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ABSTRACT

A spreadsheet program for determining system efficacy, power input and light output of common 4 ft fluorescent lighting systems under realistic operating conditions is described. The program uses accepted IES engineering principles to precisely account for ballast factor, existing thermal conditions and maintenance practices. The spreadsheet, which includes a data base of lamp and ballast performance data, can be used to calculate the cost-effectiveness of many common lighting retrofits.

INTRODUCTION

Increased concern for reducing operating costs in buildings has led to the emergence of many new efficient fluorescent lighting products during the past 15 years. The surfeit of choices has increased the complexity of the specifier's task, which is further compounded by wide performance variations between components and systems [1,2]. For example, the rated lumen output of a four-foot fluorescent lamp may be as low as 1925 lumens or as high as 3700. Similarly, ballast factors for various 4-foot lamp/ballast systems can vary from under 0.8 to approximately 1.3. Finally, elevated lamp wall temperatures under typical application conditions can cause the lamp lumen output to be nearly 20% below its rated value [3,4]. The overall effect of this performance variability serves to seriously compromise the designer's ability to specify lighting systems that provide the correct light level.

Difficulty in calculating actual lumen output, while a problem in new design, is often particularly troublesome in retrofit applications. The task of collecting and correctly interpreting manufacturers' component performance data, determining integrated system performance, and deciding the appropriateness and cost effectiveness of retrofits is often delegated to facility managers and others who have little expertise in lighting.

This paper describes a micro-computer spreadsheet program that uses accepted illuminating engineering principles to precisely determine system efficacy, power input and light output of common 4 ft fluorescent lighting systems under realistic operating conditions. The spreadsheet is targeted at facilities managers, building energy managers, designers, energy analysts and utility specialists. These individuals are often influential in the way energy is used in a building yet lack the information base and analytical means to make knowledgeable decisions about improving lighting efficiency. It is assumed that the end-user will have access to a personal computer and will have at least passing familiarity with using spreadsheet programs.

METHODS

To determine system efficacy, power input, and light output of four foot fluorescent systems, it is not enough to know the performance characteristics of the lamp and ballast separately. The lamp and ballast operate as a system and their performance can only be properly characterized as a system. In addition to lamp/ballast considerations, the fixture also affects lighting performance. Lumen output (and input system power) from a lamp/ballast system is a function of the ambient lamp temperature. Different fixture designs cause the lamp to operate at different temperatures. Thus ambient temperature is another key parameter for analyzing lighting system performance.

An important part of this project was to develop algorithms that describe system performance based on key lighting parameters. The key parameters that must be identified for the system under analysis are the ballast factor, the lamp lumen rating, the lamp/ballast system input power, the thermal factors (for light output and power input), and the luminaire lumen maintenance properties. The ballast factor is defined as:

$$\text{Ballast Factor} \equiv \frac{\text{Lamp lumens from commercial ballast}}{\text{Rated lamp lumens (on reference ballast)}}$$

The term in the denominator is simply the rated lamp lumens as given by the lamp manufacturer. The numerator is the lumens produced by the lamp when operated by the ballast of interest in a 25 °C ambient temperature. The thermal factor for light output (TF_{light}) indicates how much light the system produces under field conditions compared to the same lamp/ballast system operating at a 25°C ambient temperature. TF_{power} is an analogous factor that accounts for how input power varies as a function of lamp ambient temperature. Finally, lamp lumen and luminaire dirt depreciation factors must be calculated. These factors describe how the lumen output of the luminaire changes over time.

Once the appropriate algorithms for determining these parameters are identified, the calculations required to estimate system efficacy, energy usage and cost-effectiveness are straightforward but tedious to execute. Consequently, a microcomputer program is an ideal method for implementing these calculations. In this project, we elected to encode the first version of this analysis program as a spreadsheet prototype. Implementing the analysis as a spreadsheet expedites delivery of a working prototype and also allows the equations used in the calculation to be readily inspected and modified as necessary. The spreadsheet, code-named LEAR (Lighting Energy Analysis for Retrofits), is being developed as a template for a popular spreadsheet program that runs on both commonly-encountered types of personal computers.

Scope

Our first task in developing the lighting retrofit analysis program was to decide which retrofits to incorporate into the prototype program. Due to their widespread use in commercial applications, 4 foot fluorescent systems were selected for the analysis. In identifying retrofits for these systems, we classified fluorescent lighting conservation measures into the following categories:

Category 1: Retrofits that do not significantly alter the relative distribution of light (candlepower distribution) from a luminaire. Thus this category covers de-lamping, re-lamping, re-ballasting, combinations of re-lamping and re-ballasting and altered maintenance practices. The replacement of T12 lamps with T8 lamps would be considered in this category since the effects of thinner diameter tubes on fixture light distribution are small.

Category 2: Retrofits that significantly affect the fixture's candlepower distribution. This category includes specular reflector inserts, lens substitutions, added louvers, etc. Entire fixture replacements would be considered in this category.

Category 3: Retrofits that alter the hours of usage or control input power dynamically. These include most lighting controls such as programmable timers, occupant sensors, and daylight-linked lighting systems.

The initial version of LEAR treats Category 1 retrofits. Narrowing the project scope to Category 1 retrofits eliminates the need to include a luminaire data base containing candlepower arrays in the prototype program.

Figure 1 is a flow chart showing the structure of the LEAR program. The program consists of three major components; a formatted worksheet that is completed by the user, an analysis portion which does most of the computational work, and output forms onto which all results are reported. During program execution, a set of product performance data bases are accessed.

Using the Program

When the program is first run, the user is presented with a blank worksheet. Both the inputs and outputs are consolidated in this worksheet which serves as the interface between the user and the rest of the program. Users will enter inputs here, and see the final calculated outputs. All the tasks of operating the entire system, setting up the work sheet for the user, searching the appropriate database, and finally organizing and presenting the results on the worksheet are accomplished with custom macros written in the spreadsheet's macro language.

To start an analysis, the user enters in the required information about the basecase lighting system (i.e., the system as it presently exists). Generally, this consists of about 15 pieces of information. The entries for lines marked with bullets in Figure 5 indicate the required inputs. All other cells are calculated by the program. Some of the required input data can be obtained simply by reading the nameplate label on the existing ballast(s) or the lamp. This avoids the need for the user to learn any new terminology or to perform any calculations that he/she is not familiar with. Once the requisite information about the basecase is entered, the user types a keycommand to activate a macro that accesses all the necessary databases and completes the basecase column in the worksheet.

Next, the user enters in the information required to analyze the energy performance of the proposed lighting retrofits alongside the basecase column. Again, once all the required user inputs are entered, a user-activated macro performs all the necessary calculations and completes the remaining columns of the worksheet. By adding cost data to an accompanying economic analysis worksheet, the user can determine the cost-effectiveness of the alternative retrofits (see Fig. 6 for a completed example).

In the current version of LEAR, the user directly types values into the spreadsheet cells. Therefore, the user must be a careful typist. (Misspelling the manufacturer's name will cause an error!). Only a limited amount of error checking is incorporated. The user will be informed if a system entered does not exist in the databases but no reasonability checks are applied to the input data. Also, LEAR does not supply the user with recommended default values.

Database Considerations

While they are not normally visible to the user, LEAR relies on several data bases to perform its calculations. Because the attributes of a lighting component category (such as a lamp) are specific to that category, we found it more efficient to construct several, small databases for each component category rather than one monolithic data base containing all the information. This structure also facilitates updating the databases. Product updates made to a lighting component category (such as lamps) need only be concerned with those attributes specific to that category.

Some of the entries in the data bases are product specific, not generic. While it is often desirable to use generic data, in some cases that is not possible without severely compromising the utility of the program. For example, ballast factors for electronic ballasts vary widely between manufacturers and even within a given manufacturer's product line. (One can even request custom electronic ballasts with a specified ballast factor). Thus, differences in product performance are accurately reflected in the databases of LEAR.

Determination of Lamp Lumens

Lamp performance data as extracted from published lamp manufacturer's information are contained in the data base LAMP_DATABASE. An excerpt of this database is given in Fig. 2. At this point, LAMP_DATABASE contains most of the 4-foot fluorescent lamps offered by the four largest manufacturers of fluorescent lamps.

Note that the data base contains information about lamp color rendition and color temperature in addition to the manufacturer's lumen ratings and lifetimes. These fields were included to allow a lighting quality component to be added to a future version of LEAR. For example, LEAR could do an initial screening of lamp types by rejecting all those lamp with phosphors of a CRI lower than some cut-off. This will also reduce computation time, by reducing the search space.

Determination of Ballast Factor

LEAR determines ballast factors to use for the lamp/ballast systems under examination by looking in the database SYSTEM_DATABASE. As shown in Fig. 3, this data base lists ballast factors, system input power (ballast + lamp power) and ballast efficiency factors for various four-foot lamp/ballast systems. By ANSI standard [8], these performance data are reported for lamps operating in a 25 ± 1 °C ambient temperature. Ideally, the ballast factors and input wattages should be supplied by the ballast manufacturers. However, many ballast manufacturers supply only system input wattage values for the different lamp types but not ballast factors. In the current version of LEAR, input power and ballast factors in SYSTEM_DATABASE are given for manufacturers that lists ballast factors (actually the ballast efficiency factors from which ballast factors can be calculated) in their technical performance data for their electronic ballast operating various lamp types. It is not yet clear how and if data from other sources, such as [9] will be incorporated into LEAR.

It is important to note in SYSTEM_DATABASE that, while the ballast factor is specific to a particular manufacturer's ballast, the lamp category is generic.[1] Structuring the data base in this way keeps the number of records in the SYSTEM_DATABASE to a reasonable number.

Determination of Thermal Factor

As shown in Fig. 4, the THERMAL_DATABASE contains, for each lamp/ballast system, four coefficients for relative light output and four coefficients for system input power. These are the coefficients of cubic functions that reasonably fit the relationship between ambient temperature and light output and power input. These cubic functions have been scaled so that the thermal function for light output, TF_{light}, and input power, TF_{power}, are unity under ANSI conditions (i.e., with the ambient temperature at 25°C). Although these thermal functions have been derived using ambient temperature as the independent variable, minimum lamp wall temperature could be been used instead.

As with the SYSTEM_DATABASE, the THERMAL_DATABASE is product specific with respect to ballast but generic with respect to lamp category. Unfortunately, there are many lamp/ballast systems for which the thermal functions are not available. In the current version of LEAR, the thermal data is drawn primarily from [3].

As of this writing, the user must enter in appropriate values of *in-situ* ambient temperature (i.e. the temperature that surrounds the lamp in the fixture) both for the basecase and for any retrofits to be examined. Armed with ambient temperature (which can vary for different systems), LEAR can account for the effect of thermal environment on the luminous and energy performance of the examined systems. It is recognized, though, that few users will know these temperatures. In the first version of LEAR, then, a simple lookup table will be used to provide an estimate of the ambient lamp temperature based on a physical description of fixture type (i.e. lensed, parabolic louvered, or open), ceiling integration (i.e. recessed-mounted in plenum, surface-mounted, or pendant-mounted), fixture geometry (2x4, 1x4, etc.), etc. Plans to improve the precision of this thermal model are discussed in the discussion section.

Determination of Maintained Illuminance

LEAR calculates lumen maintenance effects with regards to lamp lumen depreciation and dirt depreciation using standard IES methods [reference 5, pgs. 8-29, 9-6 through 9-10]. These methods require that the user know the IES Luminaire Maintenance Category (Categories I through VI), IES atmospheric dirt condition (very clean through very dirty) and the lamp loading category (light, medium or heavy). LEAR does not require the lamp loading category as an explicit input because it is a property of the lamp alone and has been incorporated into the lamp database. However, the luminaire maintenance category is a required input. Unfortunately, most end-users will not know this parameter. This problem is discussed later in the paper.

LEAR uses the IES alternative procedure for computing luminaire dirt depreciation [Reference 5, pg. 9-9] since this is more amenable to computation than the IES graphs. Also, the lamp lumen depreciation curves given in [Reference 5, pg. 8-29] have been approximated using a linear fit to

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[1] There are four major categories of 4-foot fluorescent lamp: 40W F40 T12, 34W F40 T12, 40W F40 T10, and 32W F40 T8. These lamp categories are based on the electrical properties of the lamp.

the square root of burning hours. This formulation was found to reasonably fit the graph in [Reference 5, pg. 8-29].

With regards to lighting maintenance, LEAR calculates a) the minimum total depreciation factor over the planning horizon and b) the total depreciation factor at any given time. The total depreciation factor is the product of the lamp lumen depreciation and the luminaire dirt depreciation. The minimum total depreciation factor is useful for determining whether a lighting retrofit will result in a light level that could fall below the maintained light level from the existing system. The total depreciation factor at any given time is most often useful for determining how light levels will change immediately after the retrofit.

Effects of room surface depreciation and non-recoverable light losses (except thermal effects) are not treated in LEAR.

Cost-Effectiveness Calculation

The cost-effectiveness of the various retrofits is calculated by finding the discounted payback time and the savings/investment ratio (SIR). The discounted payback time is the time taken to payback the incremental cost of the efficient retrofit taking into account the opportunity cost of money. Both the cost of money and the economic planning horizon are user inputs. The SIR is a standard Federal Government method for ranking investment alternatives. These calculations are performed according to standard methods [6]. We have simplified the calculation by annualizing non-annual costs (such as lamp replacements and cleaning) over the maintenance time interval. We have not attempted to be exhaustive in the economic model, only illustrative. Other cost-effectiveness yardsticks such as net present value, internal rate of return, cash flow tables or even simple payback, can be added as required.

SAMPLE RESULTS

Figure 5 presents a typical output from LEAR showing a basecase lighting system and four possible retrofits. Figure 6 presents the associated economic worksheet for the same examples. The basecase lighting system for the example given in Figures 5 and 6 is a typical four-lamp lensed troffer using standard CBM ballasts and standard 40W lamps. Four retrofits are shown:

1. Replacing standard ballasts with energy-efficient core-coil ballasts and re-lamping with standard lamps.
2. Replacing standard ballasts with energy-efficient core-coil ballasts and re-lamping with 34-watt TP70 tri-chrome lamps.
3. Replacing standard ballasts with electronic ballasts and re-lamping with 34-watt TP70 tri-chrome lamps.
4. Replacing standard ballasts with electronic ballasts and re-lamping with T-8 lamps.

Although we have chosen reasonable values for the parameters shown in these examples (including the ambient temperature values obtained from an analysis of [3,7]), the specific manufacturer's products mentioned in the examples are meant to be illustrative only and do not constitute a recommendation for any particular system or product.

Examination of Figure 5 permits several features of the program to be discussed. The ballast factors (row C3) for the lamp/ballast systems examined are extracted from the SYSTEM_DATABASE. Rows D2 and D3 are dummy variables. In a later version of LEAR, these values will be plugged into a regression model to estimate the lamp ambient temperature, which is currently a required user input (row E1). The fixture efficiency (row D5) is a required input, but only for the basecase. (Fixture efficiency is easily found on the fixture's standard photometric report. If the user does not know its value, he/she can estimate it using the values given in [reference 5, Fig. 9-62]). LEAR calculates optical efficiency for the basecase using this value for the fixture efficiency and the calculated thermal factor (row E3) for the basecase. Since LEAR handles only category 1 retrofits, the program forces the optical efficiency for all the test cases to be the same as the basecase. But fixture efficiency is seen to vary across the different cases[2]. The values given in row D7 are the input power values that would be obtained if the lamps in the luminaire were in a 25°C environment (which they typically aren't). The thermal factors for input power and light, given in rows E2 and E3, respectively, are the multipliers that account for the fact that the ambient temperature about the lamps in the luminaire is (usually) higher than the 25°C ambient used in the ANSI test condition.

From the retrofit engineer's perspective, rows E6 and E8 are of the most use. E6 gives the input power for the basecase and the test cases with the thermal factor included. (E7 gives the estimated error for this value assuming an uncertainty of ±2°C in the ambient temperature). E8 gives the total lumen output of the luminaire corrected for ballast factor, thermal factor and optical losses in the fixture. Thus the values in E6 and E8 can be used to directly compare the performance of the base case and the test cases on an equal basis. (E9 gives the estimated error for luminaire lumen output assuming an uncertainty of ±2°C in the ambient temperature).

Note that dividing the value in cell E8 by the corresponding value in cell E6 gives the luminaire efficacy rating (LER) for the particular luminaire under analysis. Since LER is the actual lumens out of the fixture divided by the actual watts in, it can be used to rank order different lamp/ballast/fixture systems by their efficacy. Thus LEAR can be used to analytically determine the LER of a fixture with any lamp/ballast combination given only the fixture efficiency for that same fixture with whatever particular combination of lamp and ballast was used in the photometric test.

Finally, the values in row F9 give the minimum luminaire lumen output, i.e., the lumen output that occurs just prior to re-lamping and/or cleaning.

Inspection of Figure 5 illustrates how lighting parameters analyzed by LEAR can affect system performance. For example, if one were to use the lamp lumens from the lamp catalog only, one would think that the Test Case 4 lumens should be lower than that of the basecase. But row E8 shows that Test Case 4 actually produces more lumens than the basecase because of the effect of ballast factor.

Figure 6, the economic analysis output screen, illustrates some of the economic trade-offs between the four sample retrofits. Note, for example, that Test Case 1 saves a small amount of lighting energy but at an added cost that will not payback over the assumed planning horizon. The last

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[2] The variability of fixture efficiency with lamp/ballast system is the major reason that fixture efficiency has been criticized as a metric for comparing different fixtures. However, the optical efficiency of a luminaire, which may be thought of as the fixture efficiency that would be obtained for a non-temperature sensitive (i.e., imaginary) fluorescent lamp, is *invariant* with respect to the lamp/ballast system.

line of the economic analysis worksheet marks the examined retrofits as "feasible" if the discounted payback time is less than the planning horizon or if the calculated savings/investment ratio is greater than one.

DISCUSSION

The spreadsheet described in this paper represents only the first step in the development of a general decision-making tool for specifying lighting retrofits. It was developed as a prototype for the lighting energy analysis portion of a more general tool that would use expert system programming techniques to 1) optimize retrofit selection based on a user-inputted set of performance criteria, 2) assist in auditing the existing lighting system and 3) perform system performance diagnostics and assistance.

The spreadsheet lighting analysis program has no user-interface beyond that supplied by the manufacturer of the spreadsheet program. Nonetheless, LEAR demonstrates the potential to be a powerful tool for analyzing retrofits for some common lighting systems. We believe it has the appropriate degree of rigor with respect to characterization of the most important lighting parameters. It minimizes the technical information required from the user while requiring sufficient input data to estimate system performance to a degree of precision appropriate for analyzing lighting retrofits. To the most reasonable extent, we have used existing IES procedures or ANSI procedures for characterizing and analyzing fluorescent lighting systems and have resisted the temptation to invent new analytical methods.

Besides from the lack of a user interface, the major limitations of the spreadsheet with respect to its general usefulness are:

1. Inability to treat lighting retrofits that change the relative distribution of light from a luminaire.
2. Lighting controls not handled.
3. Inability to select the "best" retrofit using a user-selected set of criteria.
4. Lack of complete data for all product categories, especially ballast factor and thermal data.

In the current version, the spreadsheet covers most Category 1 lighting retrofits but none in Category 2 or 3. Although many simple lighting retrofits are category 1, other types of retrofits, especially integrated packages of measures that may consist of improved lenses, reflectors and controls, in addition to re-ballasting and re-lamping, are not currently treated. Adding the capability to treat static controls (i.e. current limiters and branch circuit dimmers that uniformly reduce light levels) is straightforward and could be incorporated into the existing database structure with little difficulty. However, other retrofits will require extensive additional databases such as a luminaire photometric performance database.

LEAR makes no attempt to cycle through all possible retrofits that meet a user-selected set of criteria and select the "best" ones. In fact, the choice of retrofits to be examined depends entirely upon the user and their understanding of what is available and appropriate for their needs. Although LEAR will show how luminaire lumen output will change as a result of various retrofits, it is up to the user to use this information judiciously in selecting an appropriate retrofit. This is clearly a limitation for the less knowledgeable individual (such as might be found in a small commercial facility that has no in-house plant or facilities engineering personnel).

The thermal model in the first version of LEAR is a stop-gap measure for estimating lamp temperature. A more complete regression model should be developed and verified. The parameters incorporated into the current model include fixture type, geometry, and system input power. A more complete model would take account the air temperature in the room as well as the air temperature in the ceiling plenum. It would also permit the analysis of air-flow lighting systems that draw room air through the lamp compartment to optimize the thermal performance of the luminaires.

In order to perform the lumen depreciation calculation, LEAR requires the user to enter the IES maintenance category of their luminaires. While these categories are useful for engineering estimates, they are not commonly used terms that will be familiar to the typical end-user. In the current version of LEAR, the user will need to determine this category by following the written IES procedure that will be included in the program documentation. In a future version, the user would be able to choose the appropriate luminaire category simply by selecting the appropriate graphic image of the luminaire from a pull-down menu.

The lumen depreciation model used in LEAR needs to be further refined to account for the lamp lumen depreciation properties of the newer, more efficient tri-chrome lamp phosphors. The IES lamp lumen depreciation graphs [Reference 5, pg. 8-29] that LEAR uses in its analysis are for conventional calcium halophosphates only. Several manufacturers have published performance data that indicate that the lumen depreciation rate of the tri-chrome lamps may be about half that of the older phosphors. The addition of a fourth "extra light" curve to IES lamp lumen depreciation graph would be an easy workaround to this problem.

The most significant limitation of the program is the incompleteness of the product data bases. Much of the information that LEAR needs to analyze lighting systems requires data that is not easily available. For example, some ballast manufacturers do not report ballast factors for their products operating standard lamps (i.e., 40W F40 T12) much less other lamp categories (viz. 34W F40 T12, 40W F40 T10, and 32W F32 T8 lamps). Without ballast factor values for the various lamp types, programs such as LEAR cannot perform precise lighting calculations. The solution of a "generic" value for the ballast factor for all electronic ballasts, for example, is, in our view, useless. Ballast factors can vary so widely, especially with electronic ballasts, that it makes as much sense to ignore ballast factor altogether as simply use one value.

Although data have been published on the effects of temperature on the light output and energy performance of standard core-coil-ballasted fluorescent lighting, thermal data is scarce for many electronically-ballasted systems. In contrast to core-coil ballasts, manufacturers of electronic ballasts can design the ballast circuitry to partly compensate for variances in light output caused by the fixture thermal environment. Thus a "generic" characterization of the thermal performance of electronically-ballasted systems would fail to describe the potential benefits of improved ballast designs. Testing of several dozen combinations of lamp/ballast systems have been performed [3,4], but many systems currently on the market need to be tested and new products are appearing all the time.

Because ballast factor and thermal factor data are so critical to precise calculation, the lack of this information for many systems means that LEAR can only be considered demonstrative. Lacking a comprehensive data base, the program cannot be considered a complete general retrofit design program. However, we believe that the methodology used by LEAR is appropriate to the task for which it was designed. Furthermore, we hope that the existence of programs such as LEAR will spur lighting manufacturers and their representative trade associations into providing the ballast factor and thermal factor data so urgently needed by the lighting community.

With respect to performance data in general, there is clearly a need for a central repository of lighting equipment performance data. It is the authors' hope that the appropriate industry organization would agree to serve as the compiler and custodian of this data. This repository should be of the form of an easy-to-update electronic data base. The electronic format would help manufacturers to update the product performance database as new products emerge and would provide a central location for end-users to periodically download the most up-to-date lighting equipment performance data. As a source for certified performance data, this database would encourage the use of more efficient technologies by removing some of the uncertainties that end-users have with regards to the energy-savings claims and performance of efficient lighting technologies.

SUMMARY

A spreadsheet program for determining system efficacy, power input and light output of common 4 ft fluorescent lighting systems under realistic operating conditions has been described. The program uses accepted IES engineering principles to precisely account for ballast factor, existing thermal conditions and maintenance practices. The spreadsheet, which includes a data base of lamp and ballast performance data, can be used to calculate the cost-effectiveness of many common lighting retrofits.

REFERENCES

[1] Lewin, I. and J. McFarlane, "Performance Characteristics of Fluorescent Lamp and Ballast Combinations," *Journal of the Illuminating Engineering Society*, Vol. 13, No. 1, October 1983.

[2] Levin, R., "The Photometric Connection," *Lighting Design and Application*, Sept., Oct., Nov., and Dec. 1982, Vol. 12, Nos. 9-12.

[3] Bleeker, N., and W. Veenstra, "The Performance of Four Foot Fluorescent Lamps as a Function of Ambient Temperature on 60Hz and High Frequency Ballasts," *Proceedings of the 1990 Annual IES Conference*, Baltimore, August 1990.

[4] Siminovitch, M., F. Rubinstein and R. Verderber, "Determining Lamp/Ballast System Performance with a Temperature-Controlled Integrating Chamber," *Journal of the Illuminating Engineering Society*, Vol. 14, No. 1, pp. 364-378, October 1984.

[5] Kaufman, J., IES Lighting Handbook, Reference Volume, Illuminating Engineering Society of North America, New York, NY, 1984.

[6] Brown, R. and R. Yanuck, "Life Cycle Costing: A Practical Guide for Energy Managers," Fairmont Press, Inc., Atlanta, GA, 1980.

[7] General Lighting Cost Analysis, GE Lighting, 1990.

[8] American National Standard, ANSI C82.2-1977, "Methods of Measurement of Fluorescent Lamp Ballasts."

[9] California Energy Commission, Advanced Lighting Technologies Application Guidelines, "Energy-Efficient and Electronic Ballasts," March 1990.

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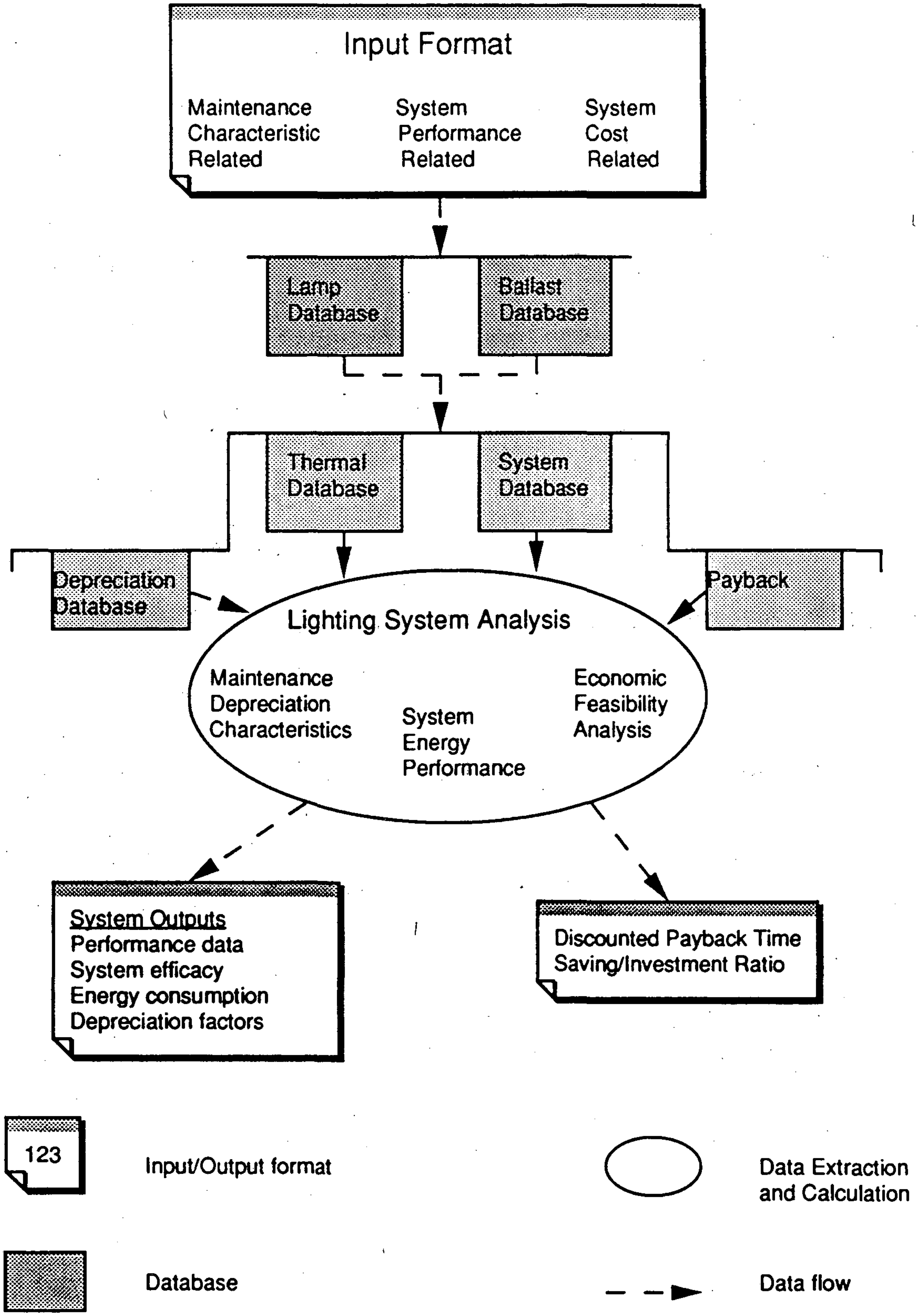

Figure 1. Structure of spreadsheet and information flow

Figure 2. Excerpt from LAMP DATABASE

Source	Manufacture	Trade name	Circuits Type	Manu. Designation	Standard code	Input wattage	Diameter	Length	Base	Rated lumens	Color Temp.	CRI	Gas Filled	Phosphor	Life time	loading cat.	Description
Fluorescent	Philips	Ultralume Preheat	Rapid Start	F40/30U	F40WT12	40	12/8	4	Md. Bipin	3300	3000	85	Argon	Thick-phosphor	20000	light	Ultralume Trichromatic
Fluorescent	Philips	Ultralume Preheat	Rapid Start	F40/35U	F40WT12	40	12/8	4	Md. Bipin	3300	3500	85	Argon	Thick-phosphor	20000	light	Ultralume Trichromatic
Fluorescent	Philips	Ultralume Preheat	Rapid Start	F40/41U	F40WT12	40	12/8	4	Md. Bipin	3300	4100	85	Argon	Thick-phosphor	20000	light	Ultralume Trichromatic
Fluorescent	Philips	Ultralume Preheat	Rapid Start	F40/50U	F40WT12	40	12/8	4	Md. Bipin	3300	5000	85	Argon	Thick-phosphor	20000	light	Ultralume Trichromatic
Fluorescent	Philips	Econ-o-watt	Rapid Start	F40LW/RS/EW-II	F34WT12	34	12/8	4	Md. Bipin	2925	4100	51	Argon Krypton	Halophosphate	20000	light	Lite-white
Fluorescent	Philips	Econ-o-watt	Rapid Start	F40CW/RS/EW-II	F34WT12	34	12/8	4	Md. Bipin	2775	4100	62	Argon Krypton	Halophosphate	20000	light	Cool-white
Fluorescent	Philips	Econ-o-watt	Rapid Start	F40CWX/RS/EW-II	F34WT12	34	12/8	4	Md. Bipin	1925	4200	89	Argon Krypton	Halophosphate	20000	light	Cool-white deluxe
Fluorescent	Philips	Econ-o-watt	Rapid Start	F40D/RS/EW-II	F34WT12	34	12/8	4	Md. Bipin	2350	6500	79	Argon Krypton	Halophosphate	20000	light	Daylight
Fluorescent	Philips	Econ-o-watt	Rapid Start	F40SPEC30/RS/EW-II	F34WT12	34	12/8	4	Md. Bipin	2925	3000	70	Argon Krypton	Thin-phosphor	20000	light	SPEC Trichromatic
Fluorescent	Philips	Econ-o-watt	Rapid Start	F40SPEC35/RS/EW-II	F34WT12	34	12/8	4	Md. Bipin	2925	3500	73	Argon Krypton	Thin-phosphor	20000	light	SPEC Trichromatic
Fluorescent	Philips	Econ-o-watt	Rapid Start	F40SPEC41/RS/EW-II	F34WT12	34	12/8	4	Md. Bipin	2925	4100	70	Argon Krypton	Thin-phosphor	20000	light	SPEC Trichromatic
Fluorescent	Philips	Econ-o-watt	Rapid Start	F40W/RS/EW-II	F34WT12	34	12/8	4	Md. Bipin	2825	3500	58	Argon Krypton	Halophosphate	20000	light	White
Fluorescent	Philips	Econ-o-watt	Rapid Start	F40WW/RS/EW-II	F34WT12	34	12/8	4	Md. Bipin	2825	3000	53	Argon Krypton	Halophosphate	20000	light	Warm white
Fluorescent	Philips	Econ-o-watt	Rapid Start	F40WW/RS/EW-II/EM	F34WT12	34	12/8	4	Md. Bipin	2825	3000	53	Argon Krypton	Halophosphate	20000	light	Warm white
Fluorescent	Philips	Econ-o-watt	Rapid Start	F40WWX/RS/EW-II	F34WT12	34	12/8	4	Md. Bipin	1925	3000	79	Argon Krypton	Halophosphate	20000	light	WW Deluxe
Fluorescent	Philips	Ultralume Econ-o-watt	Rapid Start	F40/30U/RS/EW-II	F34WT12	34	12/8	4	Md. Bipin	2925	3000	85	Argon Krypton	Thick-phosphor	20000	light	Ultralume Trichromatic
Fluorescent	Philips	Ultralume Econ-o-watt	Rapid Start	F40/35U/RS/EW-II	F34WT12	34	12/8	4	Md. Bipin	2925	3500	85	Argon Krypton	Thick-phosphor	20000	light	Ultralume Trichromatic
Fluorescent	Philips	Ultralume Econ-o-watt	Rapid Start	F40/41U/RS/EW-II	F34WT12	34	12/8	4	Md. Bipin	2925	4100	85	Argon Krypton	Thick-phosphor	20000	light	Ultralume Trichromatic
Fluorescent	Philips	Ultralume Econ-o-watt	Rapid Start	F40/50U/RS/EW-II	F34WT12	34	12/8	4	Md. Bipin	2925	5000	85	Argon Krypton	Thick-phosphor	20000	light	Ultralume Trichromatic
																light	
Fluorescent	Philips	Econ-o-watt Preheat	Rapid Start	F40CW/EW-PH	F34WT12	34	12/8	4	Md. Bipin	2850	4100	62	Argon Krypton	Halophosphate	20000	light	Cool white
Fluorescent	Philips	Econ-o-watt Preheat	Rapid Start	F40WW/EW-PH	F34WT12	34	12/8	4	Md. Bipin	2900	3000	53	Argon Krypton	Halophosphate	20000	light	Warm white
Fluorescent	Philips	Advantage X Preheat	Rapid Start	F40AX30	F40WT10	41	10/8	4	Md. Bipin	3700	3000	80	Argon	Trichromatic	24000	light	Advantage
Fluorescent	Philips	Advantage X Preheat	Rapid Start	F40AX35	F40WT10	41	10/8	4	Md. Bipin	3700	3500	80	Argon	Trichromatic	24000	light	Advantage
Fluorescent	Philips	Advantage X Preheat	Rapid Start	F40AX41	F40WT10	41	10/8	4	Md. Bipin	3700	4100	80	Argon	Trichromatic	24000	light	Advantage
Fluorescent	Philips	Preheat Extended	Rapid Start	F40T10/CW/99	F40WT10	41	10/8	4	Md. Bipin	3200	4100	62	Argon	Halophosphate	24000	light	Cool white
Fluorescent	Philips	Preheat Extended	Rapid Start	F40T10/CWX/99	F40WT10	41	10/8	4	Md. Bipin	2270	4200	89	Argon	Halophosphate	24000	light	CW Deluxe
Fluorescent	Philips	Preheat Extended	Rapid Start	F40T10/D/99	F40WT10	41	10/8	4	Md. Bipin	2700	6500	79	Argon	Halophosphate	24000	light	Daylight
Fluorescent	Philips	Preheat Extended	Rapid Start	F40T10/LW-SB/99	F40WT10	41	10/8	4	Md. Bipin	3400	4100	61	Argon	Halophosphate	24000	light	Lite-white, Super-bright
Fluorescent	Philips	Preheat Extended	Rapid Start	F40T10/W/99	F40WT10	41	10/8	4	Md. Bipin	3250	3500	58	Argon	Halophosphate	24000	light	White
Fluorescent	Philips	Preheat Extended	Rapid Start	F40T10/WW/99	F40WT10	41	10/8	4	Md. Bipin	3250	3000	53	Argon	Halophosphate	24000	light	Warm white
Fluorescent	Philips	Octolume	Rapid Start	F032/41	F32WT8	32	8/8	4	Md. Bipin	2900	4100	85	Argon	Thick-phosopha	20000	light	Octolume Trichromatic
Fluorescent	Philips	Octolume	Rapid Start	F032/30	F32WT8	32	8/8	4	Md. Bipin	2900	3000	85	Argon	Thick-phosopha	20000	light	Octolume Trichromatic
Fluorescent	Philips	Octolume	Rapid Start	F032/35	F32WT8	32	8/8	4	Md. Bipin	2900	3500	85	Argon	Thick-phosopha	20000	light	Octolume Trichromatic
Fluorescent	Philips	Octolume	Rapid Start	F040/30	F40WT8	40	8/8	4	Md. Bipin	3650	3000	85	Argon	Thick-phosopha	20000	light	Octolume Trichromatic
Fluorescent	Philips	Octolume	Rapid Start	F040/41	F40WT8	40	8/8	4	Md. Bipin	3650	4100	85	Argon	Thick-phosopha	20000	light	Octolume Trichromatic
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40/D830	F40WT12	40	12/8	4	Md. Bipin	3300	3000	80	Argon	Thick-phosopha	20000	light	Designer 800 3000K
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40/D835	F40WT12	40	12/8	4	Md. Bipin	3350	3500	80	Argon	Thick-phosopha	20000	light	Designer 800 3500K
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40/D841	F40WT12	40	12/8	4	Md. Bipin	3350	4100	80	Argon	Thick-phosopha	20000	light	Designer 800 4100K
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40/D30	F40WT12	40	12/8	4	Md. Bipin	3300	3000	69	Argon	Thin-phosophor	20000	light	Designer 3000K
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40/D35	F40WT12	40	12/8	4	Md. Bipin	3250	3500	69	Argon	Thin-phosophor	20000	light	Designer 3500K
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40/D41	F40WT12	40	12/8	4	Md. Bipin	3300	4100	69	Argon	Thin-phosophor	20000	light	Designer 4000K LWX
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40/CG	F40WT12	40	12/8	4	Md. Bipin	2750			Argon	Halophosphate	20000	light	Cool green
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40/B	F40WT12	40	12/8	4	Md. Bipin	1800			Argon	Halophosphate	20000	light	Blue
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40/CW	F40WT12	40	12/8	4	Md. Bipin	3150	4200	62	Argon	Halophosphate	20000	light	Cool white
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40/CWX	F40WT12	40	12/8	4	Md. Bipin	2100	4100	89	Argon	Halophosphate	20000	light	Cool white deluxe
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40D	F40WT12	40	12/8	4	Md. Bipin	2700	6300	76	Argon	Halophosphate	20000	light	Daylight
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40DSGN50	F40WT12	40	12/8	4	Md. Bipin	2200	5000	90	Argon	Thin-phosophor	20000	light	Designe 50
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40G	F40WT12	40	12/8	4	Md. Bipin	4100			Argon	Halophosphate	20000	light	Green
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40GRO	F40WT12	40	12/8	4	Md. Bipin				Argon	Halophosphate	20000	light	Gro-lux
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40GRO/WS	F40WT12	40	12/8	4	Md. Bipin				Argon	Halophosphate	20000	light	Gro-lux Wide spect
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40IF	F40WT12	40	12/8	4	Md. Bipin	1560	2750	89	Argon	Halophosphate	20000	light	Incandescent/Flourescent
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40N	F40WT12	40	12/8	4	Md. Bipin	2120	3600	86	Argon	Halophosphate	20000	light	Natural white
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40PK	F40WT12	40	12/8	4	Md. Bipin	1270			Argon	Halophosphate	20000	light	Pink
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40W	F40WT12	40	12/8	4	Md. Bipin	3200	3450	57	Argon	Halophosphate	20000	light	White
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40WW	F40WT12	40	12/8	4	Md. Bipin	3200	3000	52	Argon	Halophosphate	20000	light	Warm white
Fluorescent	Sylvania	Rapid Start	Rapid Start	F40WWX	F40WT12	40	12/8	4	Md. Bipin	2200	2950	74	Argon	Halophosphate	20000	light	Warm white deluxe
Fluorescent	Sylvania	Rapid Start	Rapid Start	FR40CW/235	F40WT12	40	12/8	4	Md. Bipin				Argon	Halophosphate	20000	light	Cool white,235Deg. Ref
Fluorescent	Sylvania	Supersaver	Rapid Start	F40/D830/SS	F34WT12	34	12/8	4	Md. Bipin	2925	3000	80	Argon Krypton	Thick-phosopha	20000	light	Designer 800 3000K
Fluorescent	Sylvania	Supersaver	Rapid Start	F40/D835/SS	F34WT12	34	12/8	4	Md. Bipin	3000	3500	80	Argon Krypton	Thick-phosopha	20000	light	Designer 800 3500K
Fluorescent	Sylvania	Supersaver	Rapid Start	F40/D841/SS	F34WT12	34	12/8	4	Md. Bipin	3000	4100	69	Argon Krypton	Thick-phosopha	20000	light	Designer 800 4100K
Fluorescent	Sylvania	Supersaver	Rapid Start	F40/D30/SS	F34WT12	34	12/8	4	Md. Bipin	2925	3000	69	Argon Krypton	Thin-phosophor	20000	light	Designer 3000K
Fluorescent	Sylvania	Supersaver	Rapid Start	F40/D35/SS	F34WT12	34	12/8	4	Md. Bipin	2925	3500	69	Argon Krypton	Thin-phosophor	20000	light	Designer 3500K
Fluorescent	Sylvania	Supersaver	Rapid Start	F40/D41/SS	F34WT12	34	12/8	4	Md. Bipin	2925	4100	69	Argon Krypton	Thin-phosophor	20000	light	Designer 4100K
Fluorescent	Sylvania	Supersaver	Rapid Start	F40D/SS	F34WT12	34	12/8	4	Md. Bipin	2350	6300	76	Argon Krypton	Halophosphate	20000	light	Daylight
Fluorescent	Sylvania	Supersaver	Rapid Start	F40CW/SS	F34WT12	34	12/8	4	Md. Bipin	2750	4200	62	Argon Krypton	Halophosphate	20000	light	Cool white
Fluorescent	Sylvania	Supersaver	Rapid Start	F40CWX/SS	F34WT12	34	12/8	4	Md. Bipin	1925	4100	89	Argon Krypton	Halophosphate	20000	light	Cool white deluxe
Fluorescent	Sylvania	Supersaver	Rapid Start	F40LW/SS	F34WT12	34	12/8	4	Md. Bipin	2925	4150	48	Argon Krypton	Halophosphate	20000	light	Lite white
Fluorescent	Sylvania	Supersaver	Rapid Start	F40W/SS	F34WT12	34	12/8	4	Md. Bipin	2800	3450	57	Argon Krypton	Halophosphate	20000	light	White
Fluorescent	Sylvania	Supersaver	Rapid Start	F40WW/SS	F34WT12	34	12/8	4	Md. Bipin	2800	3000	52	Argon Krypton	Halophosphate	20000	light	Warm white
Fluorescent	Sylvania	Supersaver	Rapid Start	F40WWX/SS	F34WT12	34	12/8	4	Md. Bipin	1925	2950	74	Argon Krypton	Halophosphate	20000	light	Warm white deluxe
Fluorescent	Sylvania	Octron	Rapid Start	F032/31K	F32WT8	32	12/8	4	Md. Bipin	2900	3100	75	Argon	Thick-phosopha	20000	light	Octron 3000K
Fluorescent	Sylvania	Octron	Rapid Start	F032/35K	F32WT8	32	12/8	4	Md. Bipin	2900	3500	75	Argon	Thick-phosopha	20000	light	Octron 4100K
Fluorescent	Sylvania	Octron	Rapid Start	F032/41K	F32WT8	32	12/8	4	Md. Bipin	2900	4100	75	Argon	Thick-phosopha	20000	light	Octron 3000K
Fluorescent	General Electri	Rapid Start	Rapid Start	F40D	F40WT12	40	12/8	4	Md. Bipin	2550	6250	75	Argon	Halophosphate	20000	light	Daylight
Fluorescent	General Electri	Rapid Start	Rapid Start	F40CWX	F40WT12	40	12/8	4	Md. Bipin	2250	4175	89	Argon	Halophosphate	20000	light	Cool white deluxe
Fluorescent	General Electri	Rapid Start	Rapid Start	F40WWX	F40WT12	40	12/8	4	Md. Bipin	2200	3025	77	Argon	Halophosphate	20000	light	Warm white deluxe

Lamp	Ballast		System					
Standard Code	Manufacture	Trade Name	Catalog No.	Voltage	No. Lamps	Input Power	BEF	BF
F40WT12	Advance	Standard	RQM2S40-TP	120	2	96	0.995	0.95
F40WT12	Advance	Standard	VQM2S40-TP	277	2	96	0.995	0.95
F40WT12	Advance	Mark III	R-140-TP	120	1	50	1.7	0.85
F40WT12	Advance	Mark III	R-2S40-TP	120	2	86	1.09	0.94
F40WT12	Advance	Mark III	V-140-TP	277	1	50	1.7	0.85
F40WT12	Advance	Mark III	V-2S40-TP	277	2	86	1.09	0.94
F40WT12	Advance	Mark V	RIC-140-TP	120	1	36	2.36	0.85
F40WT12	Advance	Mark V	RIC-2S40-TP	120	2	71	1.24	0.88
F40WT12	Advance	Mark V	VIC-140-TP	277	1	36	2.35	0.85
F40WT12	Advance	Mark V	VIC-2S40-TP	277	2	72	1.23	0.89
F40WT12	Advance	Mark VII	RDC-140-TP	120	1	36	2.36	0.85
F40WT12	Advance	Mark VII	RDC-2S40-TP	120	2	71	1.21	0.86
F40WT12	Advance	Mark VII	RDC-3S40-TP	120	3	106	0.77	0.82
F40WT12	Advance	Mark VII	VDC-140-TP	277	1	36	2.35	0.85
F40WT12	Advance	Mark VII	VDC-2S40-TP	277	2	72	1.23	0.89
F40WT12	Advance	Mark VII	VDC-3S40-TP	277	3	104	0.79	0.82
F40WT12	Advance	Discrete	REL-1S40-TP	120	1	36	2.36	0.85
F40WT12	Advance	Discrete	REL-2S40-TP	120	2	71	1.21	0.86
F40WT12	Advance	Discrete	REL-3S40-TP	120	3	109	0.75	0.82
F40WT12	Advance	Discrete	VEL-1S40-TP	277	1	36	2.35	0.85
F40WT12	Advance	Discrete	VEL-2S40-TP	277	2	71	1.23	0.89
F40WT12	Advance	Discrete	VEL-3S40-TP	277	3	109	0.75	0.82
F34WT12	Advance	Mark III	R-140-TP	120	1	43	2.02	0.87
F34WT12	Advance	Mark III	R-2S40-TP	120	2	72	1.22	0.88
F34WT12	Advance	Mark III	R-3S34-TP	120	3	100	0.88	0.88
F34WT12	Advance	Mark III	V-140-TP	277	1	43	1.95	0.84
F34WT12	Advance	Mark III	V-2S40-TP	277	2	72	1.22	0.88
F34WT12	Advance	Mark III	V-3S34-TP	277	3	100	0.88	0.88
F34WT12	Advance	Mark V	RIC-140-TP	120	1	31	2.8	0.87
F34WT12	Advance	Mark V	RIC-2S40-TP	120	2	59	1.44	0.85
F34WT12	Advance	Mark V	VIC-140-TP	277	1	31	2.71	0.84
F34WT12	Advance	Mark V	VIC-2S40-TP	277	2	60	1.44	0.86
F34WT12	Advance	Mark VII	RDC-140-TP	120	1	31	2.8	0.87
F34WT12	Advance	Mark VII	RDC-2S40-TP	120	2	60	1.43	0.86
F34WT12	Advance	Mark VII	RDC-3S40-TP	120	3	95	0.93	0.88
F34WT12	Advance	Mark VII	VDC-140-TP	277	1	31	2.71	0.84
F34WT12	Advance	Mark VII	VDC-2S40-TP	277	2	60	1.44	0.86
F34WT12	Advance	Mark VII	VDC-3S40-TP	277	3	93	0.95	0.88
F34WT12	Advance	Discrete	REL-1S40-TP	120	1	32	2.72	0.87
F34WT12	Advance	Discrete	REL-2S40-TP	120	2	59	1.46	0.86
F34WT12	Advance	Discrete	REL-3S40-TP	120	3	93	0.95	0.88
F34WT12	Advance	Discrete	VEL-1S40-TP	277	1	31	2.71	0.84
F34WT12	Advance	Discrete	VEL-2S40-TP	277	2	59	1.46	0.86
F34WT12	Advance	Discrete	VEL-3S40-TP	277	3	93	0.95	0.88
F40WT10	Advance	Mark III	R-140-TP	120	1	50	1.62	0.81
F40WT10	Advance	Mark III	R-2S40-TP	120	2	86	1.09	0.94
F40WT10	Advance	Mark III	V-140-TP	277	1	50	1.62	0.81
F40WT10	Advance	Mark III	V-2S40-TP	277	2	86	1.09	0.94
F40WT10	Advance	Mark V	RIC-140-TP	120	1	36	2.26	0.81
F40WT10	Advance	Mark V	RIC-2S40-TP	120	2	71	1.24	0.88
F40WT10	Advance	Mark V	VIC-140-TP	277	1	36	2.26	0.81
F40WT10	Advance	Mark V	VIC-2S40-TP	277	2	73	1.19	0.87

Figure 3. Excerpt from DATABASE

Lamp	Ballast		Relative Light Output(T)=A*T^3+B*T^2+C*T+D				Relative Power Input(T)=A'*T^3+B'*T^2+C'*T+D'			
Standard Code	Manufacture	Trade Name	A	B	C	D	A'	B'	C'	D'
F40WT12	Advance	Standard	9.0606E-06	-1.2454E-03	4.5034E-02	5.1032E-01	1.2004E-06	-2.1064E-04	4.6619E-03	9.9500E-01
F40WT12	Advance	Mark V	1.1427E-05	-1.5624E-03	6.2290E-02	2.4137E-01	2.2311E-06	-4.3718E-04	1.7870E-02	7.8951E-01
F40WT12	Advance	Mark III	1.0999E-05	-1.3739E-03	4.7118E-02	5.1106E-01	2.9671E-06	-3.5381E-04	8.1031E-03	9.7166E-01
F40WT12	Advance	Mark VII	1.1427E-05	-1.5624E-03	6.2290E-02	2.4137E-01	2.2311E-06	-4.3718E-04	1.7870E-02	7.8951E-01
F40WT12	Advance	Discrete								
F34WT12	Advance	Mark V	1.7046E-05	-2.4096E-03	1.0253E-01	-3.2475E-01	9.3055E-06	-1.2547E-03	5.0640E-02	3.7336E-01
F34WT12	Advance	Mark VII	1.7046E-05	-2.4096E-03	1.0253E-01	-3.2475E-01	9.3055E-06	-1.2547E-03	5.0640E-02	3.7336E-01
F34WT12	Advance	Mark III	2.9810E-05	-3.7736E-03	1.4749E-01	-8.0623E-01	1.1082E-05	-1.3771E-03	5.2055E-02	3.8262E-01
F34WT12	Advance	Discrete								
F40WT10	Advance	Mark V	8.0130E-06	-1.2551E-03	5.4670E-02	2.9079E-01	3.4636E-06	-5.3444E-04	2.0999E-02	7.5490E-01
F40WT10	Advance	Mark VII	8.0130E-06	-1.2551E-03	5.4670E-02	2.9079E-01	3.4636E-06	-5.3444E-04	2.0999E-02	7.5490E-01
F40WT10	Advance	Mark III	1.1442E-05	-1.4099E-03	4.7556E-02	5.1187E-01	1.9650E-06	-2.8531E-04	6.8321E-03	9.7679E-01
F40WT10	Advance	Discrete								
F32WT8	Advance	Mark V	1.3589E-05	-1.9560E-03	8.1404E-02	-2.4853E-02	8.8409E-06	-1.1490E-03	4.0991E-02	5.5410E-01
F32WT8	Advance	Mark VII	1.3589E-05	-1.9560E-03	8.1404E-02	-2.4853E-02	8.8409E-06	-1.1490E-03	4.0991E-02	5.5410E-01
F32WT8	Advance	Standard	9.7669E-06	-1.3283E-03	4.9967E-02	4.2749E-01	2.3079E-06	-3.2898E-04	9.9290E-03	9.2088E-01

Figure 4. Excerpt from THERMAL DATABASE

LIGHTING ENERGY ANALYSIS SPREADSHEET -- LEAR V0.9

	Row	Description	Base Case	Test Case 1	Test Case 2	Test Case 3	Test Case 4
BALLAST	**B1**	* **Ballast Manufacturer**	**Advance**	**Advance**	**Advance**	**Advance**	**Advance**
	B2	* **Trade name**	**Standard**	**Mark III**	**Mark III**	**Mark V**	**Mark V**
	B3	Ballast Type	Stan. Magn.	EE Magnetic	EE Magnetic	Electronic IC	Electronic IC
	B4	Circuits Type	Rapid Start	Rapid Start	Rapid Start	Rapid Start	Rapid Start
	B5	Catalog No.	RQM2S40-TP	R-2S40-TP	R-2S40-TP	RIC-2S40-TP	RIC-2S40-TP
	B6	Sound rating	A	A	A	A	A
	B7	Dimming range (from 100%)	1.00	1.00	1.00	1.00	1.00
LAMP	**C1**	* **Lamp manufacturer**	**Philips**	**Philips**	**Philips**	**Philips**	**Sylvania**
	C2	Trade name	Preheat	Preheat	Econ-o-watt	Econ-o-watt	Octron
	C3	* **Manufacturer designation code**	**F40CW**	**F40CW**	**F40SPEC35/I**	**F40SPEC35/I**	**F032/35K**
	C4	Lamp Descriptive Code (Standard Code)	F40WT12	F40WT12	F34WT12	F34WT12	F32WT8
	C5	Circuits Type	Rapid Start	Rapid Start	Rapid Start	Rapid Start	Rapid Start
	C6	Lamp wattage	40.00	40.00	34.00	34.00	32.00
	C7	Initial rated lumens	3150.00	3150.00	2925.00	2925.00	2900.00
	C8	Color rendition index	62.00	62.00	73.00	73.00	75.00
	C9	Gas fill	Argon	Argon	Argon Kryptor	Argon Kryptor	Argon
	C10	Phosophor	Halophosphate	Halophosphate	Thin-phospho	Thin-phospho	Thick-phosopt
	C11	* **Group relamp interval [years]**	2.00	2.00	2.00	2.00	2.00
	C12	Lamp life [hrs]	20000.00	20000.00	20000.00	20000.00	20000.00
LUMINAIRE	**D1**	* **Number of ballasts per Luminaire**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**
	D2	* **Number of lamps per ballast**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**
	D3	* **Luminaire operating voltage**	**120.00**	**120.00**	**120.00**	**120.00**	**120.00**
	D4	Luminaire operating wattage at 25°C	192.00	172.00	144.00	118.00	150.00
	D5	CU					
	D6	Ballast factor	0.95	0.94	0.88	0.85	1.07
	D7	Rated luminaire lumen output	11970.00	11844.00	10296.00	9945.00	12412.00
	D8	Min. luminaire depreciation factor	0.73	0.73	0.73	0.73	0.73
	D9	Minimum rated lumen output	8788.24	8695.73	7559.21	7301.51	9112.75
	D10	* **Cleaning interval [YEARS]**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**
	D11	* **Total operation hours/year**	**3000.00**	**3000.00**	**3000.00**	**3000.00**	**3000.00**
	D12	Lamp load cat. (light,medium,heavy)	light	light	light	light	light
	D13	* **IES maint. cat. (I,II,III,IV,V,VI)**	**III**	**III**	**III**	**III**	**III**
	D14	* **Atmos. conditions (C,D,M,VC,VD)**	**C**	**C**	**C**	**C**	**C**
	D15	* **Month of analysis (1-60)**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**
	D16	Depreciation Factor at month of analysis	0.77	0.77	0.77	0.77	0.77
	D17	Actual lumen output at month of analysis	8253.45	8619.24	8038.08	7977.25	8306.97
	D18	* **Est. operating ambient temp. C**	**40.00**	**35.00**	**34.00**	**34.00**	**48.50**
	D19	Relative System Lumen Output (w/r to 25	0.90	0.95	1.02	1.05	0.87
	D20	System Power Input [watts]	176.89	163.24	143.44	119.23	127.21
	D21	System Efficacy [lumens/watt]	60.83	68.84	73.06	87.23	85.14
	D22	Actual System Efficacy w/ Dep. Factor	46.66	52.80	56.04	66.91	65.30
ENERGY	F1	Energy use [kWh/yr/fixture]	530.66	489.72	430.33	357.69	381.62
	F2	* **Cost of electricity [$/kWh]**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**
	F3	Electricity cost [$/yr/fixture]	53.07	48.97	43.03	35.77	38.16

Figure 5. Sample output of LEAR analysis of four lighting retrofits. Lines with * are user inputs.

ECONOMIC ANALYSIS SPREADSHEET -- LEAR V0.9

		Description	Base Case	Test Case 1	Test Case 2	Test Case 3	Test Case 4
System		Ballast manufacturer	Advance	Advance	Advance	Advance	Advance
		Ballast trade name	Standard	Mark III	Mark III	Mark V	Mark V
		Lamp manufacturer	Philips	Philips	Philips	Philips	Sylvania
		Lamp manufacturer designation code	F40CW	F40CW	F40SPEC35/F	F40SPEC35/F	F032/35K
		Number of ballasts per fixture	2	2	2	2	2
		Number of lamps per ballast	2	2	2	2	2
Initial Cost	*	**Purchase price per ballast (with discount)**	**$5.00**	**$8.00**	**$8.00**	**$12.00**	**$12.00**
	*	**Purchase price per lamp (with discount)**	**$1.00**	**$1.00**	**$2.00**	**$2.00**	**$2.00**
		Total purchase cost [$/fixture]	$14.00	$20.00	$24.00	$32.00	$32.00
	*	**Installation cost per ballast**	**$10.00**	**$10.00**	**$10.00**	**$10.00**	**$10.00**
	*	**Installation cost per lamp**	**$1.00**	**$1.00**	**$1.00**	**$1.00**	**$1.00**
		Total installation cost [$/fixture]	$24.00	$24.00	$24.00	$24.00	$24.00
		Total cost per fixture (purchase & installatio	$38.00	$44.00	$48.00	$56.00	$56.00
		Add. purchase/installation cost w/r to BaseC	N/A	$6.00	$10.00	$18.00	$18.00
Maintence &Relamp	*	**Est. ballast failures [%/yr]**	**1.00%**	**1.00%**	**1.00%**	**1.00%**	**1.00%**
	*	**Est. lamp failures [%/yr]**	**2.00%**	**2.00%**	**2.00%**	**2.00%**	**2.00%**
		Spot replace cost [$/ballast]	$25.00	$28.00	$28.00	$32.00	$32.00
	*	**Spot relamp cost [$/lamp]**	**$6.00**	**$6.00**	**$7.00**	**$7.00**	**$7.00**
		Spot relamp cost [$/fixture]	$0.98	$1.04	$1.12	$1.20	$1.20
	*	**Group relamp cost [$/lamp]**	**$2.00**	**$2.00**	**$3.00**	**$3.00**	**$3.00**
		Group relamp interval [years]	2	2	2	2	2
	*	**Group cleaning cost [$/lamp]**	**$0.50**	**$0.50**	**$0.50**	**$0.50**	**$0.50**
		Group cleaning interval [years]	2	2	2	2	2
		Annual group relamp & clean cost[$/fixture]	$5.00	$5.00	$7.00	$7.00	$7.00
		Total maintence and relamp cost [$/fixture]	$5.98	$6.04	$8.12	$8.20	$8.20
		Add. cost for relamp&maint. w/r to BaseCase	N/A	$0.06	$2.14	$2.22	$2.22
Energy		Electricity consumed per year [KWH/fixture]	530.66	489.72	430.33	357.69	381.62
		Electricity saved per year [KWH/fixture]	N/A	40.94	100.33	172.96	149.04
		Cost of electricity [$/KWH]	$0.10	$0.10	$0.10	$0.10	$0.10
		Annual saving of electricity [$/fixture]	N/A	$4.09	$10.03	$17.30	$14.90
DPT & SIR		*Annual net saving [$/fixture]* {Energy saving - maintence&cleaning cost}	N/A	$4.03	$7.89	$15.08	$12.68
	*	**Interest rate (%)**	**8.00%**				
	*	**Planning horizon (1- 15 years)**	**5**	**year(s)**			
		Discounted Payback Time	N/A	1.65	1.39	1.30	1.57
		Saving/Investment Ratio	N/A	2.68	3.15	3.34	2.81
The new system is economically			**N/A**	**Feasible**	**Feasible**	**Feasible**	**Feasible**

Figure 6. Sample output of LEAR economic analysis for same examples as Fig. 5. Lines with * are user inputs.

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