APPENDIX A. ENGINEERING ANALYSIS SUPPORTING DOCUMENTATION

A.1 ENGINEERING CALCULATIONS SUMMARY

The ballast trial standard levels set minimum Ballast Efficacy Factor (BEF) values. BEF is a measure of ballast system performance or efficacy. This factor is defined as:

BEF = Percent Ballast Factor/Input Power

The BEF is defined as the ballast factor in percent divided by the ballast input power in Watts. The ballast factor (BF) for a specific ballast is the ratio of the light output of a lamp tested on the specific ballast to the light output of the same lamp tested on a "reference" ballast under identical environmental conditions. The data set reproduced in Section A.3 below was used to determine BEF and wattage values for each lamp/ballast combination.

The method used to select technology option values for BEF, BF, and ANSI Watts[1] from the data was different for different technology options as described below.

Baseline (energy-efficient magnetic) and cathode cutout. The BEF value used for the baseline option was the average value of the BEF computed from the data set. BF values for this technology option were chosen to be typical of current models (1), (2). Once the values for BEF and BF were selected, the power was computed from these values with the formula: Watts = BF/BEF. It was assumed that this calculated power is equivalent to the ANSI Watts of a ballast that has both its BEF and BF values equal to the selected BEF and BF. A ballast with this exact combination of BEF, BF and ANSI Watts may not presently exist in the market. The linear relationship observed between measured values of BF and input Watts supports the assumption that a ballast with the calculated values of BF, Watts, and BEF could be manufactured.

Electronic rapid start and electronic instant start. For these technology options, "representative" ballasts were first chosen from the data set. The ballast whose BEF is closest to the median but on the high side of 50% was usually selected from the data, since no real ballast had a BEF that exactly placed it at the median. The one exception was for 4-lamp F32T8 electronic instant start ballasts, where the ballast below the median was chosen since a comparison to the other ballasts in that class showed that the BF for the ballast on the high side of the median was abnormally low. The BF and ANSI Watts for each "representative" ballast were selected from the data set for use in the energy calculations. These ballasts exist in the market.

[1] Watts as measured by test procedures established by the American National Standards Institute.

The explanation for these different methods is that the technology options representing well-established technologies should be based on the average properties of current market products, while technology options representing newer technologies should be based on the properties of an actual ballast that is characteristic of that technology option in the market.

NEMA then reviewed these selections and suggested adjustments to many of the wattage and BF values. The analysis adopts these adjustments, most of which are very small. Therefore, in some cases, there is not an exact correspondence between the ballast data sets in Section A.3 and the values used in the analysis.

Normalized Fixture Watts

Described below are the details of applying power input corrections to the ANSI Watts used for each technology option. A correction was applied to ANSI Watts for 3- and 4-lamp ballast technology options to account for thermal effects on power input. We would have also applied a correction factor for the thermal effects on light output, but for the options presented in this chapter, the factor was 1 (no effect). The correction factors were derived from empirical data described later in this Appendix.

A BF power correction was also applied to each technology option in all classes to "normalize" (equalize) light output to the baseline option (the energy-efficient magnetic ballast). The rationale for adjusting the Watts for the thermal effect on light output and for the ballast factor impact is that the technology options must be compared assuming equivalent light output to the baseline.

The following equation performs the corrections described above. Normalized Fixture Watts (NFW) represent the wattage of the lamp/ballast combination in the fixture, installed in a plenum, and normalized to a baseline BF as shown in the following equation:

$$\text{Normalized Fixture Watts} = \text{ANSI Watts} \times \text{WTF/LTF} \times \text{BF}_o / \text{BF}_n$$

where:

WTF is the Wattage Thermal Factor that corrects the ANSI Watts to actual Watts used when the ballast is installed in a fixture and a ceiling plenum.

LTF is the Light Output Thermal Factor that adjusts the wattage for the change in light output when the ballast is installed in a fixture and ceiling plenum.

BF_o is the ballast factor for the baseline technology option. BF_n is the ballast factor of technology option *n* and BF_o / BF_n is referred to as the normalization factor.

Baseline Ballast Factors

The baseline ballast factors used in the analysis are shown in Chapter 3, Table 3.5 and described in section 3.4.

Thermal Factor Power Input and Light Output Correction Factors

Performance data are available for some but not all of the lamp-ballast system combinations covered in this report under typical luminaire operating conditions. The available data from the *Advanced Lighting Guidelines* (3), the work of Bleeker and Veenstra (4), and National Lighting Product Information Program published data (5) have been used to derive the values in Table A.1 for 3- and 4-lamp ballast systems. This table lists the thermal correction factors for power input and light output (WTF and LTF). The WTF for a particular ballast system is the ratio of the power input for a recessed static enclosed luminaire at the operating temperature to the power input for a suspended open luminaire at 25EC with the same lamp/ballast system. The suspended open luminaire power input and light output are assumed to be identical to the values obtained under the ANSI test conditions. The thermal factors for the recessed static enclosed luminaire type are assumed to be representative of the thermal factors for the "average" luminaire type, since parabolic recessed luminaires tend to have higher thermal factors (less wattage change) and wraparound luminaires tend to have lower thermal factors (greater wattage change). The LTF is the corresponding ratio for light output, and is applied to the fixture wattage. Since we only analyzed T12/ES and T8 lamps, the LTFs were 1 and therefore there was no adjustment in this TSD.

Table A.1 Thermal Correction Factors

Lamp-ballast combination	Technology Option	WTF	LTF
3-F40T12	Electronic RS	0.93	0.94
3-F40T12/ES	Electronic RS	0.98	1
3-F40T12	Magnetic	0.91	NA
3-F40T12/ES	Magnetic	0.96	NA
3-F40T12	Cathode Cutout	0.91	NA
3-F40T12/ES	Cathode Cutout	0.96	NA
3-F32T8	Electronic RS	0.95	1
3-F32T8	Electronic IS	0.95	1
3-F32T8	Magnetic	0.93	NA
4-F40T12	Electronic RS	0.93	0.94
4-F40T12/ES	Electronic RS	0.98	NA
4-F40T12	Magnetic	0.91	NA
4-F40T12/ES	Magnetic	0.96	NA
4-F40T12	Cathode Cutout	0.91	NA
4-F40T12/ES	Cathode Cutout	0.96	NA
4-F32T8	Electronic RS	0.95	1
4-F32T8	Electronic IS	0.95	1
4-F32T8	Magnetic	0.93	NA
4-F32T8	Cathode Cutout	0.93	NA

NA: LTFs are not used in the LCC analysis

Thermal corrections are applied only to the input power and light output for 3- and 4-lamp luminaires. For 1- and 2-lamp luminaires, the elevation in ambient temperature is sufficiently small that there is little change in lumen output and input power from the ANSI values. The resulting normalized fixture Watts used in the engineering analysis are shown in Chapter 3.

A.2 LAMP PRICES

Lamp prices are calculated from the manufacturer lamp price lists and from the February 1994 Defense General Supply Center/Defense Logistics Agency (DLA) price catalog(6). For the commercial/industrial sector, an estimated typical discount of 40 percent for large end-user purchases was determined from a survey of lamp price databases and from distributor and supplier price quotes and interviews. For the federal government purchases, the DLA catalog price was used. The lamp price is calculated assuming that 95 % of lamp purchases are at the price in the Lamp Price Schedule less 40%, and 5 % of lamp purchases are at the DLA catalog price. Where no DLA catalog price is available for a lamp, 100% of purchases are at the price in the Lamp Price Schedule less 40%.

Table A.2 Lamp Prices Used in the Analysis

Lamp Type	Unit Price
F40T12/ES	$1.64
F32T8/RE70	$2.61
F96T12/ES	$2.94
F96T12/HO/ES	$6.89

A.3 BEF, BF, AND POWER CONSUMPTION DATA

Table A.3 is a summary of computed BEFs based on the data submitted by the National Association of Electrical Manufacturers (NEMA), the New York State Energy Office (NYSEO), and the Seattle Lighting Design Lab (SLDL). These data are listed in Tables A.4 through A.39. The abbreviations ES, EEM, CC, ERS, and EIS represent: energy saver, energy-efficient magnetic, cathode cutout, electronic rapid start, and electronic instant start ballasts, respectively. The BEFs in Table A.3 are computed values representing the 10, 50 (median), and 90 percentile rankings for each class. As an example of interpreting the table, 10 percent of the ballasts in the database for the 1-F40 Cathode Cutout ballast will have BEFs below 1.91, 50 percent below 1.94, and 90 percent below 1.97. In cases where the BEFs are identical at all levels, only one data point was available.

Table A.3 Overview of Ballast Efficacy Factor, (ND=No Data)

Lamp	EE Magnetic			Cathode Cutout			Electronic RS			Electronic IS		
	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%
1 F40	1.82	1.85	1.92	1.91	1.94	1.97	2.29	2.34	2.43	ND	ND	ND
1F40/ES	2.01	2.09	2.16	2.26	2.26	2.26	2.61	2.71	2.84	ND	ND	ND
2 F40	1.05	1.07	1.08	1.13	1.15	1.16	1.17	1.19	1.22	ND	ND	ND
2F40/ES	1.21	1.22	1.22	1.30	1.34	1.37	1.35	1.42	1.45	ND	ND	ND
3 F40	ND	ND	ND	ND	ND	ND	0.76	0.78	0.81	ND	ND	ND
3F40/ES	ND	ND	ND	ND	ND	ND	0.90	0.91	0.93	ND	ND	ND
4F40	ND	ND	ND	ND	ND	ND	0.60	0.61	0.60	ND	ND	ND
2 F96	0.58	0.59	0.60	ND	ND	ND	ND	ND	ND	0.63	0.65	0.66
2F96/ES	0.69	0.70	0.71	ND	ND	ND	ND	ND	ND	0.77	0.79	0.80
2 F96HO	0.40	0.40	0.40	0.42	0.42	0.42	0.43	0.43	0.44	ND	ND	ND
2F96HO/ES	0.42	0.45	0.46	0.47	0.48	0.48	0.49	0.50	0.52	ND	ND	ND
1 F32T8	2.43	2.45	2.46	ND	ND	ND	2.73	2.88	2.96	2.84	2.95	2.99
2 F32T8	1.26	1.28	1.29	1.37	1.37	1.37	1.40	1.43	1.49	1.47	1.5	1.53
3 F32T8	ND	ND	ND	ND	ND	ND	0.92	0.97	1.01	1.01	1.03	1.04
4 F32T8	ND	ND	ND	ND	ND	ND	0.72	0.72	0.73	0.77	0.77	0.78

Table A.4 NEMA Data for 1-Lamp F40T12 EEM Ballast

Volts	Watts	BF	BEF
120	49.5	95	1.92
277	49	94	1.92
120	49.8	93.1	1.869
277	51.2	94.9	1.854
120	51	94.3	1.85
277	50.7	93.3	1.84
120	52	95	1.82
277	52	95	1.82

Table A.5 NEMA Data for 1-Lamp F40T12 CC Ballast

Volts	Watts	BF	BEF
120	45	89	1.978
277	47	89.2	1.898

Table A.6 NEMA Data for 1-Lamp F40T12 ERS Ballast

Volts	Watts	BF	BEF
120	36.6	90.9	2.484
120	36.2	88.2	2.436
277	37	89.6	2.422
120	37.6	91	2.41
277	37.4	90	2.407
120	38.4	89.9	2.342
120	36.5	85.4	2.342
277	38	89	2.335
277	40.3	93.7	2.325
277	37.4	86.9	2.324
277	39	87	2.29
120	38	85	2.24

Table A.7 NEMA Data for 1-Lamp F40T12/ES EEM Ballast

Volts	Watts	BF	BEF
277	43.6	85.9	1.97
120	43.7	88.2	2.02
277	41.9	86.5	2.07
277	44.6	92.6	2.08
120	42.3	88.2	2.1
120	43.7	91.3	2.09
277	41	88	2.15
120	40	87	2.18

Table A.8 NYSEO Data for 1-Lamp F40T12/ES CC Ballast

Volts	Watts	BF	BEF
120	36.7	83	2.26

Table A.9 NEMA Data for 1-Lamp F40T12/ES ERS Ballast

Volts	Watts	BF	BEF
120	30.2	88	2.91
277	30.3	86.3	2.85
277	31.2	88.1	2.82
120	30.4	85.1	2.8
120	31.1	87	2.8
277	29.8	83.2	2.79
277	31.1	84.5	2.72
120	31.3	84.2	2.69
120	33	88.7	2.69
277	34.3	91.6	2.67
120	33	87	2.64
277	34	89	2.62
120	32.4	84.4	2.61
277	32.2	83	2.58

Table A.10 NEMA Data for 2-Lamp F40T12 EEM Ballast

Volts	Watts	BF	BEF
120	86.2	93.9	1.089
277	87.6	94.7	1.081
120	89	95	1.07
120	90.4	96.6	1.069
120	90.4	96.6	1.069
277	90	95	1.06
277	90	94.8	1.053
277	90	94.8	1.053

Table A.11 NEMA Data for 2-Lamp F40T12 CC Ballast

Volts	Watts	BF	BEF
120	80.9	94.2	1.164
120	68	79	1.16
277	69	80	1.15
120	73.7	85.4	1.159
277	72.5	83.4	1.15
277	81.7	93.5	1.144
120	83	93.8	1.129
277	84.8	93	1.097
277	84.1	74.4	1.13
120	82.9	70.7	1.173

Table A.12 NEMA Data for 2-Lamp F40T12 ERS Ballast

Volts	Watts	BF	BEF
277	70.8	87.1	1.23
120	71	86	1.22
277	71	86	1.22
120	71.5	87	1.217
277	73.6	89	1.21
277	71.9	85.9	1.195
120	72.2	86.1	1.193
277	71.4	85.2	1.193
120	74.8	89	1.19
277	74.4	88.1	1.184
120	72.2	85.3	1.181
120	72.9	85.9	1.178
120	76.1	89.1	1.171
277	77.9	90.1	1.157

Table A.13 NEMA Data for 2-Lamp F40T12/ES EEM Ballast

Volts	Watts	BF	BEF
120	72	88	1.22
120	74.4	90.6	1.22
120	73	88.8	1.22
277	72.4	87.8	1.21
277	75.5	91.2	1.21
277	73	88	1.21

Table A.14 NEMA Data for 2-Lamp F40T12/ES CC Ballast

Volts	Watts	BF	BEF
120	57.9	79.5	1.37
120	59	81	1.37
277	60	81	1.35
120	66.9	89.8	1.34
277	60.7	80.8	1.33
120	68.7	90.8	1.32
277	68.8	90.3	1.31
277	70	90	1.29

Table A.15 NEMA Data for 2-Lamp F40T12/ES ERS Ballast

Volts	Watts	BF	BEF
277	60	88	1.47
120	60	87	1.45
277	62.9	90.6	1.44
277	63.4	91.3	1.44
120	60.1	86.3	1.44
277	63.2	90.4	1.43
277	65.8	93.5	1.42
120	62.6	87.6	1.4
120	63.8	88.7	1.39
120	64.3	88.7	1.38
120	64.6	88.5	1.37
120	64	86.6	1.35
277	65	87.2	1.34

Table A.16 NEMA Data for 2-Lamp F96T12 EEM Ballast

Volts	Watts	BF	BEF
277	160.4	96.1	0.599
120	156.7	92.8	0.592
120	158	94	0.59
277	158	94	0.59
277	163.2	95.6	0.586
120	160.7	93.1	0.579

Table A.17 NEMA Data for 2-Lamp F96T12 EIS Ballast

Volts	Watts	BF	BEF
277	129	86	0.666
277	136.1	88.8	0.652
277	136.1	88.6	0.651
120	132	86	0.651
277	131.8	85.8	0.651
120	139.2	90	0.647
120	140	88.1	0.629
120	149	91.9	0.617

Table A.18 NEMA Data for 2-Lamp F96T12/ES EEM Ballast

Volts	Watts	BF	BEF
120	125.6	89.5	0.71
277	126.9	89.7	0.71
277	129.6	91.2	0.7
120	127.2	88.3	0.69
120	124	85	0.69
277	124	85	0.69

Table A.19 NEMA Data for 2-Lamp F96T12/ES EIS Ballast

Volts	Watts	BF	BEF
277	111.3	89.1	0.79
120	108	86	0.8
277	108	86	0.8
120	113.4	89.5	0.79
277	113.7	89.4	0.79
277	110.1	86.5	0.79
120	115.7	89.1	0.77
120	122.8	92.9	0.76

Table A.20 NEMA Data for 2-Lamp F96T12HO EEM Ballast

Volts	Watts	BF	BEF
120	237	95.3	0.402
277	237	97	0.4
277	241.2	96.5	0.4
120	237	96	0.4
277	245.2	97.9	0.399
120	241.2	95.8	0.397

Table A.21 NEMA Data for 2-Lamp F96T12HO CC Ballast

Volts	Watts	BF	BEF
120	211.6	89.8	0.424
277	219.2	91.2	0.416

Table A.22 NEMA Data for 2-Lamp F96T12HO ERS Ballast

Volts	Watts	BF	BEF
277	205.5	90	0.438
120	195	85	0.435
277	195	85	0.435
120	207.6	89.2	0.43
277	196.3	84.2	0.429
120	194.5	82.6	0.425

Table A.23 NEMA Data for 2-Lamp F96T12HO/ES EEM Ballast

Volts	Watts	BF	BEF
120	196.1	89.4	0.46
277	198.4	89.5	0.45
120	204	91	0.45
277	205	91	0.44
277	201.1	84.9	0.42
120	200.7	84.3	0.42

Table A.24 NEMA Data for 2-Lamp F96T12HO/ES CC Ballast

Volts	Watts	BF	BEF
120	180.8	86.4	0.48
277	186.6	87.7	0.47

Table A.25 NEMA Data for 2-Lamp F96T12HO/ES ERS Ballast

Volts	Watts	BF	BEF
120	164	85	0.52
277	164	85	0.52
277	176.3	87.9	0.5
120	177.3	87.6	0.49
277	169.4	82.3	0.49
120	169.2	81.2	0.48

Table A.26 NEMA Data for 3-Lamp F40T12 ERS Ballast

Volts	Watts	BF	BEF
277	104.4	90	0.859
120	109.2	88.8	0.813
277	107.1	86	0.803
277	109.8	86.1	0.784
277	109.8	85.7	0.781
120	109	85	0.78
120	108.1	84	0.774
120	114.3	87.8	0.768
120	112.6	86.4	0.767
277	114.3	87.3	0.764
120	114.6	86.5	0.755

Table A.27 NEMA Data for 3-Lamp F40T12/ES ERS Ballast

Volts	Watts	BF	BEF
277	90	86	0.96
277	92.8	86.2	0.93
120	89.1	82.6	0.93
277	94.4	86.6	0.92
277	95.1	86.7	0.91
120	92.8	84.4	0.91
120	94.7	86.1	0.91
120	97.6	88.5	0.91
277	90.6	81.7	0.9
120	99.3	88.6	0.89

Table A.28 SLDL Data for 4-Lamp F40T12 ERS Ballast

Volts	Watts	BF	BEF
120	146	87	0.6

Table A.29 NEMA Data for 1-Lamp F32T8 EEM Ballast

Volts	Watts	BF	BEF
277	38.6	95.1	2.464
120	38.7	95.1	2.457
120	39.3	95.8	2.44
277	41	95.4	2.43

Table A.30 NEMA Data for 1-Lamp F32T8 ERS Ballast

Volts	Watts	BF	BEF
277	31.9	94	2.974
120	29.8	88.2	2.96
277	27.2	79	2.905
277	29.7	86.1	2.9
120	30	85.5	2.85
120	27	75	2.792
120	31.1	85	2.753
277	32.1	86.3	2.688

Table A.31 NEMA Data for 1-Lamp F32T8 EIS Ballast

Volts	Watts	BF	BEF
277	30	90	3.00
277	30	89.7	2.99
120	31	92.4	2.98
120	30.7	91.2	2.97
277	29.1	85	2.92
120	30	89	2.9
120	32.9	89	2.9
277	32.8	88	2.68

Table A.32 NEMA Data for 2-Lamp F32T8 EEM Ballast

Volts	Watts	BF	BEF
120	73.8	95.8	1.298
120	75.3	97.1	1.29
277	76	97.9	1.288
277	74.4	94.6	1.272
120	76	97	1.27
277	77	96	1.25

Table A.33 NEMA Data for 2-Lamp F32T8 CC Ballast

Volts	Watts	BF	BEF
120	62.6	85.5	1.366
277	61.8	84.4	1.366
277	62.3	85	1.365
120	61.7	84.2	1.365

Table A.34 NEMA Data for 2-Lamp F32T8 ERS Ballast

Volts	Watts	BF	BEF
277	62.2	94.7	1.523
277	85.5	130	1.465
120	63.8	95.4	1.495
277	60.4	89.7	1.485
120	54.2	80	1.42
120	61	90	1.45
120	89.2	130	1.431
120	61.3	89.2	1.456
277	62	90	1.45
120	61.9	88.8	1.435
277	55.9	80	1.43
120	61.5	88	1.43
277	61.5	88	1.43
277	62.8	88.3	1.406
120	61.6	85.9	1.394
277	63.9	89	1.393

Table A.35 NEMA Data for 2-Lamp F32T8 EIS Ballast

Volts	Watts	BF	BEF
277	58.5	89.8	1.535
120	61.7	94.4	1.53
277	59	90	1.53
277	58.5	88.5	1.513
277	51.4	77.5	1.508
120	58.8	88.6	1.507
120	51.5	77.6	1.507
120	62	93	1.5
277	62	93	1.5
277	58.5	87.7	1.499
277	58.2	87.2	1.498
120	59.3	88.6	1.494
120	59	88	1.5
120	59.4	88.4	1.488
120	59.5	86.4	1.45
277	59.7	86.5	1.45

Table A.36 NEMA Data for 3-Lamp F32T8 ERS Ballast

Volts	Watts	BF	BEF
277	75.7	77	1.02
277	90.5	91	1.009
120	86.8	87	1.005
277	94.3	93	0.986
120	96.9	94.1	0.971
120	78.4	76	0.971
120	92.0	88.7	0.964
277	91.8	87.9	0.958
277	95.7	88.1	0.921
120	97.4	88.5	0.909

Table A.37 NEMA Data for 3-Lamp F32T8 EIS Ballast

Volts	Watts	BF	BEF
120	87.9	93	1.058
277	86.5	89.7	1.037
277	76.1	78.5	1.032
277	90.9	93.9	1.03
120	90.6	93.3	1.03
277	90.5	93.2	1.03
277	85	88	1.03
120	76	78	1.026
120	87.7	89.8	1.024
120	86	87	1.02
277	88.2	89.7	1.017
277	86.6	87.8	1.015
120	88.3	89	1.008
120	86.1	85.8	0.995

Table A.38 NEMA Data for 4-Lamp F32T8 ERS Ballast

Volts	Watts	BF	BEF
120	122.8	89.1	0.726
277	124.8	89.5	0.717

Table A.39 NEMA Data for 4-Lamp F32T8 EIS Ballast

Volts	Watts	BF	BEF
277	112.1	87.7	0.782
277	100	78.1	0.781
277	112.1	87.4	0.78
277	101	79	0.78
120	114.2	89	0.779
120	113.3	88.3	0.779
120	101.2	78.5	0.776
277	108.2	83.6	0.773
120	111	86	0.77
277	111	85	0.77
120	106.9	82.3	0.77
120	101	78	0.77
277	114.1	87.3	0.765
120	113	85.1	0.753

A.4 LIGHTING HOURS DATA

The lighting operating hours used in the engineering analysis were derived from a database of lighting equipment audits conducted by Xenergy Inc. Extracts of Xenergy's XENCAP database containing over 32,000 audits for the commercial and industrial sectors were obtained. These were aggregated to the three-digit zip code level to protect the confidentiality of Xenergy's customers. This database includes information on building type, building floor space, audit year, building operating hours, whether the lighting is interior or exterior, average lighting hours for each type of lighting equipment, and lamp counts. Lighting equipment is identified by its lamp type (including wattage), the number of lamps per fixture, and, in the case of fluorescent lamps, by its ballast type.

We used a database management program to aggregate the Xenergy data. Data from audit years 1990-1995 (over 24,000 buildings) were aggregated across these audit years and across all zip codes to estimate national average lighting hours by Xenergy building type. This aggregation was done separately for 4-foot systems, 8-foot systems, and 8-foot high output systems. Only those lamp/ballast combinations that are considered in the engineering and national energy analyses were included in the average.

To obtain averages, lighting hours for each of the original Xenergy database records were weighted by the ballast count associated with each record. Because the Xenergy data reported the number of fixtures rather than number of ballasts, we made the following assumptions to estimate ballasts per record. For magnetic ballasts, we assumed that 1- and 2-lamp fixtures contained one ballast, and that 3- and 4- lamp fixtures contained 2 ballasts per fixture. For electronic ballasts, we assumed one ballast per fixture for all cases (the highest reported number of lamps per fixture was 4). LBNL used the following commercial building types in the analysis: small office, large office, restaurant, retail, grocery, warehouse, schools, colleges, health, lodging, assembly, and miscellaneous. For those building types where one LBNL building type corresponded to more than one Xenergy building type, data were combined to get average lighting hours by LBNL building type.

Next we obtained an average across the commercial sector building types. We used the Xenergy lighting hours for each commercial building type, weighted by the square footage of each building type found in the U.S., as reported in CBECS(7). The average lighting hours obtained for the commercial sector (rounded to the nearest 100) were 3600 for 4-foot lamp ballasts, 3600 for 8-foot lamp ballasts, and 4000 for 8-foot high output lamp ballasts.

For this analysis, industrial lighting is represented by one building type. We simply used the average for each ballast type obtained for the Xenergy industrial building type. The average annual industrial lighting hours (rounded to the nearest 100) for the systems considered in the industrial sector were 4000 for 8-foot lamp ballasts, and 5000 for 8-foot high output lamp ballasts.

Finally, these hours were adjusted to account for the fact that the hours for magnetic ballasts, which are affected by standards, tend to be lower than those for the entire ballast stock. In contrast, electronic ballasts tend to have higher operating hours since users with higher hours would tend to switch to more efficient ballasts earlier on. The weighted averages of the commercial sector annual lighting hours for the different lamp-ballast combinations are: 3400 hours for F40T12 and F32T8; 3300 hours for F96T12; and 3700 hours for F96T12HO. The industrial sector annual lighting hours for the applicable lamp-ballast combinations are: 3700 hours for F96T12 and 4600 hours for F96T12HO. The commercial sector hours are used for the F40T12, F32T8, and F96T12 lamp-ballast combinations, while the industrial hours are used for the F96T12HO lamp-ballast combinations.

We performed additional analysis and found that for 4-foot commercial ballasts in the Xenergy data set, there is a significant difference in the lighting hours for magnetic ballasts (annual average 3600 hours/year) and electronic ballasts (annual average 4100 hours/year). We found similar results for other ballast types where enough data were available to make a comparison (4-foot industrial and 8-foot commercial), and for the Green Lights data set. This is consistent with the proposal that magnetic ballast end users have lower average operating hours because users with higher hours are more likely to switch to electronic ballasts. For more detail, see Chapter 4.

Since standards would impact only those end users who have not already switched to electronic ballasts, the distribution and point value that should be used for the analysis are those that would be representative of magnetic ballast users in the year that a ballast efficiency standard would go into effect. Simply using the distribution and average values for magnetic ballasts from the Xenergy data set is not likely to be representative of the lighting hours for magnetic users in the year standards would be implemented because the Xenergy data were taken at a point in time when only 5% of those surveyed had switched to electronic. Over time, it is expected that the lighting hours for magnetic users will shift downward, as users with higher lighting hours shift to electronic ballasts. Lighting hours for electronic ballasts should also shift downward over time, since it is expected that the earliest adopters will be at the highest hours, and later adopters will have somewhat lower average hours.

DOE assumed that 50% of the ballasts in the building stock would be electronic at the time a standard goes into effect leaving 50% as magnetic. The goal, then, was to estimate the distribution of lighting hours for magnetic ballasts at a point when their percentage penetration in buildings is 50%. It was assumed that the overall lighting hours distribution for all ballasts would not change as the penetration shifts from magnetic to electronic ballasts. Therefore, if electronic ballasts were to achieve 100% penetration, their lighting hours distribution would be the same as the total distribution for electronics plus magnetics. Since the electronic ballast distribution is expected to shift from the curve derived from the Xenergy data, where their penetration is 5%, to the curve for all ballasts derived from the Xenergy data with 100% penetration of electronics, the assumption was made that at 50% penetration of electronics, each point in the distribution would be halfway between the distribution for all ballasts and the distribution for electronics at 5% penetration. The magnetic lighting hours distribution was then estimated for 50% penetration by subtracting the distribution estimated for 50% electronic penetration from the distribution for all ballasts.

Using this procedure, the projected average lighting hours for electronic ballasts at 50% penetration is shifted upward from the overall average by half the amount that the 5% average is shifted upward. For example, the average lighting hours for 4ft commercial electronic ballasts at 5% penetration is 4100 hours per year, which is 14% higher than the average for all ballasts of 3600 hours per year. The projected lighting hours for 4ft commercial electronic ballasts at 50% penetration is only 7% higher than the total, or 3900 hours/yr (rounded to nearest 100). At 50% penetration, the estimated magnetic ballast hours are shifted downward from the total by the same amount that the electronic ballasts are shifted upward (in this case, 7%) so their estimated operating hours are 3300 hrs/yr. This value was therefore used as the point estimate of lighting hours for 4 ft commercial magnetic ballasts in the Life Cycle Cost analysis, and the distribution was used in the sensitivity analysis.

The same procedure was followed to derive magnetic distributions for 8ft commercial and 4ft industrial ballasts.

For commercial 8ft HO and industrial 8ft and 8ftHO ballasts, there were not enough data on electronic ballasts to use this approach. For these ballast types, we shifted all points in the total distribution down by 7% to represent the magnetic distribution. We chose 7% because it is the average shift we obtained from total to magnetic lighting hours for 4ft commercial, 4ft industrial, and 8ft commercial.

A.5 LABOR COST DATA

Labor Rates

The hourly labor rate for a journeyman electrician is $50. This rate is based on the Base Wage listed in the 1995 National Electrical Estimator (8). The Base Wage is then multiplied by 250% (the industry average multiplier which includes fringe benefits, taxes, workers compensation, overhead, and profit) yielding the fully loaded labor rate.

The hourly labor rate for the electrician's helper is $29.35. This rate is based on the typical billing rate for Helpers (average for five trades) in the Means 1994 Electrical Cost Data(9). The billing rate includes fringe benefits, workers compensation, taxes, overhead and profit.

Lamps are assumed to be changed by an electrician's helper. Ballasts are assumed to be changed by both electricians and electrician's helpers, at a rate that is the average of the two labor rates.

Labor Times

The table below lists the labor times to replace fluorescent lamps and ballasts. The lamp replacement times are a weighted average of time to change lamps under a group relamping and a spot relamping practice. Group relamping assumes that the fixture and lens are cleaned when the lamps are replaced. The group relamping percentages are from an LRI survey(10) of luminaire manufacturers and lighting management companies for various building types. According to this survey, group relamping occurs an average of 25% of the time for 4-foot systems, 37% for 8 foot systems, and 31 % for 8-foot HO systems. These percentages are used to calculate an average time to change. These "Average Relamp Time" values in Table A.40 are used in the analyses for simple lamp replacement.

When ballasts are changed, the analysis assumes that the lamps are replaced at the same time. The values for the "Ballast + Lamps Time" to change are used in the analyses. Subtracting the average relamp time from this time gives the incremental time to change just the ballast, or the "Ballast Time," although this time is not used in the analyses. For the life-cycle cost analysis, the tandem-wiring times for 3-lamp fixtures shown below were not used; instead it was assumed that the labor time was the same as that for a three-lamp fixture that is not tandem-wired.

Table A.40 Replacement Labor Times (minutes) for Fluorescent Lamps and Ballasts

Lamps	Group Relamp Time	Spot Relamp Time	Average Relamp Time
1-lamp fixture, 4 foot	13.5	26.5	23.0
2-lamp fixture, 4 foot	14.0	27.0	23.5
3-lamp fixture, 4 foot	14.5	27.5	24.0
4-lamp fixture, 4 foot	15.0	28.0	24.5
1-lamp fixture, 8 foot	10.0	20.0	16.5
2-lamp fixture, 8 foot	10.5	20.5	17.0
1-lamp fixture, 8 foot HO	13.0	26.0	22.0
2-lamp fixture, 8 foot HO	13.5	26.5	22.5
Ballasts	**Ballast Time**	**Ballast + Lamps Time**	
1-lamp ballasts, 1 per fixture			
EEM and CC	7	30	
Electronic	7	30	
2-lamp ballasts, 1 per fixture			
EEM and CC	6.5	30	
Electronic	6.5	30	
3-lamp, Electronic, 1 per fixture	11.0	35	
3-lamp, Magnetic, 2 per fixture weighted for tandem fixtures	19.3	43.3	
4-lamp, Electronic, 1 per fixture	10.5	35	
4-lamp, Magnetic, 2 per fixture	15.5	40	
8-foot, EEM, 1 per fixture	38	55	
8-foot, Electronic, 1 per fixture	38	55	
8-foot HO, EEM and CC, 1 per fixture	37.5	60	
8-foot HO, Electronic, 1 per fixture	37.5	60	

Lamp Relamp Lifetimes

The relamp lifetime is the average time after which the lamp is changed. It is calculated as an average of lamp life under spot replacement and group replacement. In spot replacement, the lamp life is the lamp rated lifetime from manufacturers' catalogs. In group replacement, it is assumed to be 75% of the lamp rated lifetime. Rated lamp lifetimes are: 20,000 hours for F40T12, F40T12/ES, and F32T8/RS; 15,000 hours for F32T8/IS; and 12,000 hours for F96T12, F96T12/ES, F96T12HO, and F96T12/ES lamps.

The percentages of spot and group replacement described in Labor Times above are used to calculate the average lamp relamp lifetimes. Also, the operation of lamps with cathode cutout ballasts is assumed to shorten the lamp life by 15%; this percentage is applied to the calculated relamp lifetime. The resulting relamp times are shown in Table A.41.

Table A.41. Fluorescent Lamp Relamp Lifetimes

Lamp	Lamp Rated Lifetime (Hours)	Lamp Relamp Lifetime, EEM or ERS Ballast (Hours)	Lamp Relamp Lifetime, CC Ballast (Hours)	Lamp Relamp Lifetime, EIS Ballast (Hours)
F40T12, F40T12/ES, F32T8/RS	20,000	19,000	16,150	NA
F32T8/IS	15,000	NA	NA	14,000
F96T12, F96T12/ES	12,000	11,000	NA	11,000
F96T12HO F96T12HO/ES	12,000	11,000	9,350	NA

A.6 COMMERCIAL AND INDUSTRIAL SHARES OF EIGHT FOOT LAMP BALLASTS

We estimated the fraction of 8-foot and 8-foot HO lamp ballasts found in each building type by assuming that the density (count per 100 ft^2) found for each building type in the Xenergy data set is representative of all buildings of that type in the U.S., and then multiplying this density times the U.S. square footage of each building type. The results are shown in Table A42 for 8-foot lamp ballasts and in Table A43 for 8-foot HO lamp ballasts. We found that for 8-foot lamp ballasts, 26% are found in the industrial sector and for 8-foot HO 35% are industrial, with the rest in the commercial sector.

Table A.42. 8-Foot Lamp Ballast Locations by Building Types

Building Type	Xenergy area, ft2	Xenergy System Counts	% of Xenergy Systems	Systems per 100ft2	US Area, million ft2*	US System Counts	% of US Systems
ASM	24620193	12780	1.7%	0.05	8337	4327621	5.3%
COL	25924413	5675	0.7%	0.02	3068	671602	0.8%
GRC	13065154	61616	8.0%	0.47	767	3617215	4.5%
HLT	44250344	4069	0.5%	0.01	1786	164230	0.2%
IND	163979006	275775	35.7%	0.17	12329	20734544	25.5%
LDG	93648582	9241	1.2%	0.01	2882	284388	0.4%
LGO	139111863	42236	5.5%	0.03	6796	2063346	2.5%
RES	14822407	8157	1.1%	0.06	1494	822171	1.0%
RET	72835256	167723	21.7%	0.23	12479	28736294	35.4%
SCH	126095464	55153	7.1%	0.04	5426	2373283	2.9%
SMO	42786075	33596	4.4%	0.08	5578	4379894	5.4%
WRH	84482979	95784	12.4%	0.11	11504	13042854	16.1%

* Commercial area from CBECS 1992, Industrial from MECS 1994

Table A.43. 8-Foot HO Lamp Ballast Locations by Building Types

Building Type	Xenergy area, ft2	Xenergy System Counts	% of Xenergy Systems	Systems per 100ft2	US Area, million ft2*	US System Counts	% of US Systems
ASM	24620193	1074	0.9%	0.0044	8337	363683	3.1%
COL	25924413	620	0.5%	0.0024	3068	73373	0.6%
GRC	13065154	6873	5.7%	0.0526	767	403485	3.4%
HLT	44250344	20	0.0%	0.0000	1786	807	0.0%
IND	163979006	55281	45.6%	0.0337	12329	4156382	35.4%
LDG	93648582	1066	0.9%	0.0011	2882	32806	0.3%
LGO	139111863	8949	7.4%	0.0064	6796	437183	3.7%
RES	14822407	514	0.4%	0.0035	1494	51808	0.4%
RET	72835256	12581	10.4%	0.0173	12479	2155526	18.3%
SCH	126095464	6292	5.2%	0.0050	5426	270750	2.3%
SMO	42786075	3589	3.0%	0.0084	5578	467896	4.0%
WRH	84482979	24502	20.2%	0.0290	11504	3336424	28.4%

A.7 LCC SPREADSHEET DOCUMENTATION

What does the Life Cycle Cost (LCC) spreadsheet do?

LCC spreadsheet (currently **LCC_v4.XLS**) calculates the life-cycle costs and payback periods of the lamp/ballast combinations analyzed.

The LCC spreadsheet operates in Excel 97 or Excel 7 (Windows 95). The Excel add-on *Crystal Ball* (version 4.0) allows the user to perform uncertainty analysis on key input variables.

What are the worksheets in the workbook?

The workbook **LCC_v4.XLS** includes the following worksheets:

RESULTS	contains the summary table of the LCC and payback periods for point values of the input variables. (Note: Frequency results of LCC and payback periods using distributions of input variables have to be generated from Crystal Ball runs.)
CALC (T12)	contains the calculations of the LCC and payback periods for T12 conversions.
CALC (T8)	contains the calculations of the LCC and payback periods for T8 conversions.
Com Elec Price	contains the various projections of commercial sector electricity prices (Constant, AEO98 Reference, GRI98, AEO98 High Growth and AEO98 Low Growth).
Ind Elec Price	contains the various projections of industrial sector electricity prices.
Ballast Price Dist	defines the distributions of incremental ballast prices.
Oper Hr Dist	defines the distributions of annual lighting operating hours.
Ballast Life Dist	defines the distributions of ballast lifetimes.
Elec Price Dist	defines the distributions of commercial and industrial electricity prices in 1996.
Default Engr	contains the default engineering and price data.
Setup	is used as an interface between user inputs and the rest of the worksheets.

How does the user operate the spreadsheet?

The user interacts with the spreadsheet by clicking choices or entering data using the graphical interface. The entry point to the user interface is the **LIST INPUTS** menu. The **LIST INPUTS** menu can be invoked by clicking the **[LIST INPUTS]** button on the **RESULTS** worksheet or by hitting **<CRTL>L** from any worksheet.

From the **LIST INPUTS** menu, the user can then enter the input screens for selecting (1) ***Electricity Price Projection***, (2) ***Effective Date of Ballast Standards***, (3) ***Discount Rate*** and (4) ***Ballast Assumptions*** by clicking the corresponding button.

When inside any one of the four input screens, the user can switch over to any other one or back to the **LIST INPUTS** menu by clicking the corresponding button at the bottom.

After making the selections, the user can start the calculation by clicking the **[CALCULATE]** button or by hitting **<ALT>C**. In case the user wants to disregard the selections that have been made, the setup session can be canceled by clicking the **[CANCEL]** button in the **LIST INPUTS** menu, or the X at the top right of any screen.

On the **SETUP** worksheet the confirmed choices represents the user-selected values for the input variables. The temporary choices store the user's choices during the input process. If the user cancels the set up session, the temporary choices are discarded. When the user clicks the **[CALCULATE]** button, the temporary choices are loaded into the confirmed choices.)

To return to the default input values for Ballast Assumptions, click on the **[Load Defaults]** button. If new results were previously calculated, another calculation must be done (using **[CALCULATE]** or **<ALT>C** in order to produce the default results. This button affects only the ballast assumptions inputs; inputs from other menus in **LIST INPUTS** must be reset individually.

NOTE: Input changes should always be made in the **LIST INPUTS** menu. The user may view the impacts on the other worksheets, but editing those sheets could cause calculation errors, especially if formulae are overwritten.

The exception is the **Default Engr** worksheet; here the user may change the default engineering values. For (1) Ballast labor cost, (2) Lamp equipment cost, (3) Fixture watt, (4) ballast factor and (5) lamp labor cost, any revised value in the Default Engr worksheet will affect the calculations in the rest of the spreadsheet immediately. For the other revised default values, the change will only affect the calculations when **Load Defaults,** and then **CALCULATE** are clicked during an input session.

How does the user run the uncertainty analysis?

To run the uncertainty analysis, the EXCEL add-in *Crystal Ball* must be installed. Without *Crystal Ball*, the spreadsheet provides calculations of LCC and payback periods based on point values of the assumptions. With *Crystal Ball,* the user can assign distributions to various assumptions to generate resulting probability distributions of LCC savings and payback periods.

The spreadsheet provides **sample** distributions for (1) electricity prices, (2) annual operating hours, (3) lifetimes, and (4) ballast prices.

The worksheet **Elec Price Dist** contains the distribution of commercial and industrial electricity prices in 1996. The original data are from EIA's *Electric Utility Sales and Revenue, 1997.* When running the simulation, an electricity price for 1997 is sampled from the distribution along with an epsilon from the Epsilon distribution. To project the electricity prices into the future, the energy price projection that the user chooses from the ***Electricity Price Projection*** screen is used as a trend. For example, to use the AEO99 Reference electricity price as a trend, the ratios of the prices in 1998, 1999, ... to 2030 relative to the price in 1997 from that forecast are calculated. Then for each iteration of the simulation, a sampled price from the distribution is used as the base price, and the prices for 1998 to 2030 are obtained by multiplying the ratios previously calculated by the sampled price.

These distributions are defined in *assumption cells.* Click on **Cell, Select All Assumptions** to highlight the assumption cells on the worksheet . Click on one of the assumption cells, then select **Cell, Define Assumptions** to view the electricity price distribution for the commercial sector. This is a custom distribution (refer to the Crystal Ball user manual).

Note: Never edit the assumption cells; this will overwrite the formulae. To change the electricity price distribution, you must alter the raw data in the worksheet, or work with LBNL to create an alternate distribution. Also, do not edit the cells in a Normalized row.

The worksheet **Oper Hr Dist** contains operating hour distributions for the 4 ballast types for the commercial and industrial sectors. When performing the simulation, these distributions are scaled so that the average operating hours equal those in the user input (*Ballast Assumptions*). In this way, the shape of a distribution is retained and the mean of the distribution reflects the operating hours that the user specifies.

The sample custom distributions are derived from the Xenergy, Inc. database for both magnetic and electronic ballasts. (LBNL is working on an updated distribution to represent magnetic ballast hours.) To view a distribution, go to the Operating Hours Distribution highlighted box (upper right of worksheet), select a product class from the Hours row, and click Cell, Define Assumption. Note that the two F40T12 distributions are identical; hours for 2-lamp and 1-lamp ballasts are calculated together. The industrial sector distributions are below the commercial sector ones on the worksheet.

The worksheet **Ballast Life Dist** contains the distributions of lifetimes (in hours) for magnetic and electronic ballasts. (The distribution for cathode cutout is assumed to be the same as that of magnetic ballasts.) During the simulation, the distributions are scaled (see operating hour distribution above) so that the mean lifetimes are the same as those specified by the user. These are Weibull distributions, and are identical for magnetic and electronic ballasts, as suggested by manufacturers at the June workshop. The mean lifetimes are scaled to user input by the same process described above, with the ratio shown in the Normalized row.

To view a distribution, go to the highlighted box Ballast Life Distribution, and click on a cell in the Hours row, and click **Cell, Define Assumption.** The sample parameters for both magnetic and electronic ballasts have been set so that the mean lifetime is 50,000 hours. The low value represents about 5 years (matching an electronic ballast warranty period). The user may adjust the endpoints (by typing in values or by moving the arrows with the cursor), the scale, or the shape factor to change the distribution curve.

The worksheet **Ballast Price Dist** contains the distributions of incremental ballast prices (magnetic/baseline minus cathode cutout or electronic) for the four ballast types. The distribution of incremental ballast prices are assumed to be normal distributions. The standard deviation of each distribution is assumed to be a certain fraction of the mean. The means of the distributions are the incremental ballast prices calculated from the ***Ballast Assumptions*** inputs.

To view a distribution, select a cell in the Incremental Price Distribution and click **Cell, Define Assumptions.** To adjust the distribution, change the prices in the ***Ballast Assumptions*** screen of ***LIST INPUTS***.

How does the user run the *Crystal Ball* simulation?

To start the Crystal Ball simulation, select *Run* from the **Run** menu (on the menu bar). After each simulation run, the user needs to select *Reset* (also from the **Run** menu) before *Run* can be selected again.

How are Run Preferences used?

Under the **Run** menu, the user can specify options for the simulation by selecting ***Run Preferences***. In particular, one can set the number of iterations in **Run Preferences, Trials**. A suggested number of iterations is 2000; a Pentium processor will run the simulation in 1 to 2 minutes. Fewer iterations would produce less robust results, and more iterations would have longer run times. For other options, please refer to the *Crystal Ball* user manual.

Can the user perform simulations on specific distributions?

Normally, Crystal Ball will perform the simulations using the distributions of all assumption cells. In the LCC spreadsheet, this would include the four variables described above, run for all four ballast classes. However, the user can choose to disable certain assumption cells while leaving others enabled (for example, studying operating hours and electricity prices, while leaving ballast prices and ballast lifetimes at their point values). Select **Freeze Assumptions** from the **Cell** menu and choose the assumptions to be disabled, or those to be enabled.

NOTE: The assumption cell **CB** must always be enabled for the simulation to work properly.

What kind of output does *Crystal Ball* generate?

Crystal Ball collects statistics on user-defined quantities called *forecast cells*. To define a forecast cell, select **Define Forecast** under the **Cell** menu.

After the simulation has finished, *Crystal Ball* displays *Frequency Charts* of the forecast cells. Currently, the life-cycle cost savings and payback periods are defined as forecast cells.

The frequency charts display the results of the simulations, or trials, performed by Crystal Ball. Click on any chart to bring it into view. The charts show the low and high endpoints of the forecasts. To calculate the probability of LCC savings being positive, either type 0 in the box by the right arrow, or move the arrow key with the cursor to 0 on the scale. The value in the **Certainty** box shows the likelihood that the LCC savings will be positive. To calculate the certainty of payback period being below a certain number of years, choose that value as the high endpoint.

To generate a printout report, select **Create Report** from the **Run** menu.

For further information on *Crystal Ball* outputs, please refer to *Understanding the Forecast Chart* in the *Crystal Ball* manual.

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