure sodium is used where color rendering and distortion of moving parts is not a concern. There is little incandescent lighting used in the industrial sector.

METHODOLOGY

Consolidating Data: LIDA

LBL has created a Lighting Database Application (LIDA) database where lighting technical and economic data are stored. Using basic data such as sectoral electricity prices, LIDA performs calculations of equipment energy use and efficiency as well as equipment and labor costs for different lighting technologies. These data and calculations provide input to the Electric Power Research Institute's (EPRI) COMMEND model, version 4.0. LIDA also processes the model output to produce reports of results.

Extensive analysis was performed on XENCAP data and the results stored in a separate database. These data include penetrations of lighting technologies in the existing building stock at both the system type and fixture type level, their operating hours, and sectoral footcandle level calculations. These are combined with another database where estimates of technology penetrations in new buildings are stored. The database application processes the LIDA data together with the technology penetration and operating data and creates the COMMEND input file.

Floorstock: The Forecast Driver

The key forecast driver in the current analysis is manufacturing floorstock. In the current model growth in industrial floorstock and energy prices are based on the latest assumptions behind the *EIA/DOE Annual Energy Outlook 1995*. The starting point for development of a floorstock time series for the U.S. manufacturing sector was 1991 US manufacturing lighting sales. These base year lighting sales estimates were drawn from the *EIA/DOE Manufacturing Consumption of Energy 1991*. Assuming an average lighting intensity of 3.8 kWh/ft^2, estimates of total US manufacturing floorstock are computed as follows:

$$Floorstock = \frac{Lighting\ Sales}{3.8kWh/ft^2}$$

The base year for the forecast was set as 1992, and lighting consumption calculated by the model is calibrated to 1992 data. (This is done because the analysis was conducted in parallel with a commercial sector analysis based on CBECS 1992 data). The ratio of 1992 industrial electricity sales to 1991 industrial sales was used to scale the 1991 floorstock value to 1992 electricity sales levels. The sales estimates are from the Monthly Energy Review (EIA/DOE, 1995). Forecasts of manufacturing floorstock are derived from the 1995 Annual Energy Outlook employment forecast for the manufacturing sector. Currently, LBL projects industrial floorstock will grow from 13.99 billion ft^2 in 1996 to 14.98 billion ft^2 in 2030.

Projections: COMMEND 4.0 (Enhanced Version)

Initially developed by EPRI for use by its member utilities in planning processes, COMMEND projects national lighting energy consumption and savings under various energy-efficient lighting scenarios. For the current analysis, RER and LBL have upgraded COMMEND 4.0 to include the industrial sector as a separate building type. Interior and exterior lighting associated with industrial buildings have been included in each building type, and are analyzed separately.

The COMMEND framework utilizes the following basic concepts:

- Floor stock (square feet of building space),
- Fuel share (percent of area served by an end use and fuel type),
- Energy-use index (energy per square foot per year for an end use),
- Energy intensity (total energy per square foot),
- Peak-day fractions (share of annual energy), and
- End-use load profiles.

By developing data for each of these concepts, a complete end use profile can be produced.

In its central energy equation, COMMEND defines current energy use as the produce of three factors: floor stock, fuel share, and an energy use index (EUI in kWh/ft^2/year). For a single building/end-use segment, the central equation is:

$$\text{Annual Energy Use} = EUI * S * F$$

where:

F is total square footage of floor stock,
S is average share of space served by the end use and fuel, and
EUI is average energy use for served space.

As an average, the EUI value embodies both average equipment efficiencies and average usage levels across a given segment. LBL calibrates the model consumption to match estimated industrial sector EUIs by adjusting lighting operating hours and footcandle levels (delivered lighting levels in lumens/ft^2)

The first step in the analysis is a baseline projection, estimating lighting electricity consumption in the absence of efficiency incentives other than market forces. Using conversion rate equations that include life-cycle cost or payback period, COMMEND projects industrial sector consumer choices from the range of available lighting technologies. Savings from scenarios using higher efficiency lighting equipment (due to regulation, utility rebates, or other incentives) can be calculated from this baseline.

A separate baseline projection is performed for interior vs. exterior lighting. This analysis does not attempt to estimate interaction of lighting efficiency changes with space conditioning energy use, since this is complicated in an industrial environment with process energy use.

In the current model, COMMEND 4.0 forecasts lighting electricity consumption for the period from the year 2000 through 2030. Energy use under scenarios of increased lighting efficiency is projected and the savings calculated. The economic impacts, including equipment costs, energy expenditures, and net present value of policies are also calculated. Other efficiency measures such as substitution of HID lamps for fluorescent lighting, and conversion of inefficient lighting systems to more efficient ones will be added in the future.

OUTPUT

The output will include a baseline for industrial lighting electricity consumption for the years 2000-2030, and consumption and net present value for several efficiency scenarios, including:

- substitution in four-foot fixtures of electronic ballasts and T12 lamps with high frequency electronic ballasts and F32T8 lamps
- substitution in 8 foot and 8 foot high output fixtures of fluorescent magnetic ballasts with high frequency electronic ballasts
- substitution of fluorescent systems with HID systems
- substitution of mercury vapor systems with metal halide systems
- substitution of mercury vapor systems with high pressure sodium systems

These efficiency upgrades are assumed to occur in new construction or when the lighting system is substantially renovated. Some amount of retrofit system conversions can be assumed. Efficient lighting measures are only applied where the new system provides the same (or better) light quality as the system it replaces.

Forthcoming work will also seek to distinguish between "light" and "heavy" industry, at least as far as lighting equipment is concerned. (This distinction will not necessarily follow the manufacturing/industrial lines used above.) Light industrial environments would tend to have shorter operating hours, "low bay" lighting (lower fixture heights), and significant fluorescent lighting. Heavy industrial would have longer operating hours, "high bay" lighting, and more HID lighting.

Though the current analysis is still at an early stage, *prima facie* evidence supports an optimistic stand on potential savings in industrial sector lighting. By presenting an overview of this first attempt at modeling such savings, it is hoped that forthcoming results will be more readily understood and appreciated.

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NOTES

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