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PACIFIC NORTHWEST LABORATORY'S LIGHTING TECHNOLOGY SCREENING MATRIX

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April 1994

Presented at the
GLOBALCON '94: Lighting
Efficiency Congress Conference
April 6-7, 1994
Anaheim, California

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

MASTER

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Pacific Northwest Laboratory's Lighting Technology Screening Matrix

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Pacific Northwest Laboratory[1] has developed the Lighting Technology Screening Matrix (LTSM), a software tool to evaluate alternative lighting retrofit technologies according to life-cycle cost. The LTSM can be used to evaluate retrofits for most configurations of fluorescent, incandescent, high- and low-pressure sodium, metal halide, mercury vapor, and exit lighting systems for any level of operation, electricity price, discount rate, and utility rebate. This tool was developed in support of the Federal Relighting Initiative as part of the Department of Energy's Office of Federal Energy Management Program (DOE/FEMP) to assist federal government facilities in their efforts to comply with the 10 CFR 436 mandated life-cycle costing for energy equipment investments.

The LTSM has been used in the course of seven site modernization projects. These projects consisted of determining the cost-effective, energy-efficiency potential at military installations. Each project treated the entire military installation as an integrated system, proposed a large number of potential efficiency projects affecting all end-uses and fuel types, and analyzed the cost-effectiveness of each project. The LTSM was used for the lighting portion of these projects. Lighting was, overall, one of the major areas of potential efficiency improvements, accounting for over 30% of the cost-effective resource. Altogether over $43 million worth of cost-effective efficiency investments

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[1] Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RL0 1830.

were identified, worth an estimated $6 million annually in energy, demand, and operations and maintenance (O&M) savings. This paper describes the LTSM and demonstrates its application in a case study at one of the federal installations analyzed.

The LTSM Program

The LTSM is a DOS-based software tool that calculates the life-cycle cost of an existing fixture and of a large number of potential energy-efficient replacements, both for one-for-one replacements and on a lumen-equivalent basis. The LTSM calculates annual energy savings of the replacements, annualized capital costs, annualized maintenance costs, and annualized energy costs. These cost elements are then combined to calculate the life-cycle cost of the fixtures. The potential replacements are then ranked according to their life-cycle cost.

The primary component of the LTSM interface is the input screen. It may help to visualize the input screen as the traffic controller of the LTSM tool. More specifically, it is the environment in which the user can retrieve, save, and modify inputs to a test application; and direct test results to the screen, a file, or to both the screen and a file. The input screen appears as shown in Figure 1.

Operation of the LTSM

In a typical session, the user would select the fixture to analyze, then specify operating parameters and characteristics of the facility. Once specifications have been made, the retrofit evaluations can be developed.

```
Inputs  Output  Help  Quit
                    Lighting Technology Screening Matrix
                  Facility Level Inputs                          Input
Discount rate (decimal form):   0.040                          Options
Average cents / kWh:             7.00                          <  Help  >
State (or US Average):          US (Region: US        )       <Retrieve>
Analysis period (years):        25                             <  Save  >
Sector: ( ) Residential ( ) Commercial  ( ) Industrial         < Cancel >
Building vintage:  ( ) Existing  ( ) New
Cost multipliers:                 Materials   Labor              Output
 ( ) Default        Installation    1.0000    1.0000            Options
 ( ) User defined   Replacement     1.0000    1.0000            <Screen  >
                  Technology Level Inputs                       < File   >
Fixture to analyze:       FL 2X4 4F40T12 STD2                  < Both   >
Fixture code:             FL1
Minimum lumen ratio:       0.000 (retrofit / existing)
Annual operating hours:    4380                                Input file name
Rebate type:              None                                  UNTITLED
Data type:                ( ) Commercial ( ) DLA
Exclude reflector retrofits: ( ) Yes    ( ) No                Output file name
Exclude cross-technology retrofits: ( ) Yes    ( ) No           UNTITLED
```

Figure 1. LTSM Input Screen

The evaluation starts by retrieving technical data for those retrofit fixtures determined to be retrofit candidates in an operational and technical sense. For each retrofit fixture, the electricity requirements and value of savings are determined. Next, the capital costs and rebate values are computed. The frequency of component replacement, and the associated costs (O&M), are determined by applying the annual hours of operation to a components life expectancy. Each of these costs is annualized, summed, then discounted in a present value calculation to arrive at the life-cycle cost. Finally, the net savings is determined as the difference between the life-cycle cost of the existing and retrofit fixtures. To facilitate a review of how retrofits compare with one another, the output shows the existing fixture followed by the retrofit fixtures ranked in descending order according to the net savings of each fixture.

Each of the steps discussed above correspond to values reported in the output, which can be viewed either on screen or in file form. A more detailed discussion of the reported computations can be found in the output discussion.

LTSM Inputs

The LTSM can be used to evaluate retrofits for all commercially available lighting types, including fluorescent, incandescent, high- and low-pressure sodium, metal halide, mercury vapor, and exit lighting systems. The input screen presents a list of these lighting types followed by a popup of the fixture configurations for the type selected.

The discount rate is used to discount future streams of costs and savings over the analysis period where the savings are a function of the melded average cents per kilowatt-hour (kWh) and operating hours (the computation of this melded rate is explained later in this paper). The state and end-use sector determine which average wage, materials, and regional energy price escalation rates are used in the analysis.

The building vintage can be either "new" or "existing." If "new" is specified, the installed cost of the hypothetical existing fixture is included in the annualized cost calculations and the fixture components have a full service life remaining. All retrofits are evaluated as if they are fixture replacements rather than component replacements. If "existing" is selected, it is assumed that one-half of the life of the existing fixture components have expired and the costs for the existing fixture do not consider the installed cost.

Cost multipliers can be either "default" or "user defined." Default multipliers indicate the ratio of state material/labor costs to U.S. costs for the state under review. Using the default multipliers as a starting point, the user can select "user defined" to adjust the multipliers to more accurately represent local or regional costs.

The input called "minimum lumen ratio" represents the minimum ratio of retrofit lumens to existing lumens a fixture must have to be included in the results. This capability ensures that a replacement fixture maintains lumen output at the same level, a greater level, or some minimum acceptable level. This feature allows the user to analyze alternatives for underlit areas (by specifying a lumen ratio greater than 1.0) and overlit areas (by specifying a lumen ratio less than 1.0).

There are five types of rebate programs that can be represented: percent of installed cost, dollars per kW saved, dollars per kWh saved, fixed dollar per unit, and fixed percentage per unit. If one of the last two rebate types is selected, a list of the existing fixture and all candidate retrofits will be presented. In these two types of programs, each retrofit can have a unique rebate specification, either dollars offered per retrofit or percent of installed cost offered per retrofit.

Two sources of component cost data are provided: commercial vendors and the Defense Logistics Agency (DLA). The latter accommodates military facility applications, as well as other government agencies who purchase through the Defense General Supply Center (DGSC). The DLA data currently only provides alternative lamp cost data; all other component cost data is provided by commercial vendors.

In the event reflector replacements and cross-technology retrofits are not desired (e.g., fluorescent to HID), switches for each can be set to exclude these retrofits from the list of candidates.

LTSM Outputs

Output can be either viewed on screen or sent to a file. If sent to the screen, the user is prompted for the type of results to report: one-for-one or lumen-equivalent. One-for-one means that

the analysis assumes each existing fixture is replaced with one fixture, regardless of the lumen ratio. Lumen-equivalent means that each existing fixture is replaced with the exact number of fixtures needed to maintain the lumen output at its original level. Results written to a file will include both output types. The full list of outputs that the LTSM provides for the existing lighting system and each retrofit alternative is shown below:

Fixture name	Value of 1st year savings
Fixture code	Annualized ballast cost
Activity type	Annualized lamp cost
Lumen ratio	Annualized total O&M cost
Watts	Annualized capital cost
Ballast life (yrs)	Annualized energy cost
Lamp life (yrs)	Annualized total cost
Data type	Life-cycle cost
Installed cost	Levelized energy cost
Rebate value	Net savings
Annual kWh savings	Simple payback

A partial layout of screen results is shown in Figure 2.

```
Inputs  Output  Help  Quit  Browse
■      >>> One-for-One results. Strike [ESC] when done. <<<
```

Fixture name	Code	NPV	Life-cycle cost
FL 2X4 4-40 STD	F1	0.00	1011.91
FL 2X4 2-T8 ELC REF	F57	520.43	491.48
FL 2X4 2-T8 EEF REF	F45	497.16	514.75
FL 2X4 4-40 ELC REF	F31	138.59	873.32
FL 2X4 4-40 EEF	F13	110.06	901.85

Figure 2. LTSM Screen Results

Several reported results warrant an explanation beyond that provided in the earlier discussion.

Installation cost includes the materials and labor costs adjusted for regional cost differences, net of rebate values. The value of a rebate offering is determined from the rebate type specified. If

the rebate offered exceeds the installed cost of a retrofit action, then the rebate value is equal to the installed cost. That is, it is assumed a utility will only reimburse a customer up to the amount of the installation. The sum of the installed cost and rebate value indicates the true full cost of installation.

An annualized cost is a cost measured over the duration of the analysis period, evaluated to an annual basis. This result is much like an annual payment on a loan where the replacement costs over the full analysis period and the time-value-of-money of those costs are considered.

Reported annualized costs include those for ballast and lamp costs, total O&M (sum of annualized ballast and lamp costs), capital (installed cost), energy, and total (sum of capital, O&M and energy).

Four reported results commonly used as decision making criteria include: life-cycle cost, net savings, levelized energy cost, and simple payback. Life-cycle cost is the present value of the annualized total cost. Net savings is nothing more than subtracting the life-cycle cost of the retrofit fixture from that of the existing fixture. A positive net savings implies that there is an economic gain to retrofitting the existing fixture with the replacement fixture.

The levelized energy cost is the cost of conserved energy, calculated as the net annualized capital and O&M costs (i.e., [annualized capital + annualized O&M costs for the retrofit] - [annualized capital + annualized O&M costs for the existing fixture]) divided by the annualized energy savings in kWh. This value may result in a negative number if the O&M costs are less for the retrofit fixture than they are for the existing fixture.

Simple payback is the number of years required for the operating savings attributable to a project to repay the original investment. Operating savings are defined as the value of annual energy savings evaluated at current energy prices plus the savings in annualized maintenance costs. The simple payback period does not account for future changes in the real price of energy or for the time value of money.

Data Used in the LTSM

The analysis and life-cycle costing performed by the LTSM is based on representative data and corresponding assumptions for each lighting technology and associated equipment represented in the software.

The data used must represent aggregate values for each of the technology and equipment types that exist in the federal sector and represented in the LTSM. For this reason, a strict average of various data points is considered inappropriate for the LTSM. Values that are considered to be "typical," based on representative samples of available products and other aggregate data sources, are considered to have the most applicability to a majority of situations. The values required for use in the LTSM for each technology include:

- Performance characteristics such as power consumption, lumen output.
- Effective life of the equipment.
- Maintenance requirements and associated cost.
- Installation or "first" cost for various installation types and configurations.
- Secondary performance metrics such as coefficients of utilization.
- Component replacement costs for lamps and ballasts.

- Applicability of technologies and equipment types.
- Labor costs for various installation and maintenance tasks.

These derived values are used in the LTSM to identify or calculate:

- Annual installation, maintenance, and energy consumption costs.
- Total life-cycle costs for various technology options.
- Relative light output of various technology options for comparison.

The identification of "typical" values incorporates various data sources that include manufacturers' data, published research data, and other commercially available information on lighting products, operation, maintenance, and costing.

Because of this necessary grouping of technologies and equipment, the LTSM's application on individual specific lighting equipment may not produce the exact result expected if more specific data was used. However, the LTSM is designed to provide general savings potential and life-cycle cost effectiveness over a wide range of lighting products for entire federal facilities and not as a design tool for specific situations.

Application of LTSM: Robins Air Force Base

Most recently, the LTSM was used to analyze the lighting potential at Robins Air Force Base (Robins AFB), Georgia, as part of a larger, base-wide energy conservation study. There are 646 commercial, industrial, and command buildings on the base, with a total floor area of 11.6 million

square feet. There are 1,416 family housing units in 822 buildings, with a total area of 1.8 million square feet.

Robins AFB receives electricity from two utilities, Georgia Power Company (GPC) and Flint Electric Membership Corporation (Flint), under four separate rate structures. The incorporation of the different rates is discussed later in this section. The typical annual electricity consumption at Robins AFB is approximately 269,085 MWh (918,386 MBtu [million British thermal units]), comprising about 47% of total energy consumption. The electricity cost for 1990 was approximately $12.2 million, or almost 80% of total annual energy expenditures. Of the electricity used, approximately 227,736 MBtu (24.8%) went to interior lighting, 13,281 MBtu (1.4%) went to exterior lighting, and 35,084 MBtu (3.8%) went to streetlighting. Of the light types, there were over 121,500 fluorescent fixtures identified for potential retrofit or replacement and over 32,000 incandescent fixtures identified for potential retrofit or replacement. Other fixtures identified for potential retrofit or replacement included high-pressure sodium, metal halide, and exit sign fixtures.

These fixtures were categorized by fixture type, annual operating hours, building type, and utility rate, and then listed as separate energy resource opportunities (EROs). Each lighting ERO was analyzed according to its specific characteristics, including fixture type, annual operating hours, minimum lumen ratio, and melded electricity rate. In the case of the utilities serving Robins AFB, no rebates were available for lighting technologies at the time of the analysis. As mentioned previously, there were four electricity rate structures in effect at the Robins AFB site: a time-of-use structure, a declining block structure, and two flat rate structures. The LTSM requires the use of a single melded rate of electricity, which encompasses the energy and demand charges, as an input. It was necessary, then, to calculate a melded rate for each of the EROs. This was accomplished by using Equation 1:

$$R = \frac{(E \times P_E) + (D \times P_D)}{E} \qquad (1)$$

where R = melded rate

E = kWh consumed by existing equipment

P_E = electricity price per kWh

D = kW required by existing equipment

P_D = electricity demand charge per kW

Depending on the type of rate structure, the above variables could be further broken down into time-of-use components or seasonal components. The result of this equation was a melded rate that was based on the actual consumption of the fixture being analyzed. It therefore accounted for differences in annual operating hours in addition to the different rate structures and fixture types.

Once all of the required information had been formulated for each lighting ERO, the data was entered into the LTSM, which analyzed all potential retrofits for each fixture type. Cross-technology retrofits were allowed at Robins AFB, and some technologies were cost-effective, including high-pressure sodium fixture replacements for some existing metal halide fixtures. While not classified by the LTSM as cross-technology replacements, there were cost-effective replacements recommended that changed incandescent fixtures to compact fluorescent fixtures.

The LTSM identified cost-effective lighting opportunities with a combined net savings of $4.1 million at Robins AFB. The overall cost of conserved lighting energy was $0.02/kWh. Tables 1 and 2 provide more detailed information on the costs and savings associated with the lighting measures. By end use, the lighting measures comprised 21.6% of the total energy savings in dollars identified at

Robins AFB, and 43.1% of the total electric energy savings in dollars. In terms of MBtu savings, lighting measures comprised 45.7% of the total MBtu savings and 52.7% of the total electric MBtu savings. In addition, lighting measures comprised 52.7% of the total electric demand savings.

Table 1. Costs and Savings of Lighting Measures at Robins AFB

Installed Cost	$5.8 Million
Present Value of Energy Savings	$6.4 Million
Present Value of Demand Savings	$2.8 Million
Present Value of O&M Savings	$0.7 Million
Present Value of Total Savings	$9.9 Million
Net Savings	$4.1 Million

Table 2. Energy and Demand Savings of Lighting Measures at Robins AFB

Existing Energy Use (All Fuels)	1,965,925 MBtu
Existing Electricity Use	918,386 MBtu
Existing Energy Demand	545,781 kW-mo
Lighting Measure Electricity Savings	53,572 MBtu
Lighting Measure Demand Savings	37,397 kW-mo

Conclusions

The LTSM allows the user an efficient way to examine a variety of lighting alternatives without requiring a significant amount of information from the user; and the user does not need to collect data on the new lighting equipment. The LTSM also allows the user to incorporate rebates that may be available from their servicing utility. In addition, regional factors, such as price

differences and labor and materials multipliers, can be accounted for within the costing framework. The LTSM provides the user with a quick and easy method of estimating the potential for cost-effective lighting retrofits within the user's facility.

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