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ASSESSING FLUORESCENT BALLAST/LAMP SYSTEMS

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ABSTRACT

In this paper nine combinations of fluorescent F40 ballast/lamp systems are compared on the basis of initial and operating costs for a new lighting layout using two- and four-lamp fixtures. The factors that influence the input power and light output are studied. Manufacturer's tolerance (lamp and ballast), minimum lamp wall temperature, fixture efficacy, ballast and lamp efficacy, and the cost of energy are considered. The ballast/lamp system that is most efficient and provides the greatest light output has the lowest initial cost in a four-lamp fixture. The same system has the lowest operating cost in a two-lamp fixture.

ASSESSING FLUORESCENT BALLAST/LAMP SYSTEMS

by

R. R. Verderber

1 INTRODUCTION

Many recently installed fluorescent lighting systems provide neither the illumination level specified nor the energy performance expected. This difficulty has arisen because of confusion in assessing the performance of fluorescent lamp and ballast combinations for any given application. Three events that have bred this confusion are discussed below.

First, since the energy crises in 1973, we have become more energy conscious and we more carefully watch watts and kilowatt hours. It sometimes seems that we have forgotten why we purchase energy-consuming products, which should be primarily for their output. Marketing strategies in the lighting industry have catered to and exacerbated our single-minded concern by overemphasizing a product's input performance (watts).

Second, the lighting industry has introduced a myriad of energy-saving lamps, ballasts, and add-on devices. While a few increase the efficiency of producing visible light, most reduce the light output of a fluorescent lamp to reduce input power. These products were introduced as retrofits for lighting systems in spaces that were obviously over-illuminated. (The most recent Illuminating Engineering Society Handbook recommends substantially reduced illumination levels for visual tasks.) Although some systems had a decreased efficacy and a higher initial cost, they met lighting needs in existing sites, were easy to install, and reduced energy consumption. These components were touted as energy-saving products, with the implication that they were energy-efficient. In too many cases these have been the only products considered in lighting designs for new construction, where the paramount reason for their use (over-illuminated spaces) does not pertain.

Finally, lighting designers traditionally have employed the industry standard for a ballast/lamp system, which is F-40 T-12 cool-white, rapid-start lamps with two-lamp F40 Certified Ballast Manufacturer (CBM) ballasts. Lighting designers could use a couple of tables, a simple equation, and their past experience to readily determine power density and meet required illumination levels. By using the F40 lamp and CBM ballast, designers were assured of the system performance, particularly the minimum light output. The minimum light output was certified by CBM to meet the American National Standards Institute's (ANSI) fluorescent lamp and ballast specification (C78.1 and C82.1).

None of the new energy-saving lamps has been specified by the ANSI committee. Therefore, a two-lamp F40 ballast designated CBM is certified only to operate the standard argon-filled, cool-white, rapid-start F40 lamp. While it will satisfactorily operate an energy-saving lamp, it has no CBM rating when it does so. The primary concern of the designer who must meet an illumination specification is that the certified ballast operate the lamp at least 95% ± 2 1/2% of the lamp manufacturer's rated output. Ballasts designed to meet the ANSI standard with the F40 lamp will provide much less, typically about 87% of the manufacturer's rated light output for a 35-watt krypton-filled, energy-saving lamp. However, because there are no ANSI standards for krypton-filled lamps, this the decrease differs significantly for ballasts from different manufacturers. More importantly, it is difficult for a designer to determine the ballast factor (the decrease in the lamps' light output) from the information supplied by the ballast manufacturer.

This short paper cannot provide all the details necessary for a lighting designer to assess all the ballast and lamp systems on the market. We will present some insight on systems' performance and efficiency. The input power and light output will be determined for three types of F40 ballasts and fluorescent lamps, considering the manufacturer's tolerance and the lamp wall temperature in the fixture. Based on these results we will examine the performance (initial and operating costs) of several ballast/lamp systems for a sample space using two- and four-lamp fixtures.

2.0 BALLAST/LAMP SYSTEMS

In addition to the standard two-lamp F40 CBM ballast and the F40 T-12 rapid-start, cool-white fluorescent lamp, several new energy-saving ballasts and lamps have been introduced by the lighting industry. The lamps include the 35-watt T-12, rapid-start, lite-white and the F40 T-12 rapid-start, lite-white lamps. The 35-watt lamp is specified to operate at 35 watts, providing a lower wattage system. As compared to a 40-watt lamp, the light output would decrease by an amount proportional to the decrease in power except for the use of lite-white phosphor in place of cool-white phosphor. This phosphor has an increased output in the yellow portion of the visible spectrum, increasing its luminous efficacy. The effectiveness is improved by decreasing the color rendition index (CRI) to a value of 55. The F40 lite-white lamp also has an improved efficacy by virtue of the lite-white phosphor, providing a greater light output than the standard F40 cool-white lamp for the same power input.

Two high-efficiency ballasts that have been introduced are the energy-efficient core-coil ballast and the solid-state ballast. The efficient core ballast uses low-resistance copper wire and improved magnetics that lower ballast losses (from 16 to 8 watts) and improve system efficacy by 8 to 10%. The solid-state ballast operates the lamp at high frequency, increasing its efficacy by 10 to 15%. The ballast is also more efficient, dissipating 4 to 6 watts compared to 16 watts for the standard CBM ballast. This provides an overall improvement in system efficacy of 22 to 25% for the solid-state ballast/lamp systems.

In this study we will consider the three types of lamps and ballasts described above. Their different performances will highlight the difficulties that can arise in a lighting design if one does not understand the interdependent characteristics of the ballast/lamp system.

Table I presents the key to understanding the various lamp/ballast systems—<u>their system efficacies</u>. This is the key because the efficacies of the same types of ballasts and lamps from different manufacturers vary only within 1 to 2%. However, because the CBM ballast is designed to meet the minimum ANSI specification for the F40 lamp's light output (95 ± 2 1/2% of the manufacturer's rating), it provides a lower relative light output for the 35-watt krypton-filled lamps. For non-CBM ballasts, manufacturers are free to select any ballast factor they desire. A simple estimate of maximum initial light output for a system is obtained by multiplying the manufacturer's specified input watts by the system efficacy listed in Table I.

3.0 FACTORS AFFECTING LIGHT OUTPUT

The sample lighting layout used in this report will make use of the two- and four-lamp fixtures described in a lighting designers' reference book [1]. The fixtures are described in Table II. In the reference a working chart is given that can be used to determine the square feet per fixture for room cavity ratios (RCRs) from 1 to 10 and a specific maintained illumination from 0 to 140 footcandles (fc).

The pertinent design targets for the lighting layout are given in Table II and include room area, room height, an RCR of 1, and average maintained footcandles. Table II also gives the total installed cost of the fixture, including a standard ballast(s) and standard F40 cool-white fluorescent lamps. To obtain a maintained illumination of 70 fc, for a lamp light output of 3200 lumens there are 80 ft^2 per fixture for the four-lamp fixtures and 40 ft^2 per fixture for the two-lamp fixtures. If the lumen output of each lamp is less, the area per fixture will decrease proportionally. If the output is 2800 lumens for the two-lamp fixture, the 40 ft^2 per fixture will decrease to 35 ft^2 per fixture ($2800 \div 3200 \times 40$).

Table III lists the factors that must be considered to determine the light output of each lamp based on the manufacturer's rating.

3.1 Lamp Wall Temperature

The static non-air-handling fixture is considered to operate in a room at 77°F ambient. We estimate that, in this environment, the minimum lamp wall temperature will be 45°C and 54°C for lamps in the two- and four- lamp fixtures, respectively. Lamp wall temperatures will be slightly lower for the more efficient ballast system and the 35-watt lamps because less heat will be generated at lower input powers. The thermal factor (relative change in light output as a function of minimum lamp wall temperature) was determined from graphs of lumen output vs minimum lamp wall temperature in the Illuminating Engineering Society Handbook, figure 8-34 [2]. Note that there are no thermal factors for lamps operated with solid-state ballasts. This is because their improved load-regulating circuits provide constant power to the lamps despite the large changes in lamp impedance at different lamp wall temperatures.

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[1] P.C. Sorcar, "Rapid Lighting Design and Cost Estimates," McGraw Hill Co., New York NY, pp. A36 and A37 (1979).

[2] J.E. Kaufman, ed., IES Lighting Handbook, 6th ed., Vol., IES of NA, New York, NY. pp. 8-29 (1981).

3.2 Manufacturer's Tolerance

3.2.1 Lamps

Typical manufacturer's tolerance of the initial rated light output of lamps is +0 to -5%. Table III is based on the assumption that the light output of commercial lamps is at the midpoint of tolerance, or -2.5%.

3.2.2 Ballasts

The CBM ballasts for operating F40 argon-filled lamps are designed to meet the ANSI limit of 95%, or a decrease of 5%. When these CBM ballasts drive a 35-watt krypton-filled lamp, the relative decrease in the lamp's rated light output typically will be between 10 and 15%. We have selected a conservative relative decrease of 10%. We have arbitrarily selected the same relative manufacturer's tolerance for the solid-state ballasts.

The table shows that the relative change in light output from the lamp manufacturer's rating, considering these three factors, can be as great as 14% in a two-lamp fixture and 27% in a four-lamp fixture. It is evident that the thermal factor predominates for higher lamp wall temperatures.

4.0 FACTORS AFFECTING INPUT POWER

Table IV lists the changes in input power for the nine lamp/ballast systems in two- and four-lamp fixtures.

4.1 Manufacturer's Tolerance

Ballast designs that provide less light than the rated light output also have a proportional decrease in input power so there is no change in system efficacy.

4.2 Thermal Factor

As the minimum lamp wall temperature increases, both light output and input power decrease. The values listed in Table IV were obtained from the graph of input power vs minimum lamp wall temperature plotted in the IES Reference Handbook [2]. The relative decrease in light output is greater than the relative decrease in power, resulting in a decrease in system efficacy at higher lamp wall temperatures. Lamps operated at lamp wall temperatures of 61°C or higher experience thermal factors as great as 25% and decreases in system efficacy of 10 to 15%. It is not uncommon to find lighting installations where lamps operate at even higher temperatures.

A solid-state ballasted system has no thermal factor. The final system efficacies listed in Table IV have been calculated from the input power and net light output given in Tables III and IV, respectively.

Notice that the system efficacies are significantly less (as much as 7%) than the bench values (listed in Table I) when one takes into account the factors that affect the light output and power input for the lamp/ballast system operating in a fixture.

5. DESIGN COSTS

The sample layout used here is for a room 100 ft long x 100 ft wide x 13 ft high, with an RCR of 1 and maintained illumination of 70 fc (100 fc initial). The cost of this layout depends on the number of fixtures required. The chart in the cost-estimating reference book [1] is used to obtain the area per fixture. The value found from the chart is for a light output of 3200 lumens per lamp. The net light output of each system listed in Table III is divided by 3200 and multiplied by the area per fixture as read from the chart to obtain the area per fixture for each ballast/lamp system. The number of fixtures is obtained by dividing the total floor area (100 ft x 100 ft = 10^4 ft^2) by the corrected area per fixture, which values are listed in Table V. The efficacy of the four-lamp fixture is 2% less than that of the two-lamp fixture. This decrease in efficiency is due to the shading effect from the additional reflections of the two added lamps. This geometric shading factor, which does not affect input power, is accounted for by reducing the light output of the lamp/ballast system. The values are listed in Table V.

The total cost of the layout is determined by multiplying the number of fixtures by the installed cost of each fixture ($97.75, $110.75) and by considering a premium cost for the efficient core and solid-state ballasts ($4 and $15, respectively) with respect to the cost of the standard CBM ballasts ($10), and a $2 premium cost for the non-standard lamps.

The layouts having lower fixture densities will have less uniform illumination. However, the spacing ratio of 1.0 or lower specified for this fixture is maintained for all layouts. The lowest density layout has 127 fixtures and a fixture density of 0.0127 fixture per ft^2. This is equivalent to an average linear spacing of 8.9 ft between fixtures. The ceiling height above the work space is 10 ft, and results in a spacing ratio 0.89. This is less than 1; thus the illumination uniformity is considered acceptable.

Table V shows that, for each ballast, the initial cost of the lighting system is lower for lamps that provide the greatest light ouput. This is because fewer fixtures are required even though there is a premium price for the F40 lite-white lamps. The initial cost of the lighting system is less between four-lamp fixtures because the cost is virtually the same as for the two-lamp fixtures and fewer four-lamp fixtures, are needed. There is a tradeoff in the uniformity of illumination between the two types of fixtures. One should notice that more lamps and ballasts will be required for the layout that uses four-lamp fixtures. This increases maintenance costs (replacement, cleaning, etc.). The number of four-lamp fixtures required is not 50% less than the number of two-lamp fixtures because of the higher thermal factor and the 2% decrease in fixture efficiency. The results show that ballast systems having no thermal factor (solid-state ballasts) approach a 50% reduction in fixture count for a four-lamp fixture layout (~51%). The system having the greatest light output and no thermal factor has the lowest initial cost. That is, the four-lamp fixture with solid-state ballasts and F40 lite-white fluorescent lamps is the least expensive arrangement at $1.89 per ft^2. This result is obtained even for a premium ballast and lamp cost of $15 and $2, respectively.

6 ENERGY COSTS

Table VI lists the energy performance of each layout considering an annual use of 3500 hours and an energy cost of $0.10 per kWh. For each type of ballast the lowest energy cost is achieved using the lamp that is most efficient and provides the greatest light output. Comparing operating costs for systems in two- and four-lamp fixture layouts, one finds that the two-lamp fixture layouts have a lower cost. This is due to the larger number of lamps and ballasts needed for the four-lamp fixture layouts. However, because of the lack of thermal factor, the operating costs for the solid-state ballasted system in the four-lamp fixtures are only 2 to 3% greater than for the two-lamp fixtures. This increase compares favorably with the other ballast systems, for which operating costs for four-lamp fixture layouts increase 6 to 7% relative to operating costs in a two-lamp fixture layout. The design that gives the lowest operating cost is the solid-state ballasted, F40 lite-white lamp in a two-lamp fixtures. However, one should note that this lamp/ballast system in the four-lamp fixture costs $10,203 less initially (35%) and has a slightly higher operating cost (1.5%).

7 FINAL REMARKS

This paper points out the important factors that affect input and output characteristics of a ballast/lamp system in a real environment. Although we used four-foot F40 systems, other ballast/lamp systems could also be considered. In order to compare them with the systems considered here, the same input-output characteristics must be known. This information must be supplied by the manufacturer.

The solid-state ballast systems have been compared using the same manufacturing tolerance (ballast factor) as the CBM core ballasts. The reader should be aware that there are no ANSI specifications for solid-state ballasts; ballast manufacturers can design any tolerance they desire. Some solid-state ballasts meet or exceed the ANSI ballast factor of 95%; others have a ballast factor (rated light output) more than 5% lower. The lighting designer should obtain this information from the ballast manufacturer.

Finally, we have used a sample fixture layout to show the relative tradeoffs (initial cost, operating costs) involved in using two- or four-lamp fixtures with different types of ballast/lamp systems. For renovations and new constructions, the key determinants of a cost-effective design are system efficiency, light output, and thermal factors. Power, the most visible cited parameter for ballast and lamp components, is of no value to the lighting designer when it is unrelated to the light provided by the ballast/lamp system in the fixture and the operating environment.

8 ACKNOWLEDGEMENT

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LIST OF TABLES

Table I

BALLAST/LAMP SYSTEM EFFICACY

Ballast/Lamp System	Input Power (watts)	Rated Light Output (lumens)	Efficacy (l/w)
St-F40	100	6300	63
St-Br	100	6900	69
St-35	91	6100	67
EC-F40	91	6300	69
EC-Br	82	6900	76
EC-35	79	6100	74
SS-F40	79	6300	80
SS-Br	79	6900	87
SS-35	71	6100	86

St Standard two-lamp F40 CBM ballast.
EC Efficient core two-lamp F40 CBM ballast.
SS Solid-state two-lamp F40 ballast.

F40 F40 T-12, rapid-start, cool-white lamp (argon-filled).
Br F40 T-12, rapid-start, lite-white lamp (argon-filled).
35 35-watt F40 T-12, rapid-start, lite-white lamp (krypton-filled).

Table II

FIXTURE DESCRIPTION - DESIGN TARGETS

Type	2 x 4 ft plastic-cube modular (2- & 4-lamp)
Louvers	45^{o} x 45^{o} light-stabilized polystyrene plastic egg-crate louver
Spacing ratio	1
Visual comfort probability	65 length/65 width
Maintenance Factor	0.7
Installed cost	
2-lamp	$97.25
4-lamp	$110.50
Illumination	
maintained	70 footcandles
initial	100 footcandles
Room cavity ratio (RCR)	1 (100 ft l x 100 ft w x 10 ft h)

TABLE III

LIGHT OUTPUT

Two-Lamp Fixtures

System	Light Output (lumens)	Lamp Wall Temperature (^oC)	Mfg. Tolerance lamp (%)	Mfg. Tolerance ballast (%)	Thermal Factor (%)	Net Light Output (lumens)
St-F40	6300	45	2.5	5	7	5420
St-Br	6900	45	2.5	5	7	5940
St-35	6100	44	2.5	10	5	5080
EC-F40	6300	44	2.5	5	5	5540
EC-Br	6900	44	2.5	5	5	6080
EC-35	6100	43	2.5	10	3	5200
SS-F40	6300	44	2.5	5	0	5840
SS-Br	6900	44	2.5	5	0	6400
SS-35	6100	43	2.5	10	0	5360

Four-Lamp Fixtures

System	Light Output (lumens)	Lamp Wall Temperature (^oC)	Mfg. Tolerance lamp (%)	Mfg. Tolerance ballast (%)	Thermal Factor (%)	Net Light Output (lumens)
St-F40	6300	54	2.5	5	21	4600
St-Br	6900	54	2.5	5	21	5040
St-35	6100	53	2.5	10	19	4340
EC-F40	6300	53	2.5	5	19	4720
EC-Br	6900	53	2.5	5	19	5180
EC-35	6100	52	2.5	10	17	4440
SS-F40	6300	53	2.5	5	0	5840
SS-Br	6900	53	2.5	5	0	6400
SS-35	6100	52	2.5	10	0	5360

Note: Systems are defined in Table I.

TABLE IV

INPUT POWER - EFFICACY

Two-Lamp Fixtures

System	Initial		Lamp Wall Temperature (°C)	Mfg. Tolerance Ballast (%)	Thermal Factor (%)	Final	
	Efficacy (1/W)	Power (W)				Efficacy (1/W)	Power (W)
St-F40	63	100	45	5	5	60	90
St-Br	69	100	45	5	5	66	90
St-35	67	91	44	10	3	64	79
EC-F40	69	91	44	5	3	66	84
EC-Br	76	91	44	5	3	72	84
EC-35	74	82	43	10	2	72	72
SS-F40	80	79	44	5	0	78	75
SS-Br	87	79	44	5	0	85	75
SS-35	86	71	43	10	0	84	64

Four-Lamp Fixtures

System	Initial		Lamp Wall Temperature (°C)	Mfg. Tolerance Ballast (%)	Thermal Factor (%)	Final	
	Efficacy (1/W)	Power (W)				Efficacy (1/W)	Power (W)
St-F40	63	100	54	5	16	58	80
St-Br	69	100	54	5	16	63	80
St-35	67	91	53	10	14	62	70
EC-F40	69	91	53	5	14	64	74
EC-Br	76	91	53	5	14	70	74
EC-35	74	82	52	10	12	68	65
SS-F40	80	79	53	5	0	78	75
SS-Br	87	79	53	5	0	85	75
SS-35	86	71	52	10	0	84	64

Note: Systems are defined in Table I.

TABLE V

SYSTEM COST

Two-Lamp Fixtures

System	Relative Fixture Eff. (%)	Light Output (lumens)	No. of Fixtures	Premium Cost/Fix. Ballast ($)	Premium Cost/Fix. Lamps ($)	System Cost Total ($)	System Cost per ft^2 ($)
St-F40	100	5420	295	-	-	28,689	2.86
St-Br	100	5940	269	-	4	27,236	2.72
St-35	100	5080	315	-	4	31,894	3.19
EC-F40	100	5540	289	4	-	29,261	2.93
EC-Br	100	6080	263	4	4	27,681	2.77
EC-35	100	5200	308	4	4	32,418	3.24
SS-F40	100	5840	274	15	-	30,757	3.08
SS-Br	100	6400	250	15	4	29,063	2.91
SS-35	100	5360	299	15	4	34,759	3.48

Four-Lamp Fixtures

System	Relative Fixture Eff. (%)	Light Output (lumens)	No. of Fixtures	Premium Cost/Fix. Ballast ($)	Premium Cost/Fix. Lamps ($)	System Cost Total ($)	System Cost per ft^2 ($)
St-F40	98	4500	172	-	-	19,669	1.97
St-Br	98	4940	162	-	8	19,197	1.92
St-35	98	4260	188	-	8	22,278	2.23
EC-F40	98	4620	173	8	-	20,501	2.05
EC-Br	98	5080	157	8	8	19,861	1.99
EC-35	98	4360	183	8	8	23,150	2.32
SS-F40	98	5760	140	30	-	19,670	1.97
SS-Br	98	6280	127	30	8	18,860	1.89
SS-35	98	5260	152	30	8	22,572	2.26

Note: Systems are defined in Table I.

TABLE VI

SYSTEM OPERATING COSTS

Two-Lamp Fixtures

System	Total Power (kW)	Annual Energy x 10^3 (kWh)	Power Density W/ft^2	Annual Operating Cost @ 10¢/kWh Total ($)	per ft^2 ($)
St-F40	26.6	93.1	2.7	9310	0.93
St-Br	24.2	84.7	2.4	8470	0.85
St-35	24.9	87.2	2.5	8715	0.87
EC-F40	24.3	85.1	2.4	8505	0.85
EC-Br	22.1	77.4	2.2	7735	0.77
EC-35	22.2	77.7	2.2	7770	0.78
SS-F40	20.6	72.1	2.1	7210	0.72
SS-Br	18.8	65.8	1.9	6580	0.66
SS-35	19.1	66.9	1.9	6685	0.67

Four-Lamp Fixtures

System	Total Power (kW)	Annual Energy x10^3 (kWh)	Power Density W/ft^2	Annual Operating Cost @ 10¢/kWh Total ($)	per ft^2 ($)
St-F40	28.4	99.4	2.8	9940	0.99
St-Br	26.0	91.0	2.6	9100	0.91
St-35	26.24	92.4	2.6	9240	0.92
EC-F40	25.6	89.6	2.6	8960	0.90
EC-Br	23.2	81.2	2.3	8120	0.81
EC-35	24.0	84.0	2.4	8400	0.84
SS-F40	21.0	73.5	2.1	7350	0.74
SS-Br	19.0	66.5	1.9	6650	0.67
SS-35	19.4	67.9	1.9	6790	0.68

Note: Systems are defined in Table I.

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