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APPLIED SCIENCE DIVISION

Performance of Electronic Ballasts and Other New Lighting Equipment (Phase II: The 34-Watt F40 Rapid Start T-12 Fluorescent Lamp)

R.R. Verderber and O. Morse

February 1988

APPLIED SCIENCE DIVISION

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PERFORMANCE OF ELECTRONIC BALLASTS AND OTHER NEW LIGHTING EQUIPMENT

(Phase II: The 34-watt F40 Rapid Start T-12 Fluorescent Lamp)

Research Project 2285-4

Phase II Final Report, February 1988

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Report Summary

Performance of Electronic Ballasts and Other New Lighting Equipment (Phase II)

Advanced lighting devices that reduce energy use by dimming lights or increasing the efficacy of lighting systems could have a profound effect on utility electric loads. Phase II of RP2285-4 has examined the new equipment operating the energy-saving 34-watt krypton-filled F40 fluorescent lamp, which is a different electrical load for a ballast than the 40-watt argon-filled F40 fluorescent lamp that was studied in Phase I.

BACKGROUND Most of the new energy efficient lighting systems have been designed to operate the standard 40-watt F40 fluorescent lamps. The lighting industry has introduced a 34-watt F40 krypton-filled lamp that will draw less power from the same lighting equipment (ballasts) than the 40-watt lamp. These lamps are being used more and more as retrofits as well as in new construction. Information on differences between the 34-watt and 40-watt lamps' system reliability, performance and effects upon the generating supply is of interest to utility companies.

OBJECTIVE To measure and evaluate the performance of auxiliary electric control equipment used to operate the 34-watt F40 fluorescent gas-discharge lamp and compare the results with the 40-watt F40 lamp.

APPROACH We measure the performances of solid-state ballasts, static lighting controls, and dynamic lighting controls all operating 34-watt F40 T-12 lamps. Three of each type device were purchased and the results averaged. The same devices that were used in Phase I to operate 40-watt F40 lamps were measured operating the 34-watt F40 lamps in Phase II. In addition, several recently introduced electronic ballasts were included in this report and were measured operating the 40-watt lamp, as well as the 34-watt F40 lamps. The data are organized to permit comparison between the various devices that have the same application, as well as the same device operating both the 40-watt F40 and the 34-watt F40 lamps.

RESULTS

- The major change in performance of solid-state ballast systems operating the 34-watt lamp rather than the 40-watt is a 4 percent decrease in the ballast factor, which reduces the manufacturer's initial rated light output by 18 percent compared to 14 percent for the 40-watt F40 lamp.

- The conductive coating used on the energy-saving 34-watt lamps to ease the starting when they are operated at 60 hertz requires a higher starting voltage when the lamps are operated at high frequency. This would contribute to reduced lamp life. The Phase I study also showed that some solid-state ballasts removed filament power after the lamp was ignited. This is another factor that could reduce lamp life. All of the latest solid-state ballast designs maintain some filament voltage on the lamps during operation.

- The 34-watt lamps have less flicker than the 40-watt lamps because of the different phosphors that are employed.

- The 34-watt lamp is more efficacious than the 40-watt lamp by about 6 percent; however, the system efficacy is only slightly improved because of increased losses in the ballast. The energy-saving lamps operate at an increased current, which increases the I^2R losses in the ballast.

The most efficacious solid-state ballast system measured was the solid-state ballast operating a T-8 fluorescent lamp; this system achieves 90 lumens per watt.

- The use of static controllers to reduce the light output of 34-watt F40 lamps can produce very large second harmonics and flicker under particular environmental conditions. In cooler ambient temperatures and in one and two-lamp open air fixtures, the minimum lamp wall temperature (MLWT) can be less than 34°C. The line current wave shape changes drastically and the lamp will flicker visibly. At higher ambient temperatures this problem does not appear.

- Dynamic controllers do not dim the 34-watt lamps over as large a range as they can dim the 40-watt F40 lamps. The efficacy of the dynamic control systems is not necessarily improved by the use of the 34-watt lamps. Greater flexibility is achieved for dynamic lighting controls with the 40-watt F40 lamps than with the 34-watt F40 lamps.

- Overall, the 34-watt F40 lamp delivers light at a higher cost than the 40-watt F40 lamp does. For a new construction or major renovations, the 34-watt lamp's performance does not warrant its preimum cost.

EPRI PERSPECTIVE

This report provides information on the state of the art in lighting equipment using 34W verses 40W F40 T12 fluorescent lamps. In addition to discussing the performance of solid-state ballasts and other control devices, it describes the effects those devices may have on the quality of electric service, identifies future research needs, and lists design parameters important in developing high-quality products. Tests of component reliability and lifetime were beyond the scope of the study.

PROJECT

RP2285-4 Phase II
EPRI Project Managers: Karl F. Johnson, Gary Purcell
Energy Management and Utilization Division
Contractor: Lawrence Berkeley Laboratory

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ABSTRACT

This study has measured the performance of energy-saving 34-watt F40, T-12, rapid-start, lite white fluorescent lamps being operated by solid-state ballasts and lighting control equipment. The performances of these lamp systems are compared with those of 40-watt F40, T-12 rapid-start cool white fluorescent lamp systems studied in the prior phase of this project.

With the 34-watt F40 lamps and various solid-state ballasts, system efficacy ranged from 67 to 84 lumens per watt and ballast factor from 0.756 to 0.908. Average system efficacy using the 34-watt lamps exceeded that of systems using 40-watt lamps and the same solid-state ballasts by only 1 percent even though the 34-watt lamps is about 6 percent more efficacious than the 40-watt lamp. This apparent discrepancy is due to increased ballast losses when operating the 34-watt lamps. However, the system efficacy of the 34-watt lamps used with a solid-state ballast exceeded that of a 34-watt, two-lamp system using the standard core-coil ballast by as much as 29 percent.

A T-8 fluorescent lamp system with a smaller lamp diameter was also included in the study. Operating this lamp with a solid-state ballast produced a high system efficacy of 90 lumens per watt, a 39 percent improvement over the efficacy of a 40-watt F40 system using the standard core-coil ballast.

The use of static controllers with 34-watt F40 lamps can result in excessive flickering (46 percent) and the generation of a second harmonic as high as 96 percent of the fundamental frequency.

The dynamic controllers, when used to dim the 34-watt lamps generally cannot be dimmed as low as the 40-watt lamp system without flickering.

In general, the 34-watt energy-saving lamps are appropriate as a retrofit to reduce illumination levels. However, for new construction, the 40-watt F40 argon filled lamps cost less, perform better, and provide a more reliable system.

ACKNOWLEDGEMENTS

We wish to acknowledge and thank the Electric Power Research Institute for their support of this work, especially the contributions of Mr. Karl F. Johnson, Mr. Gary Purcell, and Dr. Arvo Lannus.

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CONTENTS

CONTENTS
(Continued)

ILLUSTRATIONS

ILLUSTRATIONS
(continued)

TABLES

Section 1
INTRODUCTION

The initial phase of this study tested the performance of electronic ballasts and other auxiliary lighting operating 40-watt, F40,T-12, rapid-start, cool white fluorescent lamps. The ballasts are also specified to operate the 34-watt, F40,T-12, rapid-start, lite white lamps. These lamps differ from the 40-watt lamps in that they are designed to draw less power using the same ballast. The 34-watt lamps were conceived as a retrofit to lower light levels in overilluminated spaces, as an alternative to delamping and use of the phantom tube. The reduction in power results from backfilling the 34-watt lamps with krypton gas, rather than argon, which is used in the 40-watt lamps. This backfilling changes the electrical load for the ballast; the lamp is operated at a different voltage and current.

Phase II of this study examines the performance of electronic ballasts and other auxiliary equipment operating the "energy-saving" 34-watt F40 lamps. This report compares the performance of the two types of lamps and their effects on the operating equipment.

In the Phase I report,[1] eight electronic ballasts were evaluated. Since that time, several new ballasts have been developed and are included in this report. These new electronic ballasts were measured operating the 40-watt F40 lamps as well as the 34-watt, in order to make the report complete.

All of the test procedures that were employed in this study are described in the Phase I report,[1] Sections 3 and 4. To facilitate the comparisons between the 40-watt and 34-watt F40 lamps, we supply all of the data from both studies in the tables located in the appendixes to this report.

The next section of this report presents in graphic form the results measured for both lamps. It also discusses the results and points out the differences in performance between the 34-watt and 40-watt lamps. The conclusions of the study are summarized in the third section.

THE READER SHOULD BE AWARE THAT THE UNITS TESTED WERE OBTAINED FROM MANUFACTURERS THROUGH DISTRIBUTORS, RETAIL STORES, OR FACTORIES. WE TESTED A SMALL SAMPLE (THREE UNITS) OF EACH PRODUCT. ALTHOUGH THE TEST RESULTS MAY REFLECT GENERAL TRENDS, THE MEASURED VALUES PRESENTED IN THIS REPORT MAY NOT REPRESENT MEAN VALUES. IN ADDITION, SOME PRODUCTS TESTED IN THIS REPORT MAY NO LONGER BE ON THE MARKET OR MAY HAVE BEEN REDESIGNED. NONETHELESS, THE RESULTS PROVIDE AN UNDERSTANDING OF THE RANGE OF PERFORMANCE ONE CAN EXPECT FROM EACH TYPE OF BALLAST, STATIC CONTROLLER, AND DYNAMIC CONTROLLER.

Section 2
RESULTS

TWO-LAMP ELECTRONIC FLUORESCENT BALLASTS

In the Phase I report, eight types of two-lamp, F40, rapid-start ballasts were measured. Since that time, several new ballast designs have been introduced and are included in this study. We measured the new ballasts operating the 40-watt lamps as well as the 34-watt lamps. All of the data on the 40-watt and 34-watt lamps are listed in Tables A-1 and A-2, located in Appendix A.

BALLAST INPUT

Power:

The range of input power to electronic ballasts operating 40-watt F40 and 34-watt F40 lamps is shown in Figure 2.1. The average input for all of the electronic ballasts, of each voltage type, is indicated by the line through the range of values. The power inputs for a standard Certified Ballast Manufacturers (CBM) core-coil ballast operating each type of lamp are shown as solid rectangles. The input power for both the core-coil ballast and the electronic ballast systems decreases by about 15 percent when the ballast operates the 34-watt lamps. The range of input power for the different electronic ballast systems is from 85 to 63 watts with the 40-watt lamps and is reduced to 72 to 56 watts with the 34-watt lamps. The system power is clearly reduced by about 13 percent when the energy-saving lamps are used in place of the 40-watt F40 lamps.

Power Factor:

The range of power factors for the electronic ballast is shown in Figure 2.2. The power factor of the electronic ballast operating either type lamp is about the same. A ballast system with a power factor value of 0.90 or greater is designated as a high- power-factor ballast. The power factor for core-coil ballasts operating 34-watt lamps is reduced by about 4 percent.

Harmonics:

The measured range of the third and fifth harmonics for the electronic ballasts is shown in Figure 2.3. The harmonic content for standard core-coil ballasts is higher for the 34-watt lamps, than for the 40-watt lamps. The harmonic content for the two types of lamps operated with the electronic ballasts is virtually unchanged. However, the third harmonic for either type of lamp operated with the electronic ballasts is greater than when they are operated with the core-coil ballasts.

FIGURE 2.1

INPUT POWER FOR ELECTRONIC BALLASTS OPERATING F40 LAMPS

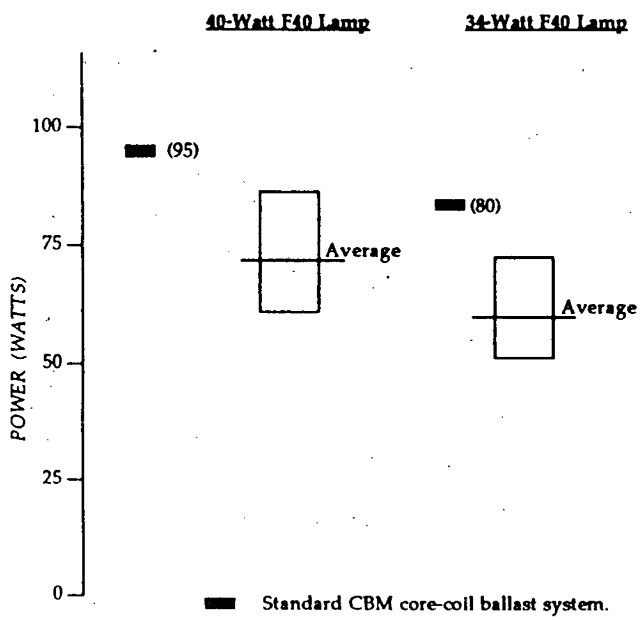


FIGURE 2.2

POWER FACTOR FOR ELECTRONIC BALLASTS OPERATING F40 LAMPS

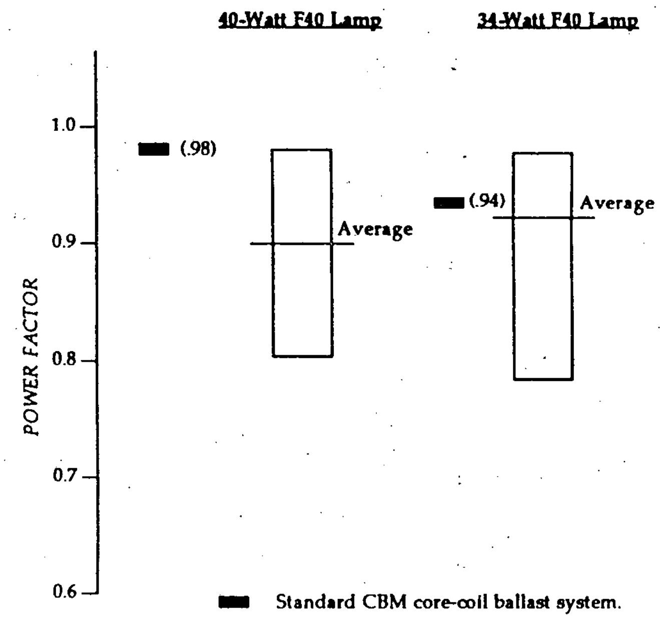
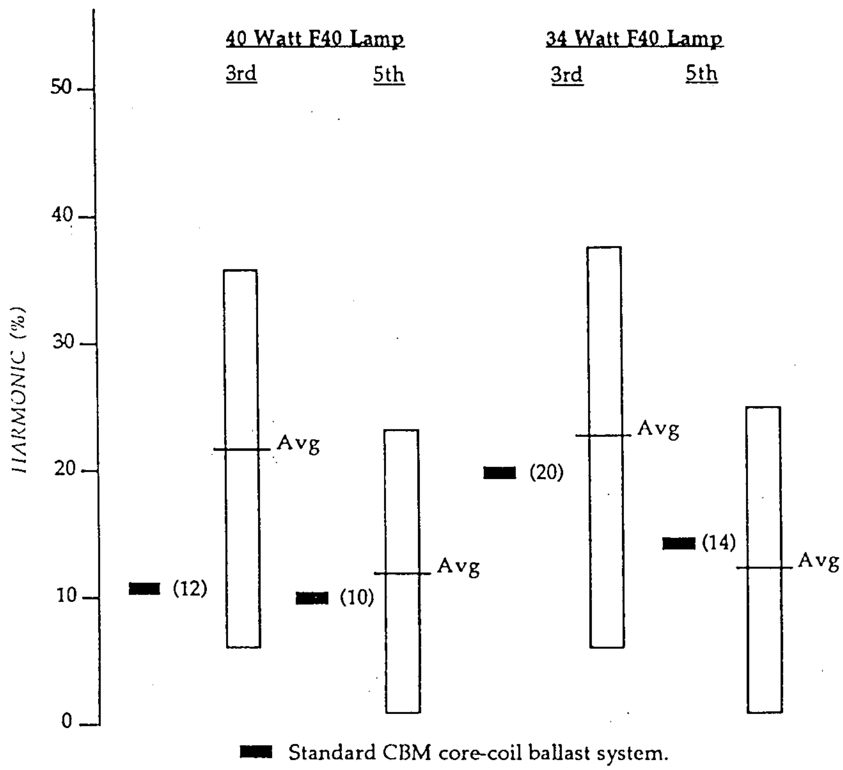


FIGURE 2.3

THIRD AND FIFTH HARMONIC FOR
ELECTRONIC BALLASTS OPERATING F40 LAMPS



LAMP INPUT

Ballast Factor:

The ballast factor is a metric that defines the relative light output provided by a ballast-lamp system with respect to the manufacturers rated light output for the lamp specified in their catalog.

The ballast factor for core-coil ballasts operating 34-watt lamps is 8 percent lower than for the same ballasts operating the 40-watt lamps. As shown in Figure 2.4, the average reduction in ballast factor is only 4 percent when electronic ballasts are used. There is a 10 to 15 percent range in the ballast factors for electronic ballasts designed by different manufacturers. The high ballast factor ballasts are most economical for new construction applications, while the low ballast factor ballasts are used as retrofits in overilluminated spaces. That is, in new construction the high light output systems would require fewer fixtures to produce a particular illumination level; in retrofits in overlit spaces the illumination levels could be reduced.

Filament Voltage:

The filament voltage applied to lamps by most electronic ballasts (2.1 to 2.4 volts) is less than that applied by a standard CBM core-coil ballast (3.4 to 3.6 volts). Figure 2.5 shows that some electronic ballasts remove all of the filament voltage during operation. This effect will tend to reduce lamp life, but it will also reduce the power and result in a more efficient system. The latest electronic ballast designs, labeled A to G, no longer remove all of the filament power (see Tables A-1 and A-2).

Lamp Current Crest Factor:

At 60 hertz the lamp current crest factor is greater for the 34-watt lamp than for the 40-watt lamp. There is virtually no difference in lamp current crest factor for the two types of lamps with the electronic ballasts, as shown in Figure 2.6. Generally, the crest factor is greater for the electronic ballast systems. However, lamp current crest factors range from 2.2 to 1.3. The higher lamp current crest factors, above the 1.7 ANSI recommended limit, could contribute to reduced lamp life.

Open Circuit Voltage:

The measured open circuit voltage for the electronic ballasts is considerably greater than that measured for the standard core-coil CBM ballast. The average and the range of values measured for the electronic ballast are shown in Figure 2.7. The higher open circuit voltage will permit the lamps to start in a cooler ambient temperature. However, at higher ambient temperatures the actual starting voltage will be considerably less than the available open circuit voltage, especially if the filaments are suitably heated.

FIGURE 2.4

BALLAST FACTOR FOR ELECTRONIC BALLASTS OPERATING F40 LAMPS

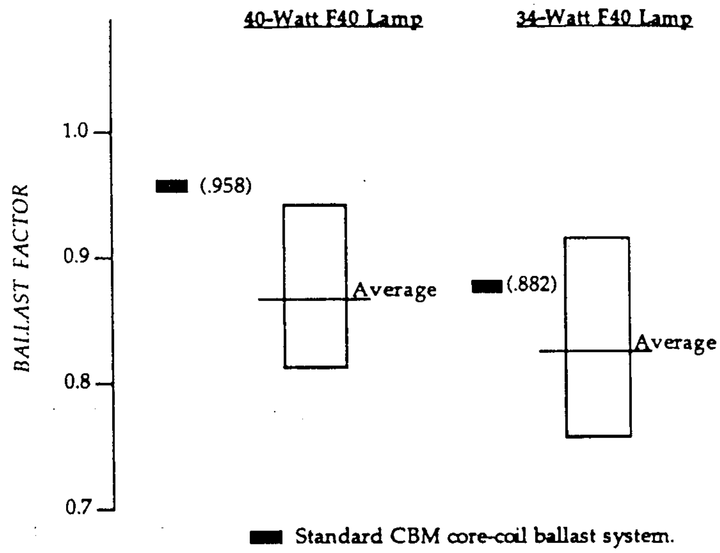


FIGURE 2.5

FILAMENT VOLTAGE FOR ELECTRONIC BALLASTS OPERATING F40 LAMPS

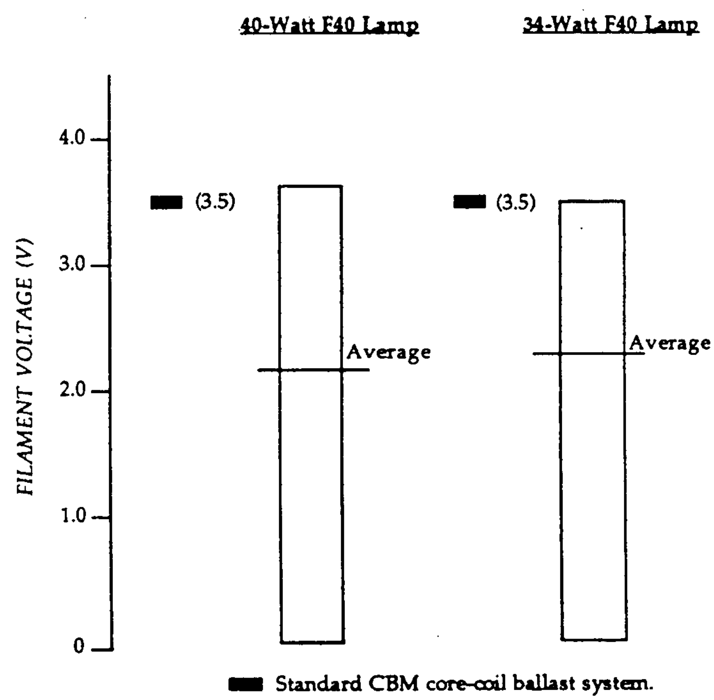


FIGURE 2.6

LAMP CURRENT CREST FACTOR FOR
ELECTRONIC BALLASTS OPERATING F40 LAMPS

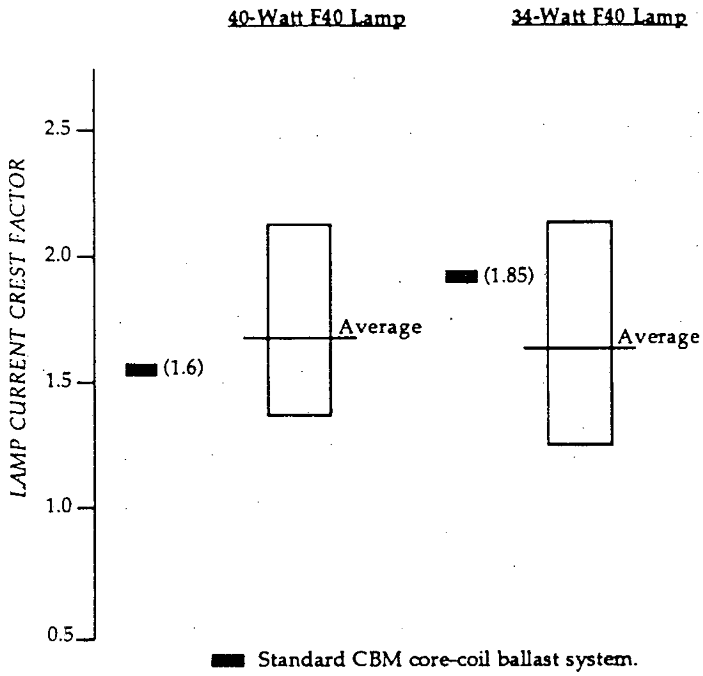
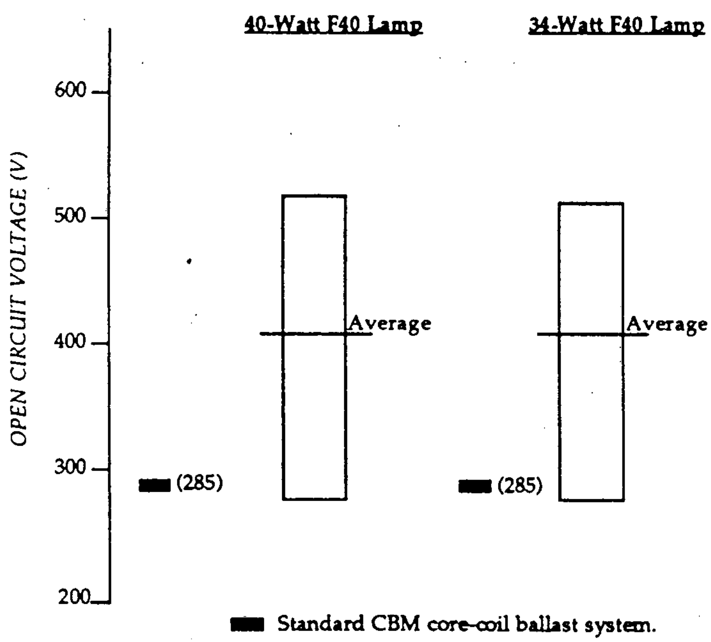


FIGURE 2.7

OPEN CIRCUIT VOLTAGE FOR ELECTRONIC
BALLASTS OPERATING F40 LAMPS



Open Circuit Voltage Crest Factor:

Figure 2.8 shows the range of values for the open circuit voltage crest factor for the electronic ballasts. The average values are about the same as those measured for the core-coil ballast. Some electronic ballasts have a value slightly above the recommended maximum of 2.0. The higher crest factors increase the degradation of the filaments at starting.

Flicker:

The range of flicker measured for the electronic ballast operating both types of lamps is shown in Figure 2.9. In general, the percent flicker is much lower when the lamps are operated at high frequency (with electronic ballasts) than at 60 hertz (with a core-coil ballast). In fact, some lamps operated at high frequency with an unmodulated waveform have no flicker. A few electronic ballasts have fully modulated wave shapes at 60 hertz which results in a percent flicker as high as that which occurs with the core-coil ballast. The 34-watt lite white lamps have a lower percent flicker than the 40-watt cool white lamps, because of the extra quantity of a yellow-emitting phosphor in the mix. The red- and yellow-emitting phosphors generally have a larger persistence than the blue emitting phosphors.

SYSTEM OUTPUT

Light Regulation:

The change in the light output for a ±10 percent change in the input voltage to the ballast is shown in Figure 2.10. In general, the light regulation is poorer for the average electronic ballast in which the light output changes by 17 percent for a 10 percent change in the input voltage. However, the large range in the regulation for the various electronic ballasts shows that ballasts can be designed with tight or loose regulation. That is, some electronic ballasts show no change in light output for a ±10 percent change in the input voltage; others show a large change.

Light Output:

Lighting designers need to know the light output for each ballast-lamp system in order to select the optimum lamp-ballast to meet their illumination needs. The range of light output from the lamps operated with the different electronic ballasts is about 10 to 15 percent. The change in the light output for all types of ballast (core-coil and electronic) operating the 34-watt F40 lamps is about 13 percent lower than the output for ballasts operating the 40-watt cool white lamp. The data are shown in Figure 2.11. We see that the reduction in power for ballast operating the 34-watt lamps also results in a proportional reduction in the light output.

FIGURE 2.8

OPEN CIRCUIT CREST FACTOR FOR
ELECTRONIC BALLASTS OPERATING F40 LAMPS

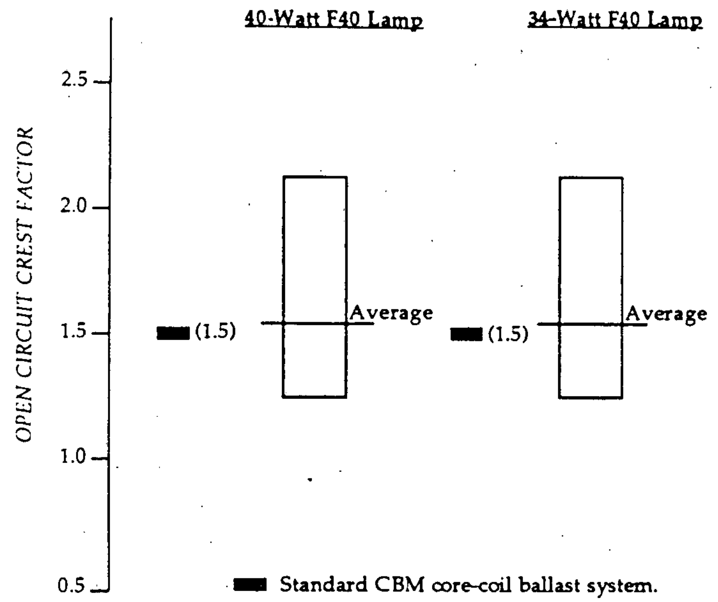


FIGURE 2.9

FLICKER FOR ELECTRONIC BALLASTS
OPERATING F40 LAMPS

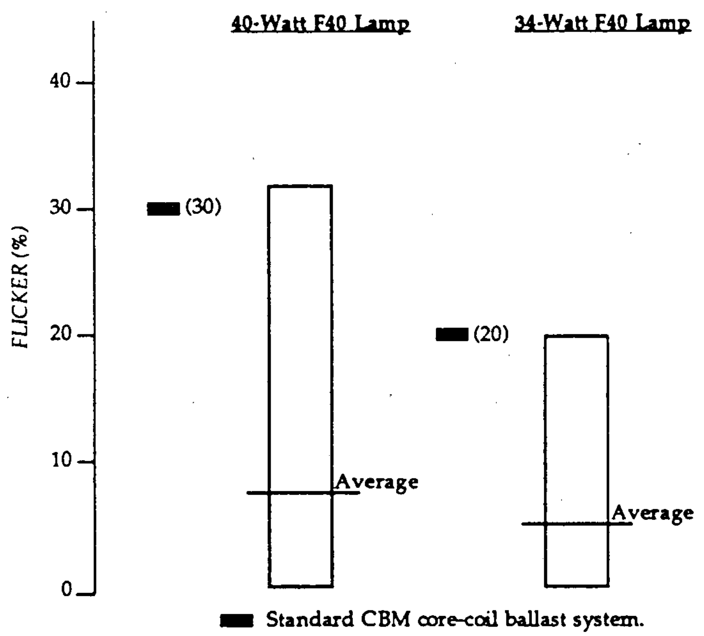


FIGURE 2.10

LIGHT OUTPUT REGULATION FOR ELECTRONIC BALLASTS OPERATING F40 LAMPS

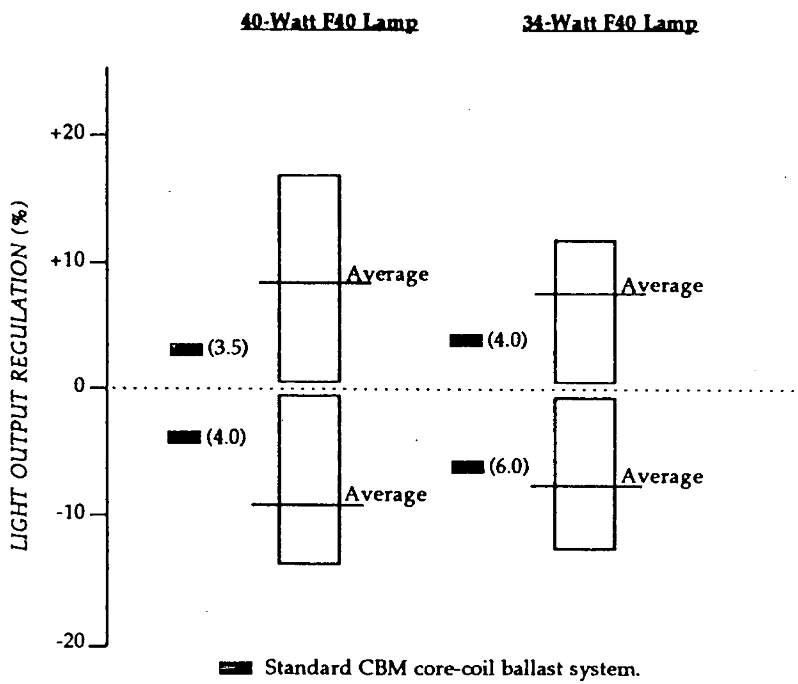
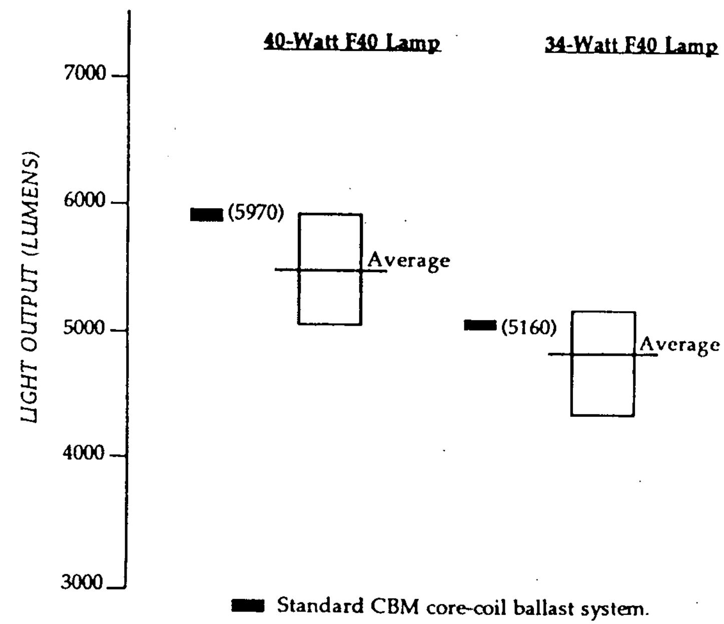


FIGURE 2.11

LIGHT OUTPUT FOR ELECTRONIC BALLASTS OPERATING F40 LAMPS



System Efficacy:

Figure 2.12 shows the efficacy of the electronic ballast system for both types of lamps. The average efficacy is 79 to 80 lumens per watt for the electronic ballast systems with either lamp. Some of the ballast designs achieves an efficacy of 83 to 84 lumens per watt. It is important to notice the very slight increase (~1 percent) in the system efficacy for the 34-watt system, even though the 34-watt lamp is about 6 percent more efficacious than the 40-watt lamp, see Table 2.1. Thus, the system efficacy is about the same for a ballast operating either lamp. We discuss the reason for this in the following section. In general, the electronic ballast systems are 20 percent more efficient than the core-coil systems operating the same lamp.

OTHER F40 SYSTEMS

Table 2.2 lists the results of the measurement for F40 lamps other than the standard two-lamp system. This includes a T-8 (1-inch diameter) lamp that requires a special ballast design for both the core-coil and electronic ballasts. The lamps are specified to be started and operated without filament (instant start). In this mode, with an electronic ballast, a system efficacy of 90 lumens per watt is attained. The smaller diameter lamp can result in an increased fixture efficiency, since the smaller diameter can improve optical control and reduce shadowing effects.

There are also core-coil ballast-lamp systems that are designed to operate without filament voltage. When these system are started, filament voltage is applied, and when the lamp is ignited, the ballast uses circuitry to remove filament power. This two-lamp system has relatively low light output, 4820 lumens, and a system efficacy of 81 lumens per watt.

The remaining systems measured in Table 2.2 are electronic ballasts designed to operate three or four F40 T-12 lamps. The use of a single ballast to operate more than two lamps reduces the initial cost of the ballast per lamp. In addition, the ballast losses are generally reduced per lamp the greater the number of lamps a ballast operates, e.g., one-lamp ballasts are less efficient than two-lamp ballasts, etc.

MINIMUM LAMP WALL TEMPERATURE (MLWT)

In the Phase I report the data were measured with the lamps at a MLWT of 40°C and 50°C, to show the changes in power and light output that occurred. In any application the lamps may operate at a MLWT between 35°C and 60°C. We have constructed an integrating chamber[2] that controls the ambient temperature from 10°C to 60°C. The curves of light output and efficacy versus MLWT for all of the two-lamp F40 systems are plotted in Figure 2.13 (a-l), operating both the 40-watt and 34-watt F40 lamps.

TABLE 2.1
DETAILED CHARACTERISTICS OF CORE-COIL BALLASTS OPERATING F40 LAMPS

	40 Watt F40 Lamp	34 Watt F40 Lamp
Ballast Input		
Voltage (V)	120	120
Current (A)	0.798	0.715
Power (W)	93.4	78.9
Power Factor	0.975	0.920
Lamp Input		
Voltage (V)	99.6	81.6
Current (A)	0.416	0.460
Cathode Voltage (V)	3.5	3.5
Ballast Factor	0.97	0.88
System Output		
Light Output (lm)	5970	5160
Flicker (%)	30	21.2
Harmonics - 3rd	12.3	19.7
Harmonics - 5th	9.6	14.3
Ballast Efficiency (%)	0.804	0.762
Lamp Efficacy (lm/W)	81.2	87.4
System Efficacy (lm/W)	64	65

TABLE 2.2
OTHER FLUORESCENT BALLAST SYSTEMS

CHARACTERISTIC	Percent of Center Volts	Two Lamp T-8 32W Lamp Core-Coil	Two Lamp T-8 32W Lamp Solid-State	Two Lamp 60 Hz Ø Filament Ballast 28W Lamp	Three Lamp F40 Ballast Core-Coil 40	Three Lamp F40 Ballast Core-Coil 34	Three Lamp F40 Ballast Solid-State 40	Three Lamp F40 Ballast Solid-State 34	Four Lamp F40 120V Core-Coil 40	Four Lamp F40 120V Core-Coil 34	Four Lamp F40 120V Solid-State 40	Four Lamp F40 120V Solid-State 34	Four Lamp F40 277V Core-Coil 40	Four Lamp F40 277V Core-Coil 34	Four Lamp F40 277V Solid-State 40	Four Lamp F40 277V Solid-State 34
SYSTEM INPUT																
	90	63	60	56	136	120	118	101	171	148	122	106	169	151	126	108
Power (W)	100	71	65	60	148	129	121	103	184	148	136	110	187	162	138	113
	110	77	72	64	160	139	124	105	196	168	135	109	203	176	138	114
	90	88	93	.99	99	97	.96	96	98	93	95	96	100	97	93	93
Power Factor	100	86	89	.97	98	97	95	95	97	93	94	94	100	96	92	92
	110	80	88	.92	96	95	95	94	96	93	94	92	99	96	91	90
Harmonics - 3rd (%)	100	7	43	15	4	13	10	10	12	17	17	17	7	15	12	12
- 5th (%)	100	6	6	14	8	10	12	14	9	14	14	15	9	12	20	23
LAMP INPUT																
	90	300	498	225	265	265	461	428	262	262	696	696	266	266	776	776
Open Circuit Voltage (V)	100	322	548	242	287	287	461	425	284	284	768	768	288	288	867	867
	110	344	600	258	310	310	462	428	306	306	845	845	310	310	957	957
	90	1.6	1.4	1.6	1.3	1.5	1.3	1.5	1.5	1.5	1.3	1.3	1.5	1.5	1.5	1.5
Open Circuit Crest Factor	100	1.7	1.4	1.5	1.3	1.5	1.3	1.5	1.5	1.5	1.4	1.4	1.5	1.5	1.5	1.5
	110	1.7	1.4	1.6	1.3	1.6	1.3	1.5	1.6	1.6	1.3	1.3	1.6	1.6	1.5	1.5
	90	3.5	0	0	3.1	3.1	2.0	2.0	3.2	3.2	2.1	1.7	3.0	3.0	2.0	1.8
Filament Voltage (V)	100	3.9	0	0	3.5	3.5	2.1	2.1	3.6	3.6	2.0	1.6	3.4	3.4	2.0	1.7
	110	4.3	0	0	3.9	3.9	2.0	2.0	4.1	4.1	2.0	1.6	3.8	3.8	2.0	1.6
	90	1.4	1.6	1.5	1.8	1.8	1.5	1.5	1.5	1.8	1.6	1.6	1.6	1.7	1.7	1.7
Lamp Current Crest Factor	100	1.3	1.5	1.6	1.8	1.8	1.5	1.4	1.6	1.9	1.7	1.6	1.6	1.8	1.7	1.7
	110	1.4	1.6	1.7	1.9	1.9	1.5	1.4	1.7	1.9	1.7	1.7	1.6	1.8	1.7	1.8
	90	4840	5330	4570	8470	7470	9080	8030	11540	9990	9780	8840	11160	9880	10140	8910
Light Output (lm)	100	5360	5820	4820	8970	7780	9250	8090	12200	10300	11110	9250	11930	10320	11200	9350
	110	5700	6280	5020	9350	8050	9340	8160	12620	10560	11140	9200	12560	10750	11170	9380
Ballast Factor	100	.924	1.003	.824	.949	.887	.978	.922	.968	880	.882	791	.947	882	889	799
Light Regulation (%)	90	-10	-8	-5	-6	-4	-2	-1	-5	-3	-12	-4	-6	-4	-10	-5
	110	+6	+8	+4	+4	+4	+1	+1	+4	+3	0	-1	+5	+4	0	0
Percent Flicker (%)	100	25	1	18	28	20	4	2	30	22	1	0	28	20	0	0
	90	76	89	82	62	62	77	80	67	67	80	83	66	65	80	82
System Efficacy	100	76	90	81	61	60	76	78	66	65	82	84	64	64	81	63
	110	74	87	78	58	58	75	78	65	63	82	85	62	61	81	82
	90	36	36	35	36	36	36	35	40	38	39	37	42	37	40	37
Lamp Wall	100	37	39	35	36	36	36	35	40	38	39	37	42	37	40	37
Temperature (°C)	110	38	39	36	36	36	36	35	40	38	39	37	42	37	40	37

FIGURE 2.12

SYSTEM EFFICACY FOR ELECTRONIC BALLASTS OPERATING F40 LAMPS

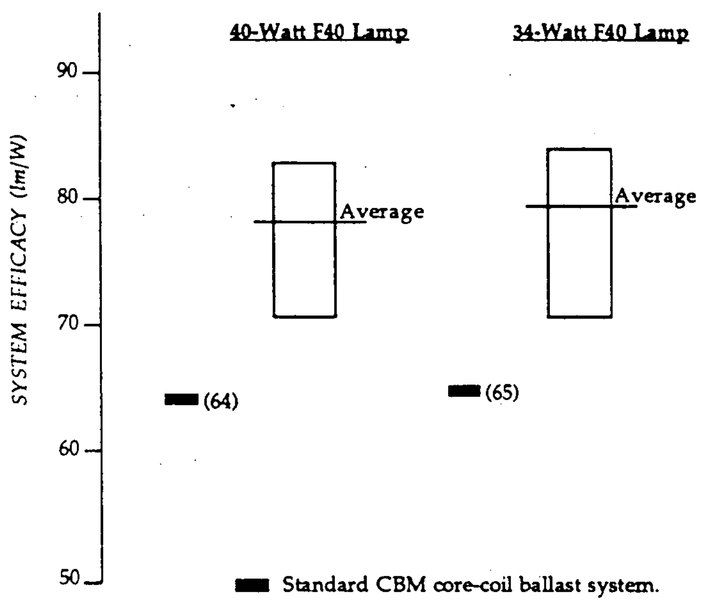


FIGURE 2.13

TEMPERATURE DEPENDENCE OF LIGHT OUTPUT AND EFFICACY
FOR 40 WATT AND 34 WATT LAMPS

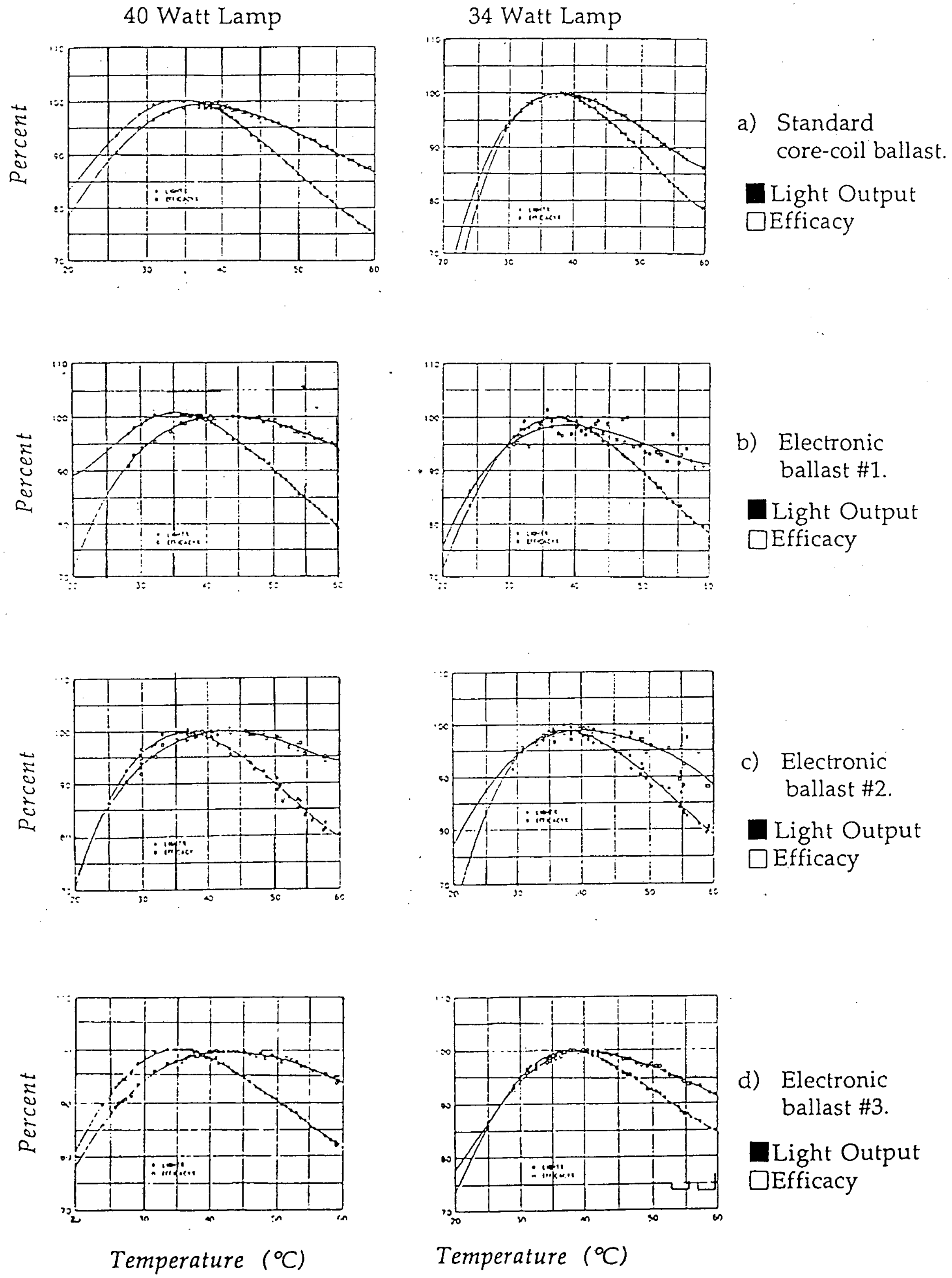


FIGURE 2.13

TEMPERATURE DEPENDENCE OF LIGHT OUTPUT AND EFFICACY FOR 40 WATT AND 34 WATT LAMPS

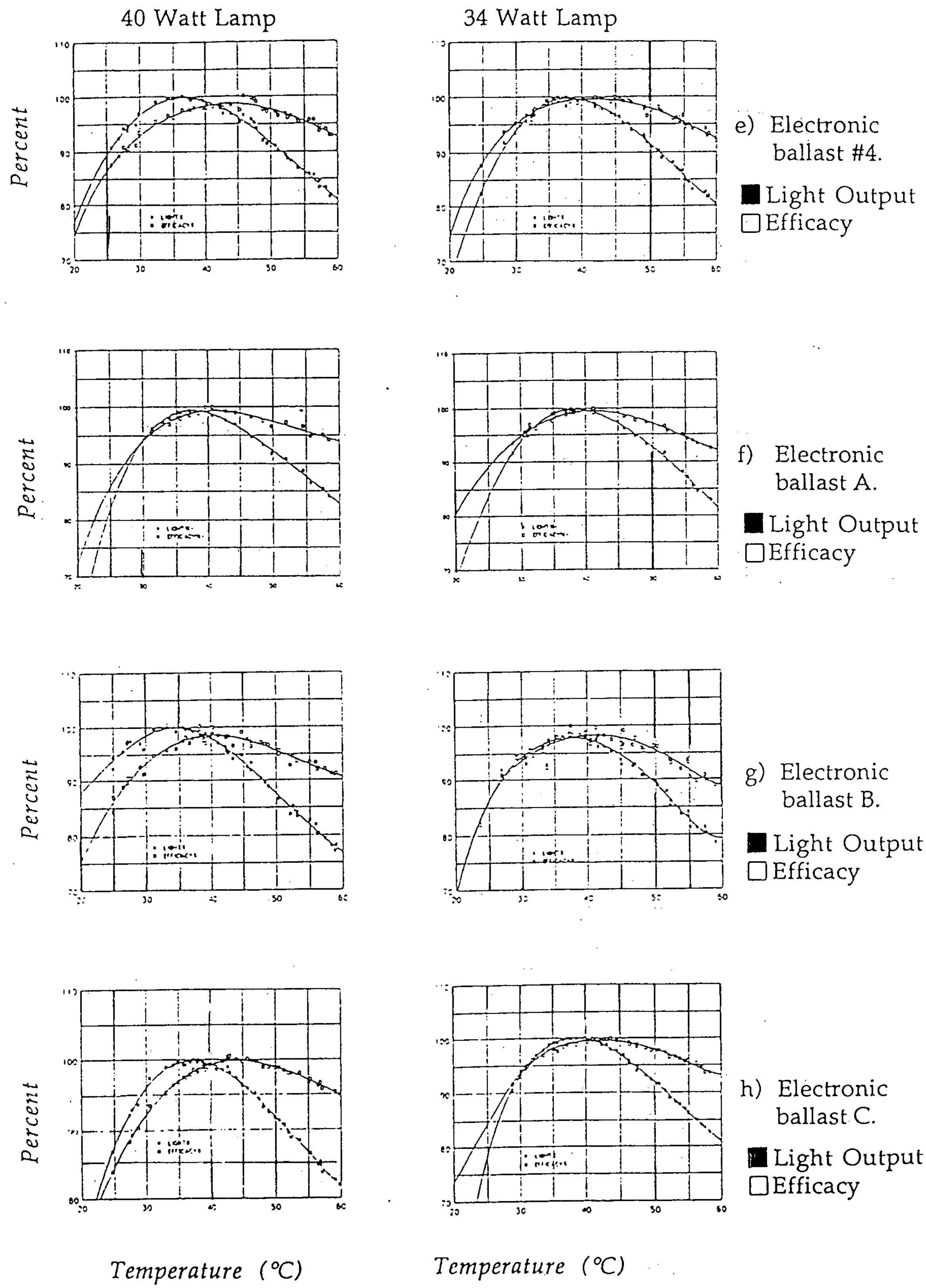
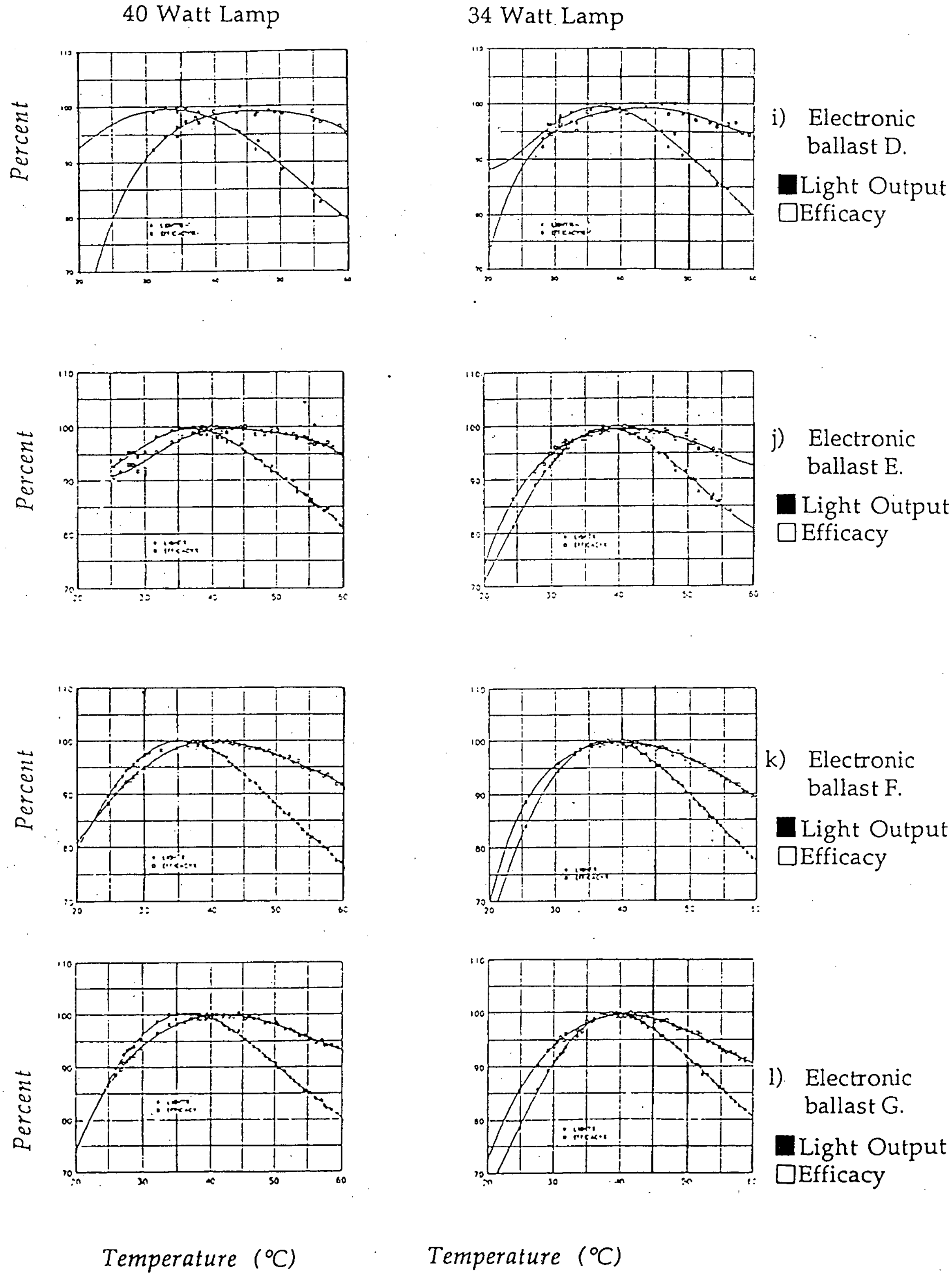


FIGURE 2.13

TEMPERATURE DEPENDENCE OF LIGHT OUTPUT AND EFFICACY FOR 40 WATT AND 34 WATT LAMPS



In general, the maxima of the light output curves are at a slightly lower MLWT than the maxima of the efficacy curve, for the 40-watt lamps. The maxima for the 34-watt lamps are at about the same MLWT (~37°C).

The light output and efficacy for the core-coil 40-watt lamp system decrease by 25 and 15 percent, respectively, from their maximum values at a MLWT of 60°C. In general, the change in light output and efficacy for the electronic ballasts and 40-watt lamps is only 20 and 7 percent, respectively, at a MLWT of 60°C. The temperature dependence of the 34-watt lamps is about the same as that for the 40-watt lamps, except that at the temperatures below the peak, the rate of decrease in light output and efficacy is much greater for the 34-watt lamps. There is also a variation in the temperature dependence for the electronic ballast systems, e.g., some ballasts have excellent thermal regulation and their efficacy decreases by only 5 percent at 60°C (ballasts 1, 2, 3 and C--all are operating 40-watt lamps).

ELECTROMAGNETIC INTERFERENCE

The conducted and radiated electromagnetic currents and fields measured for the electronic ballast operating two F40 lamps are listed in Table 2.3; the average value of each of the measurements is given. It is evident that there is no significant difference in the conducted and radiated EMI values between the ballasts operating the 40-watt and 34-watt F40 lamps.

STATIC CONTROLS

Seven static control systems were measured. These devices are designed to lower the light output of the two-lamp, four-foot, F40, T-12 rapid-start systems. The specific performances of each of the systems, for both the 40-watt and 34-watt lamp, are listed in the Appendix B.

The devices are specified to reduce the light output by about either 30 or 50 percent. Devices #1 and #4 are installed on the line power side of the ballast, while all of other static controllers are installed between the ballast and lamp.

Figure 2.14 plots the average and the range of values of the input power and line power factor for the seven units tested operating 40-watt and 34-watt lamps. The small solid rectangles are the input power and power factor of the ballast operating the two 40-watt and 34-watt lamps. All of the devices reduce the input power by virtually the same amount, i.e., the range of values is small. The line power factor is also reduced by these devices. The decrease in power factor is much greater for the 34-watt lamps. Two of the units, #1 and #4, result in the greatest decrease in power factor; these are the systems that are installed on the line side of the ballast.

FIGURE 2.14

POWER AND POWER FACTOR FOR F40 LAMPS USING 30% AND 50% STATIC CONTROLLERS

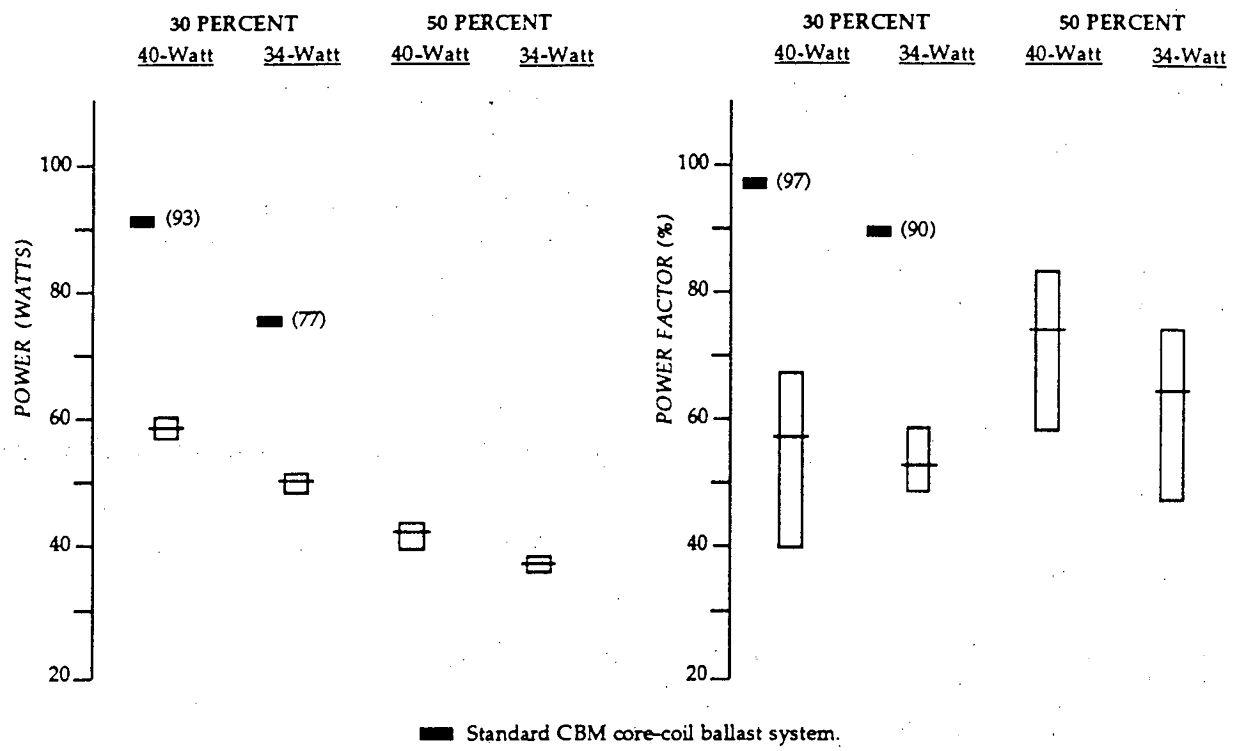


TABLE 2.3
CONDUCTED AND RADIATED ELECTROMAGNETIC INTERFERENCE

	40 Watt F40 Lamp			34 Watt F40 Lamp		
	Radiated	Conducted*		Radiated	Conducted*	
Ballast #	dBμV/M	dBμA_1*	dBμA_2*	dBμV/M	dBμA_1	dBμA_2
1	98	98	98	103	97	96
1 - Dimmed	107	86	85	100	87	86
2	135	77	69	135	77	68
3	111	58	52	112	56	53
4	127	70	67	129	71	68
6	108	93	93	105	92	91
6 - Dimmed	109	78	78	108	81	81
7	131	74	56	132	75	57
8	116	64	61	114	65	61
A	132	80	78	133	79	77
B	129	70	66	130	71	68
B - Dimmed	129	78	77	130	78	76
C	119	53	53	119	54	53
D	135	84	72	135	83	70
E	129	67	60	129	67	67
F	103	67	67	104	68	67
G	102	65	64	98	56	55
H	125	65	61	126	65	61
H - Dimmed	126	76	74	127	78	76
I	119	54	54	118	55	54
J	136	83	76	135	82	75
K	111	64	62	107	63	62
T-8	130	66	62	-	-	-
Average	120	73	69	120	72	69

* Impedance Source A_1 50 μH
Impedance Source A_2 250 μH

Figure 2.15 plots the average and the range of light output and percent flicker of the two-lamp F40 system with the static controllers. There is a large decrease in the light output of these systems.

One observes little change in the percent flicker for the 40-watt lamps with the 30 percent static controllers. Although the 34-watt lamps have less flicker than the 40-watt lamps, the percent flicker increases to 40 percent when the static controller is used. With the 50 percent static controller there is less of an increase in the percent flicker.

Figure 2.16 summarizes the input-output performance of the F40 lamp systems with the static controllers. This figure plots the relative change in the power, light output and efficacy. The 30 percent static controller shows a 35 percent decrease in both light output and input power, resulting in virtually no change in system efficacy. For the 34-watt and the 50 percent static controller all of the other data show a greater decrease in light output than power, hence a loss in system efficacy. The figure shows that the average decrease in efficacy is 8 to 14 percent. The decrease in light output for the 34-watt lamp is greater than the decrease in power, which results in a 10 to 15 percent decrease in efficacy.

Figure 2.17 shows the absolute values of the system efficacy and the current crest factor. The results show a drop in efficacy of 7 percent for the 34-watt lamp and a 5 to 10 percent drop for the lamps when the 50 percent static controller is used.

If lamp current crest factor is too high, lamp life is reduced. ANSI specifies a maximum current crest factor of 1.7. The standard ballast operating a 34-watt lamp has a crest factor exceeding 1.7 and, except for the 40-watt lamp with the 30 percent static controller, there is an increase in the crest factor for the static controllers operating 34-watt lamps. While the lamp life depends upon several factors the high crest factor will contribute to the reduction in the lamp's life.

Figure 2.18 is a plot of the 2nd, 3rd, and 5th harmonics for all of the lamp-static controller combinations. For the 30 and 50 percent static controller operating the 40-watt lamp there is an increase in only the third harmonics. The 34-watt lamps also exhibit an increase in the third harmonic. However, the second harmonic is increased by a factor of seven with the 34-watt lamps, becuase of a large distortion in the wave shape.

DYNAMIC CONTROLS

The detailed performances of the core-coil and solid-state ballast dimming systems are listed in Appendix C.

FIGURE 2.15

LIGHT OUTPUT, FLICKER FOR F40 LAMPS USING 30% AND 50% STATIC CONTROLLERS

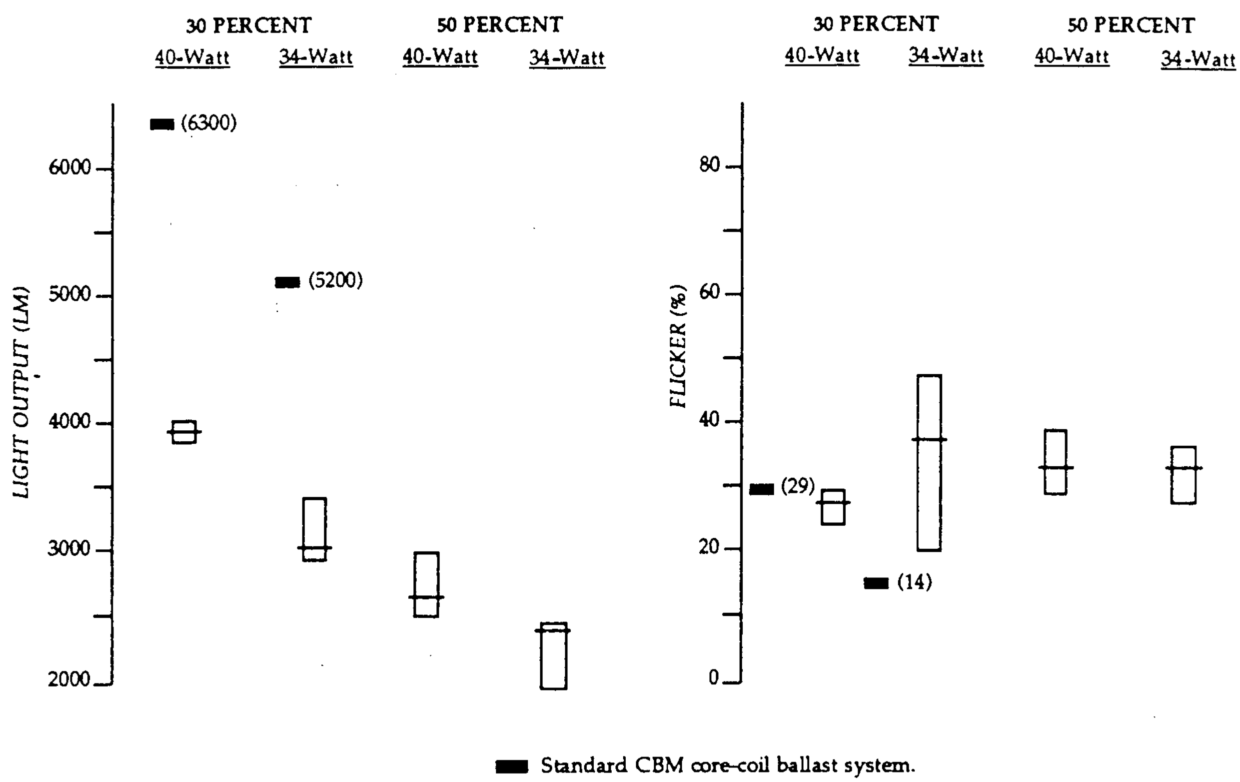


FIGURE 2.16

RELATIVE CHANGE IN POWER, LIGHT OUTPUT AND EFFICACY FOR F40 LAMPS USING 30% AND 50% STATIC CONTROLLERS

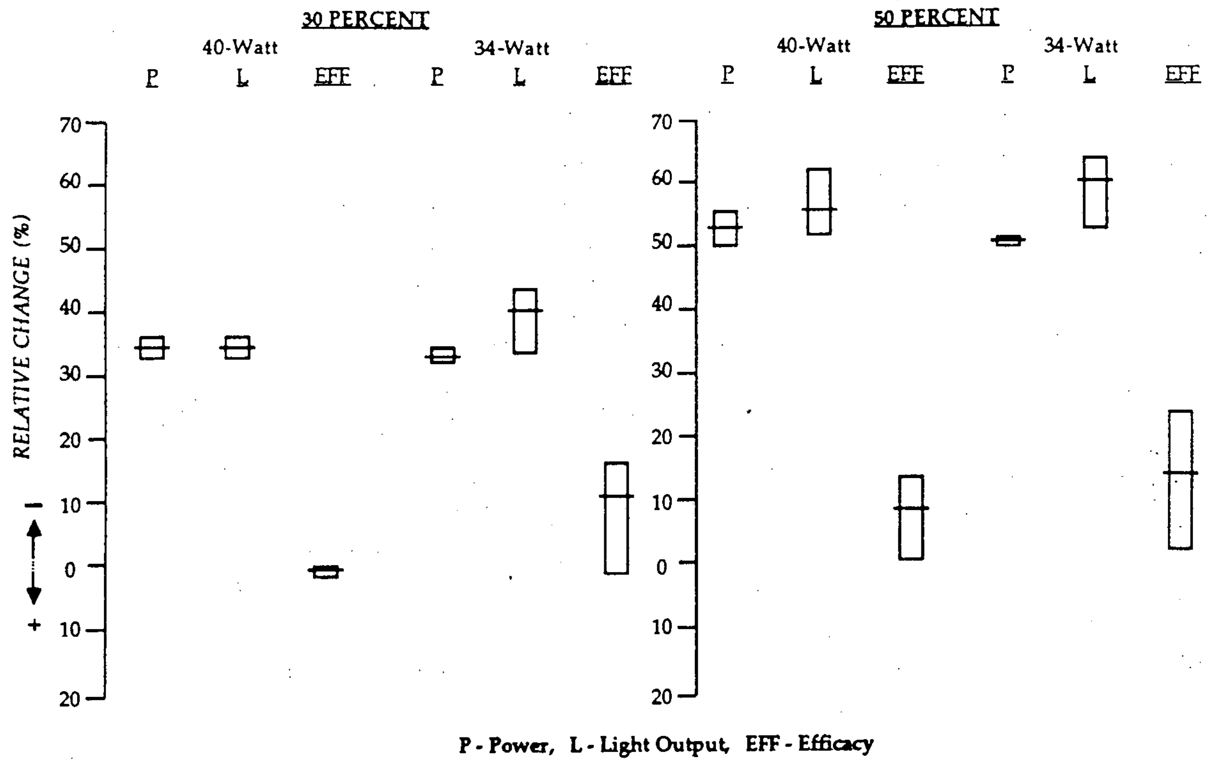


FIGURE 2.17

SYSTEM EFFICACY AND LAMP CURRENT CREST FACTOR FOR F40 LAMPS USING 30% AND 50% STATIC CONTROLLERS

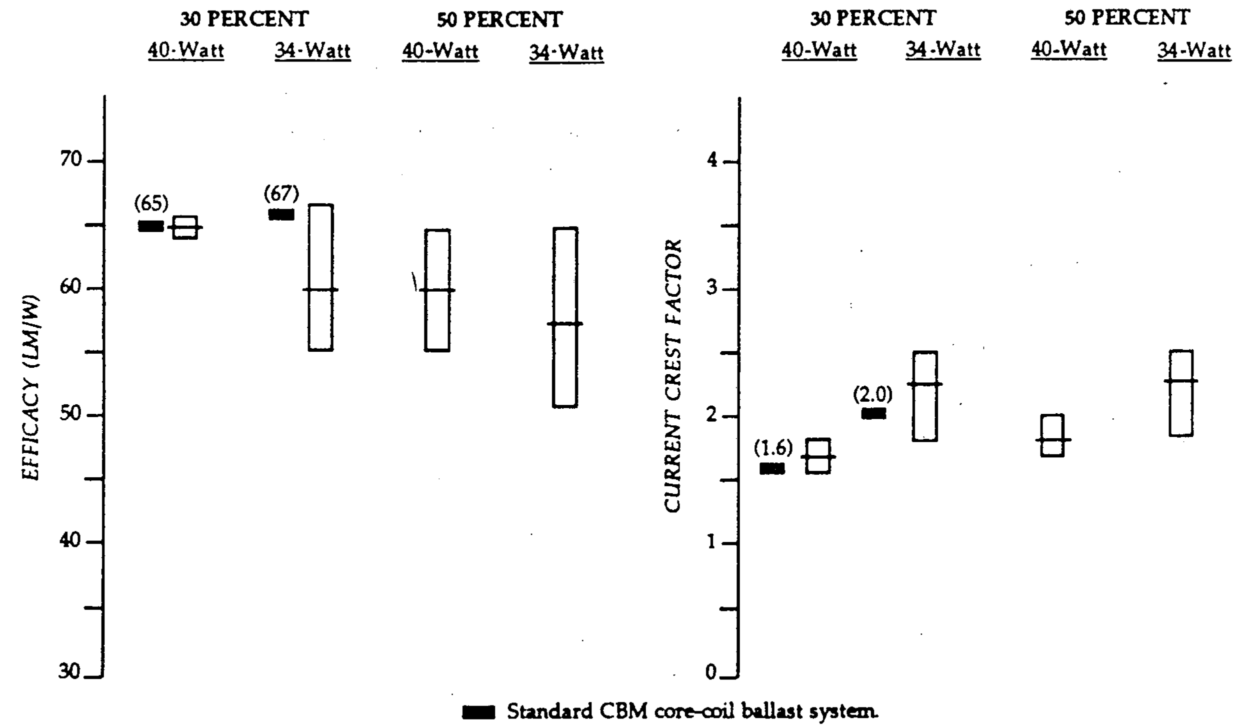
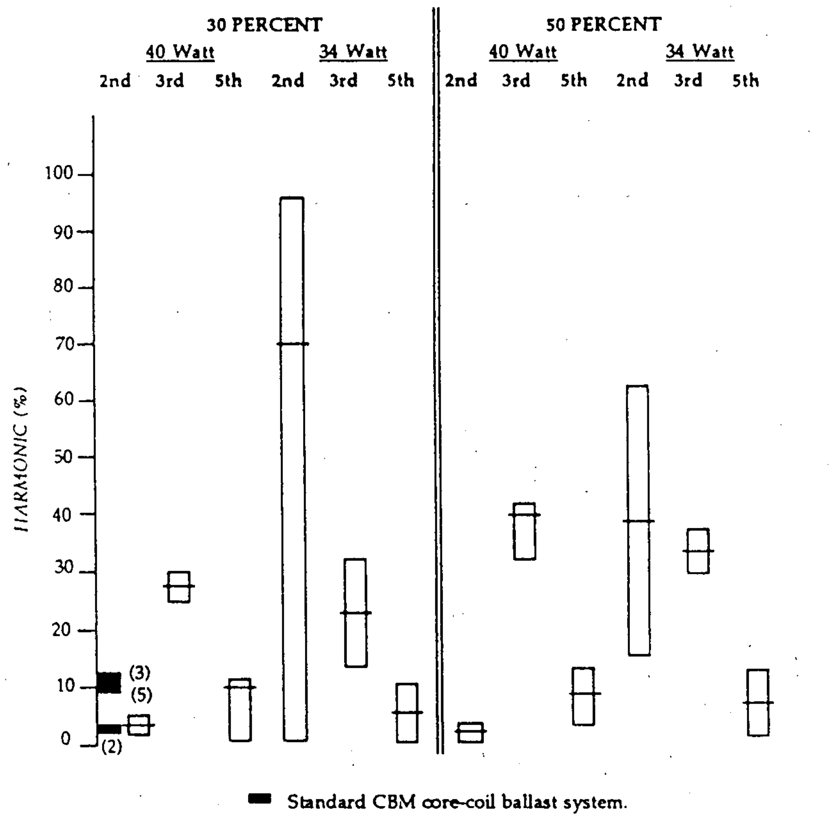


FIGURE 2.18

HARMONICS FOR F40 LAMPS USING 30% AND 50% STATIC CONTROLLER



(2) Second
(3) Third
(5) Fifth

The average and the range of power and power factor for the control of core-coil ballasts and the solid-state ballasts are shown in Figure 2.19 for the 40-watt and 34-watt F40 lamps. The measure of the power is made on the line side of the control and includes the power dissipated by the ballast and lamps, as well as the controller. The clear ranges are the values for the maximum setting, and the shaded ranges are the values for the minimum light output settings. The 60-hertz controller on the average exceeds the 95-watt and 81-watt uncontrolled ballast input for the 40-watt and 34-watt lamps, respectively. The power for the 40-watt lamps, at minimum, is 38 watts, compared to 55 watts for the 34-watt lamps, which indicates that the 40-watt lamps can be dimmed over a greater range than the 34-watt lamps. The dimming range for both lamps is the same when they are operated with the dimmable solid-state ballasts.

The power factor is slightly decreased at full light output for the 60-hertz system. However, on the average when the system fully dims the lamps, the power factor decreases to about 70 percent. The solid-state ballast system also decreases the power factor at full dimming, however the change is much smaller; the power factor exceeds 80 percent at the lowest light output setting.

The 60-hertz system increases the third harmonic when the controllers are used (Figure 2.20) and nearly doubles when operating fully dimmed. The dimmable solid-state ballast has a greater third harmonic content than the core ballast, but smaller than that of the controlled 60-hertz ballast at the lowest light level. There is also an increase in harmonic content in the fully dimmable model with the solid-state ballast. There is no significant difference in the harmonic content between the 40-watt and 34-watt lamps with the solid-state ballasts.

Figure 2.21 shows the range in light output of the system at maximum and at minimum setting. On the average, the solid-state ballast dims the fluorescent lamp over a wider range than the core-coil ballast system. However, one core-coil system can dim to a very low level. More important are the filament voltages that are maintained at the very low level. The applied filament voltage for the 60-hertz system is decreased as the lamps are dimmed. This could result in significant loss of life for systems that dim to a very low level (~ less than 50 percent). The solid-state dimmers maintain the filament voltage. However, the 1.6 volts applied to the filament by one unit may be too low at the lower light output levels. It would be desirable for the solid-state to increase the filament voltage above 3 volts at the low light output levels, as device 6 and 7 do (e.g., Table C-1).

The change in system efficacy and the range of dimming at the lowest light output setting are shown in Figure 2.22. The solid-state ballast dimming systems have a greater decrease in efficacy since they dim to a lower level and maintain the filament voltage. This results in a greater decrease in efficacy but preserves the rated lamp life.

FIGURE 2.19

AVERAGE AND RANGE OF VALUES OF POWER AND POWER FACTOR FOR DYNAMIC CONTROLS

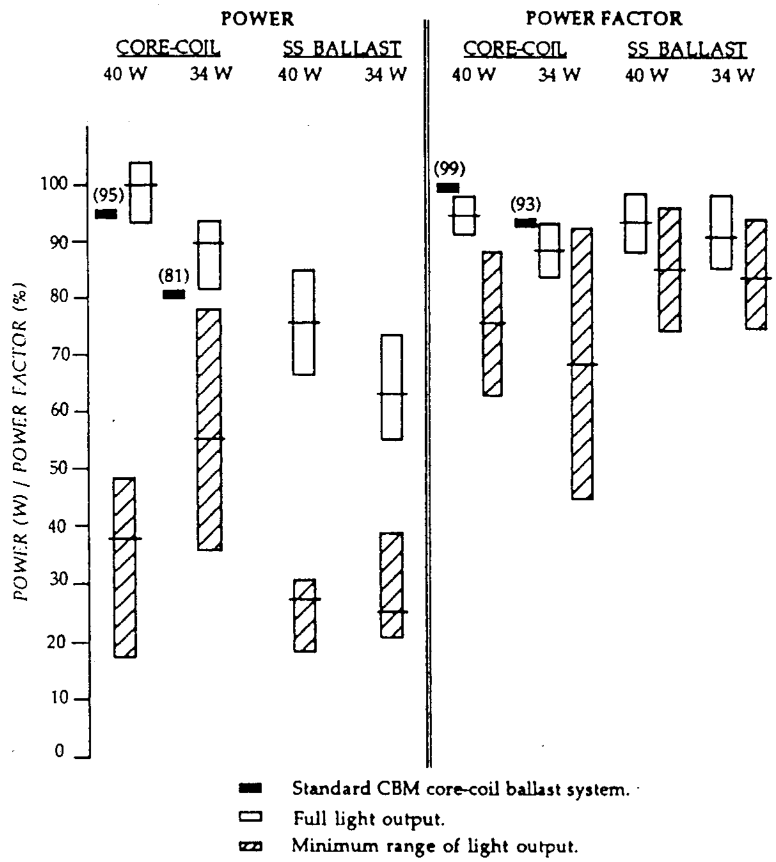


FIGURE 2.20

THIRD HARMONIC CONTENT FOR DYNAMIC CONTROLS

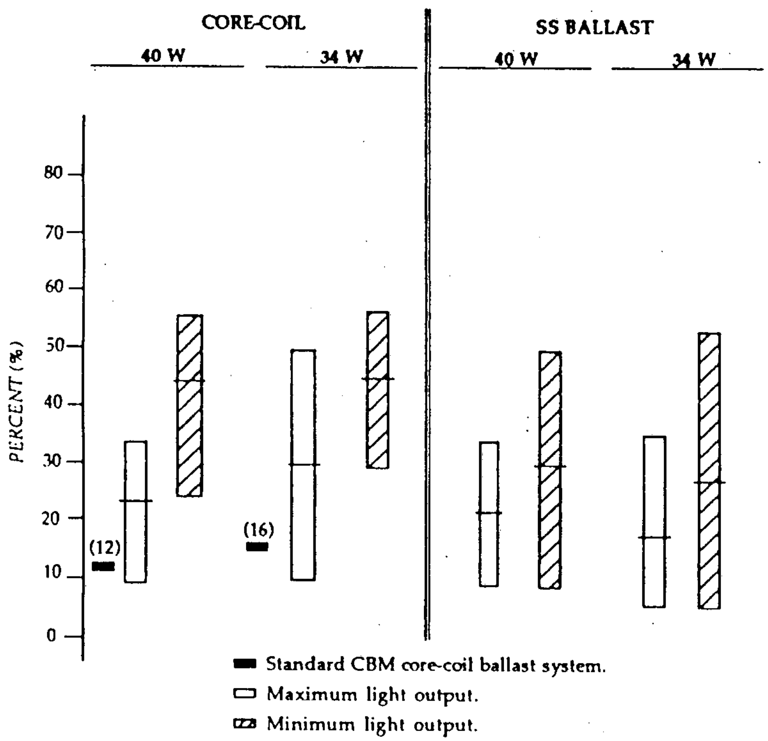


FIGURE 2.21

LIGHT OUTPUT AND FILAMENT VOLTAGE
FOR DYNAMIC CONTROLS

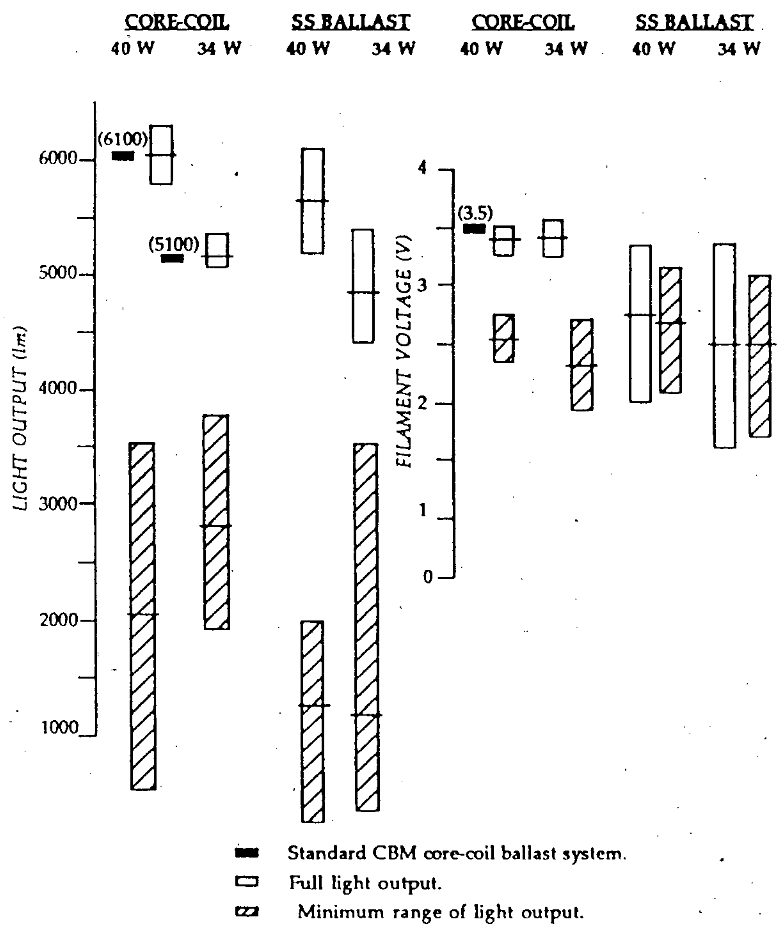
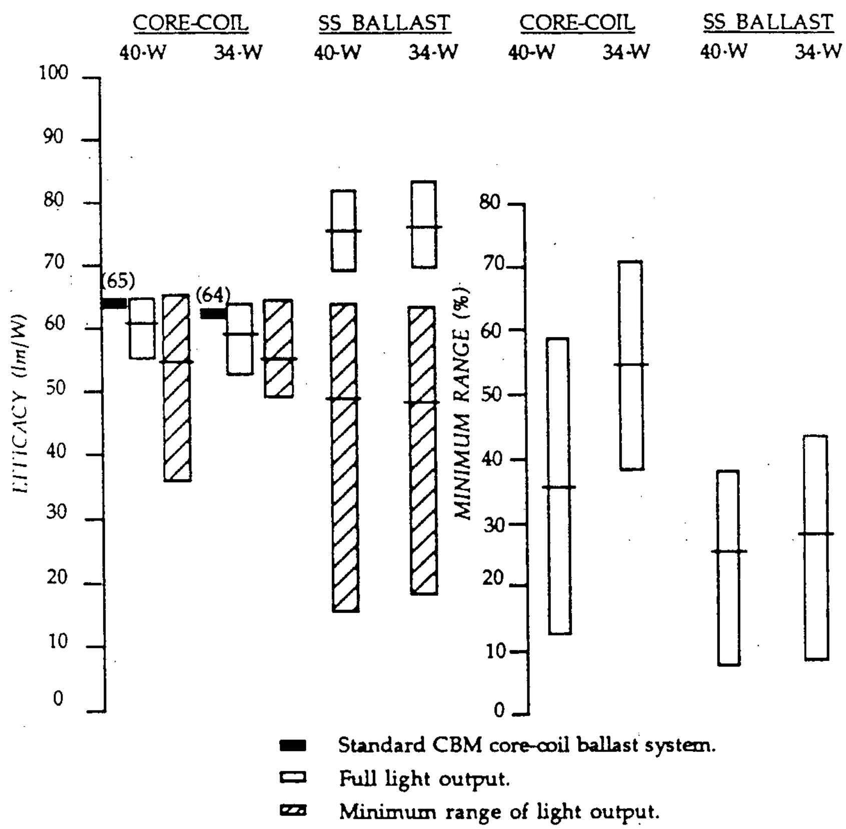


FIGURE 2.22

SYSTEM EFFICACY AND MINIMUM DIMMING
RANGE OF DYNAMIC CONTROLS



Figures 2.23-2.26 are plots for all of the system measurements of light output versus input power. All of the data points for each type of lamp fall in the same straight line. This indicates that the techniques used to dim the fluorescent lamps with the dimming solid-state ballasts and with the core-coil ballasts result in the same input-output performance.

Plotting all four curves on the same graph (Figure 2.27) shows that the light output power dependence is the same for both lamps with each type of dimming (solid-state and core-coil). However, the 40-watt lamp can be dimmed over a greater range of light output than the 34-watt lamp for each type of dimming system.

DISCUSSION

History:

The 34-watt F40 rapid-start lamp was introduced to provide a lamp retrofit that could be suitably operated with ballasts that were in place, and that would reduce illumination levels of spaces. The basic differences between the 34-watt F40 and the standard 40-watt F40 lamp are: i) back filling the 34-watt lamp with krypton instead of argon, ii) applying a conductive coating on the 34-watt tube and iii) using a new more efficient phosphor mix (lite white), in the 34-watt lamp, in place of the cool white phosphor used in the 40-watt.

The new lamp presented a different electrical load to existing ballasts and drew less power 80-watts rather than 95-watts, or 16 percent less than the 40-watt lamp. These new lamps were designated as energy-saving lamps because of this power reduction. The first energy-saving lamps had used the cool white phosphor and reduced the efficacy and the lighting levels too much. A new phosphor, "Lite White," was used to increase the rated light output from 2750 to 2925 lumens and achieved it at the expense of the color rendering index (CRI), which was reduced from 65 to 55. The "Lite White" phosphor added some yellow-emitting phosphor to the mix to provide more photons in the most sensitive regions of the eye's response to light.

The krypton-filled lamps have drastically different starting characteristics from argon-filled lamps; in particular, the krypton lamps have a peak starting voltage of nearly 400 volts, in contrast to 200 volts necessary for argon-filled lamps.[3,4] In order to reduce this voltage the lamps are coated with a conductive coating that reduces the peak starting voltage at 60-hertz to 150 volts. At 60 hertz the root mean square (RMS) starting voltage is increased from 130 volts to about 200 volts and is acceptable because of the large reduction in the peak starting voltage.

FIGURE 2.23 Light Output for 40W Lamps With Solid-State Ballasts

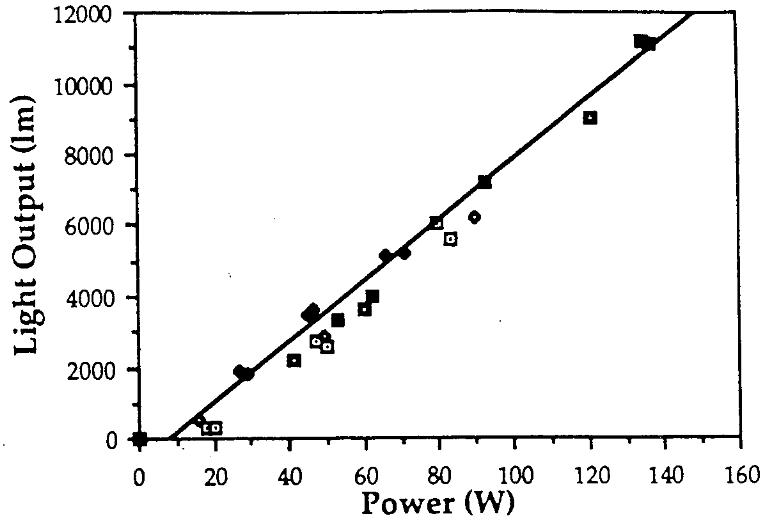


FIGURE 2.24 Light Output for 34W F40 Lamps With Solid-State Ballasts

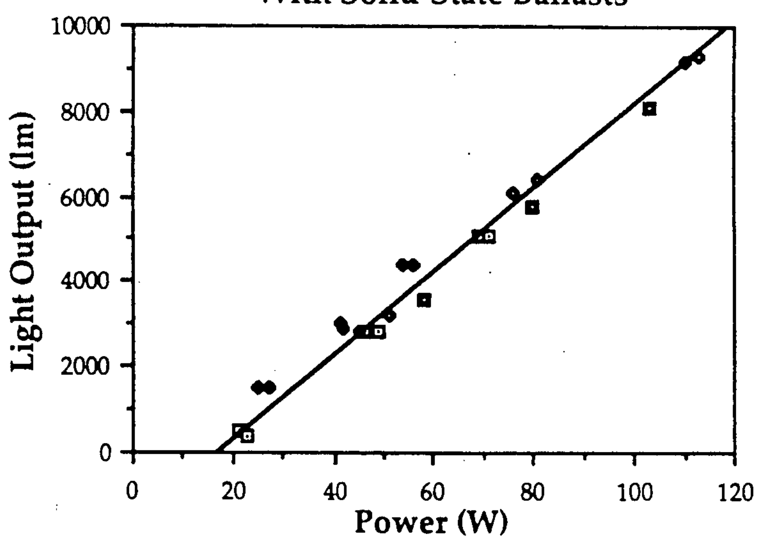


FIGURE 2.25 Light Output of 40W F40 Lamps With Core-Coil Dimming Systems

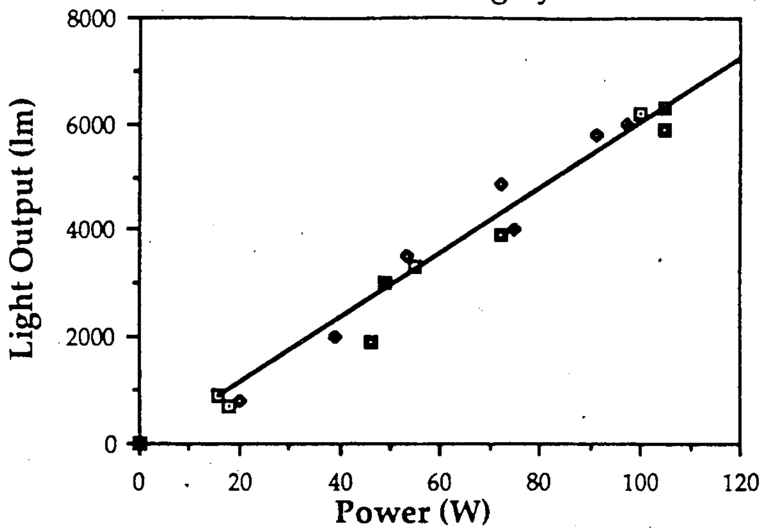


FIGURE 2.26 Light Output of 34W F40 Lamps With Core-Coil Dimming Systems

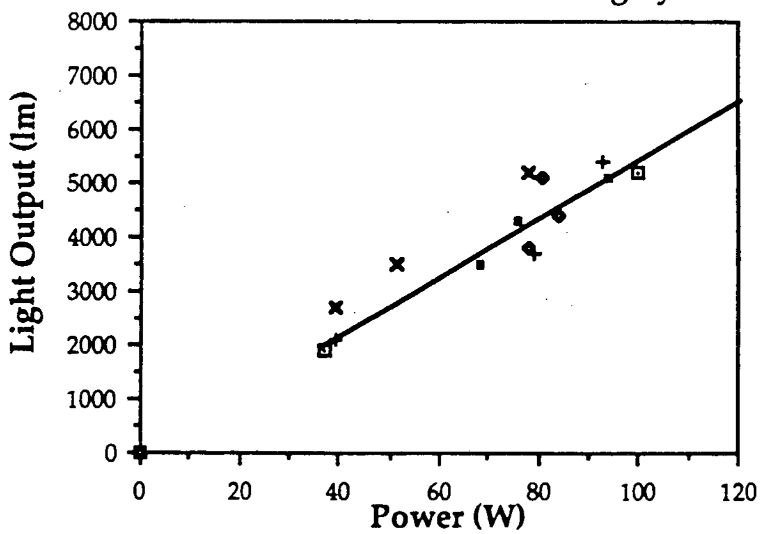
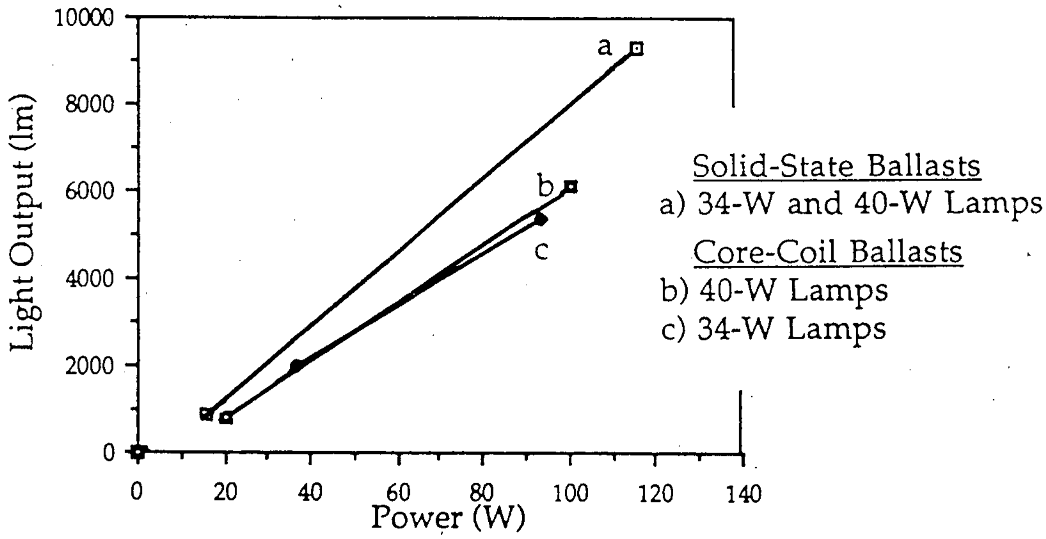


FIGURE 2.27 Light Output vs Power Input For The Dimming Systems



At high frequency the krypton-filled lamps with the conductive coating have a peak starting voltage of about 175 volts, but a high RMS starting voltage of about 290 volts.[3,4] In order for a lamp to ignite, both the starting peak and RMS voltage must be satisfied. The peak voltage initiates the end glow between electrode and starting aid, and the RMS voltage provides the potential between the electrodes to ignite and sustain the plasma.

The difficulty of starting the 34-watt lamps is acknowledged in the lamp's specifications, which indicate that it should be operated at an ambient temperature above 60°F, compared to the 50°F rating for the 40-watt argon-filled lamps. Both the higher peak and RMS starting voltages will tend to accelerate the erosion of the electrodes, hence lamp life.

If a krypton-filled lamp is to be operated at high frequency, starting voltage will be lower without a conductive coating on the lamp, which requires a 240 peak voltage and a RMS of 110 volts to start. These voltages still exceed the argon-filled 40-watt F40 lamp's (125 volts RMS and 140 volt peak).

When the 34-watt lamp was first introduced as a retrofit, there were several abnormally large core-coil ballast failures. The failures were traced to a capacitor in ballasts that were approaching the ends of their lives. From Table 2.1 one observes that the 34-watt lamp operates at a higher current and lower voltage than the 40-watt lamp operated with a core-coil ballast (this is also true with the electronic ballasts). Thus, more voltage is across the ballasts when they are operating the 34-watt lamps. Since capacitors in these ballast designs were rated based on the 40-watt lamps, the new capacitors could withstand the extra voltage stress; but, after long operation time, the capacitor would deteriorate and the extra stress would cause failure. All new ballasts have upgraded their capacitors to eliminate this problem.

<u>40-Watt and 34-Watt System Efficacy</u>:

Also shown in Table 2.1 is the increased lamp efficacy of the 34-watt lamp (primarily resulting from the increased phosphor efficiency in converting UV photons to visible radiation). The 34-watt lamp is about 6 percent more efficacious than the 40-watt lamp. However, for both the core-coil and electronic ballasts (Figure 2.12) the system efficacy is only slightly increased for the 34-watt lamp. Because of the greater ballast current in the secondary (see Table 2.1), the ballast losses increase and virtually cancel out any gains in the lamp efficacy. Thus, while 34-watt lamps save (reduce) energy use, these systems are not more energy efficient.

<u>Design</u>:

Designers doing a lighting layout must realize that there will be a difference in ballast factors for the same ballast operating a different lamp (e.g., a 34-watt in place of a 40-watt lamp). The ballast factor has no bearing on efficiency and reliability but alters the initial light output from the lamp as rated by the manufacturer. For example, two 40-watt lamps with electronic ballast A (see Tables A-1 and A-2) will provide 5870 lumens, while 34-watt lamps will provide only 5060 lumens, which is over 800 lumens per two-lamp system, and a decrease of nearly 14 percent from the output of 40-watt lamp system. In addition, the tables show the large variation in light output for the different ballasts. The designer must know the ballast factor of each ballast-lamp combination in order to accurately calculate the illumination level.

Controls:

The static and dynamic controls both with the core-coil ballasts and the dimmable electronic ballasts can function suitably with both the 40-watt and 34-watt lamps. However, in some environments, at lower ambient temperatures and lower light output, when the MLWT falls below 35°C, the 34-watt lamp flickers excessively and generates an extraordinarily large second harmonic component. This is true particularly with the static controllers.

With the dynamic controllers of core-coil ballasts the allowable measured dimming is more limited with the 34-watt lamp. In fact, these dynamic controllers also decrease filament voltage as the arc current is lower and at very low light levels (<50 percent of full light output) lamp life could be significantly reduced. The electronic ballasts tend to operate both lamps equally well, with respect to dimming range. The dimming electronic ballasts maintain filament voltage, even at low arc currents and low light output, which would preserve lamp life even when operated at low light levels. When dimming these lamps below 40 percent , it is best to maintain full electrode voltage (2.5 to 3.6 volts) to maintain lamp life.

Specification:

This report has measured the major parameters that affect the generating supply, the system reliability, the lamp life and the lighting design. The large range of values that are obtained for the different ballasts makes it essential that the end user understand his needs and properly specifies the equipment.

The parameters that affect the electrical supply are of concern not only to the end user but, to the utility companies. Recently, a study[5] by a utility has estimated that fluorescent lighting constitute 25 percent of the total customer load and may at times exceed 30 percent. The utility was concerned with the impact on its system of overloading that would result in voltage changes. One interesting test result involved a core-coil ballast 34-watt lamp systems. The VAR's increased when the supply voltage was reduced, even though the power decreases. Thus, the system power factor, and harmonics should be characterized over a range of voltages.

The system factors affecting reliability and lamp life are open circuit crest factor, lamp current crest factor and filament voltage. Unique to the operation of lamps at high frequency is the need to supply filament voltage during operation. At 60 hertz electrons bombard the anode providing most of the energy to heat the electrodes. At high frequency the anode fall (potential) is reduced and the external filament voltage is required to maintain the proper electrode temperature. In the dimmed mode, (low arc currents), full filament voltage is required to maintain a suitable temperature at all frequencies.

Finally, the lighting designer must know the performance parameters that include the power input and light output characteristic of a system. The factors affecting the above are system power, system efficacy ballast factor, light regulation and percent flicker. The input power and system efficacy permit the designer to evaluate the economics of the system since the operating cost for the light provided is:

$$\text{Cost (\$) / lumen hour} = \frac{\text{Energy Cost}}{\text{System Efficacy}}$$

The above relationship indicates that for the light provided a 40-watt system has the same cost effectiveness as a 34-watt system because their system efficacies are virtually the same.

The results of this study have shown that the above factors are quite different for solid-state ballasts from different manufacturers. Thus, if the designers are to obtain the proper illumination, they must specify the necessary factors.

Section 3
SUMMARY

SOLID-STATE BALLAST PROGRESS

The development and manufacturer of solid-state ballasts have evolved over the past ten years to a point where product credibility has been established. This is evidenced by their availability by the major ballast manufacturers as well as the smaller independent companies that spearheaded their advance. Today, even the major lamp companies offer lamps that have been optimized for high frequency operation. This should not suggest that the present lamps, particularly the 40-watt F40 lamps, will not perform well at high frequency with solid-state ballasts.

One reason for the large variation in the operation of the lamp at high frequency is the lack of a operating standard since the effect of some of these factors have not been fully resolved. These standards will be available in the near future then one will find more uniformity in the different products and further improvements in their reliability.

F40 LAMPS

The 34-watt F40 energy-saving lamp has been a suitable retrofit for the reduction of illumination levels in overlit spaces. However, as an option for new lighting layouts or major renovations, this study suggests its overall performance does not warrant its premium cost. The energy-saving lamp requires a higher RMS starting voltage, has a lower power factor as well as high harmonic content and a greater lamp current crest factor. These factors have a negative impact upon the electrical supply as well as the lamps life. When the lamps light output is controlled, statically or dynamically, the range of dimmability is limited, relative to the 40-watt lamps, and in a slightly cool environment a large second harmonic will obtain accompanied by severe flickering.

The operation limits are somewhat verified by the manufacturers rating of the 34-watt lamps, for use above 60°F only, compared to the 40-watt argon filled lamps which can be used at temperatures as low as 50°F.

With all of the negative aspects, that also include a low color rendering index of 55, it delivers light at a higher cost than the 40-watt lamps. That is, since the system efficacy is virtually the same, the operating costs are equal, however the initial cost and possible reduced life tend to make it less cost effective than the 40-watt lamps.

APPENDIX A

Table A-1 and A-2 present the complete set of data obtained for two-lamp F40 electronic ballasts operating the 40-watt and 34-watt F40 rapid-start T-12 fluorescent lamps, respectively. The data for each lamp represents the average value obtained for three ballasts of each type. The numbered ballasts are the ballasts that were measured in Phase I of this study. The lettered ballasts are from new models of electronic ballasts that have been introduced since the Phase I report was completed.

TABLE A-1
FLUORESCENT BALLASTS SYSTEM (Two Lamp 40 Watt F40)

Characteristic	Percent of Center Voltage	Core-Coil		Solid-State (120 Volt)												Solid-State (277 Volt)							Core Coil
		ANSI	120 V	1	2	3	4	5	A	B	C	D	E	F	G	6	7	8	H	I	J	K	(277 Volt)
Power (W)	90		89	84	65	61	64	70	62	70	58	65	61	66	60	80	61	58	65	56	65	56	87
	100		96	85	92	67	73	91	72	71	65	72	68	75	68	82	69	66	67	63	72	65	95
	110		102	86	80	75	80	116	81	71	72	78	75	82	75	83	77	74	68	69	79	73	103
Power Factor	90		.99	.99	.92	.90	.91	.96	.96	.90	.96	.93	.92	.96	.98	.95	.95	.81	.90	.95	.86	.97	.99
	100		.98	.99	.91	.89	.91	.96	.95	.89	.95	.92	.91	.95	.98	.94	.95	.80	.90	.94	.85	.97	.99
	110		.97	.98	.90	.89	.90	.97	.95	.88	.93	.91	.90	.94	.97	.93	.94	.78	.88	.93	.84	.96	.98
Harmonics 3rd (%)	100		12	9	33	20	28	16	24	36	35	17	30	26	10	13	28	22	31	34	12	8	7
Harmonics 5th (%)	100		10	1	17	11	18	15	14	16	7	20	19	16	8	13	7	14	23	7	11	5	10
Open Circuit Voltage (V)	90	256	262	294	336	380	427	-	352	430	465	384	425	360	332	298	323	497	442	465	374	333	265
	100	to	285	294	364	383	487	-	390	502	518	426	470	400	370	297	356	500	489	510	277	373	288
	110	330	307	294	380	380	536	-	431	638	568	470	520	445	410	295	375	500	537	558	272	412	310
Open Circuit Crest Factor	90		1.5	1.5	1.4	-	1.3	-	1.9	1.6	1.4	1.6	1.4	1.9	2.2	1.3	1.4	-	1.6	1.4	1.6	2.1	1.5
	100	20	1.5	1.5	1.4	-	1.3	-	1.9	1.6	1.4	1.6	1.4	1.8	2.2	1.3	1.4	-	1.6	1.4	1.6	2.1	1.5
	110		1.6	1.5	1.5	-	1.3	-	1.9	2.3	1.4	1.6	1.4	1.7	2.2	1.3	1.4	-	1.5	1.4	1.6	2.1	1.6
Filament Voltage (V)	90	2.5	3.1	3.3	3.2	0	-	-	2.8	2.8	1.3	2.0	1.7	3.2	1.6	2.8	3.1	0	2.5	1.4	2.1	1.5	3.0
	100	to	3.5	3.3	3.6	0	-	-	3.1	3.1	1.4	2.0	1.6	3.2	1.5	2.8	3.5	0	3.3	1.5	2.1	1.5	3.4
	110	4.0	3.9	3.3	4.0	0	-	-	3.5	3.5	1.4	2.0	1.6	3.1	1.5	2.8	3.5	0	3.6	1.5	2.1	1.5	3.8
Lamp Current Crest Factor	90		1.5	1.3	1.8	1.9	1.4	1.9	2.3	1.5	1.6	2.1	1.6	1.9	2.1	1.4	1.5	1.9	1.5	1.5	1.5	2.2	1.6
	100	1.7	1.7	1.4	1.8	1.9	1.5	1.8	2.2	1.6	1.6	2.0	1.6	1.9	2.1	1.4	1.6	1.9	1.5	1.5	1.5	2.1	1.6
	110		1.8	1.2	1.8	1.9	1.5	1.8	2.2	1.6	1.6	2.1	1.6	1.8	2.1	1.4	1.5	2.0	1.6	1.5	1.6	2.1	1.7
Light Output (lm)	90		5780	5630	5050	4760	5130	4740	5100	5280	4780	5150	5100	5240	4320	5740	4790	4630	5170	4590	5140	4580	5570
	100	5830	6100	5720	5590	5330	5830	6190	5870	5290	5360	5780	5100	5940	4850	5800	5320	5210	5210	5120	5850	5210	5980
	110		6290	5740	6080	5920	6420	7600	6510	5220	5850	6350	6250	6401	5240	5841	5820	5810	5180	5590	6400	5740	6300
Ballast Factor		.925	.968	.907	.887	.846	.925	.982	.932	.840	.851	.917	.905	.943	.770	.920	.845	.826	.827	.813	.929	.827	.949
Light Output Regulation (%)	90	-25	-5	-1	-10	-11	-12	-23	-13	0	-11	-11	-11	-12	-11	-1	-10	-11	-1	-10	-12	-12	-7
	110	+25	+3	0	+9	+11	+11	+23	+11	-1	+9	+10	+10	+8	+8	+1	+9	+12	-1	+9	+9	+10	+5
Flicker (%)	100		30	0	5	33	4	32	15	1	3	1	3	11	22	0	3	30	0	1	1	30	30
System Efficacy (lm/W)	90		66	68	78	79	80	64	82	75	82	80	84	79	78	72	78	79	79	82	79	82	64
	100		64	68	77	79	80	68	81	74	83	80	83	79	77	71	77	79	78	82	81	81	63
	110		64	67	77	79	80	66	80	73	82	82	83	78	76	70	76	79	76	81	81	79	61

TABLE A-2
FLUORESCENT BALLASTS SYSTEM (Two Lamp 34 Watt F40)

Characteristic	Percent of Center Voltage	Core-Coil ANSI	Core-Coil 120 V	Solid-State (120 Volt) 1	2	3	4	5	A	B	C	D	E	F	G	Solid-State (277 Volt) 6	7	8	H	I	J	K	Core Coil (277 Volt)
Power (W)	90		75	70	54	51	55	-	56	61	51	56	54	59	52	68	53	50	57	50	57	50	75
	100		79	72	60	58	61	99	63	62	57	62	60	66	58	69	59	58	58	56	63	57	82
	110		84	73	66	69	68	-	70	62	62	68	66	73	64	71	65	68	60	61	69	64	88
Power Factor	90		.93	.99	.92	.88	.92	-	.96	.89	.95	.93	.91	.96	.97	.94	.95	.78	.88	.95	.94	.97	.95
	100		.92	.99	.92	.88	.90	.90	.93	.88	.94	.91	.90	.95	.97	.92	.94	.78	.86	.93	.94	.96	.95
	110		.92	.99	.91	.88	.90	-	.95	.87	.92	.90	.88	.94	.96	.91	.92	.78	.84	.91	.94	.95	.94
Harmonics 3rd (%)	100		20	6	31	19	14	5	24	37	38	18	34	27	15	14	32	18	32	37	12	9	16
Harmonics 5th (%)	100		14	1	18	10	13	13	13	17	8	22	21	15	4	15	8	15	25	8	13	6	13
Open Circuit Voltage (V)	90	256	262	378	328	-	418	-	352	430	465	384	425	360	332	273	311	-	442	465	374	333	265
	100	to	285	378	360	-	465	-	390	502	518	426	470	400	370	277	346	-	489	510	415	373	258
	110	330	306	378	398	-	505	-	431	638	568	470	520	445	410	272	376	-	537	558	459	412	310
Open Circuit Crest Factor	90		1.5	1.6	1.5	-	1.4	-	1.9	1.6	1.4	1.6	1.4	1.9	2.2	1.6	1.4	-	1.6	1.4	1.5	2.1	1.5
	100	2.0	1.5	1.6	1.4	-	1.4	-	1.9	1.6	1.4	1.6	1.4	1.8	2.2	1.6	1.4	-	1.6	1.4	1.5	2.1	1.5
	110		1.6	1.6	1.5	-	1.4	-	1.9	2.3	1.4	1.6	1.4	1.7	2.2	1.6	1.4	-	1.5	1.4	1.5	2.1	1.6
Filament Voltage (V)	90	2.5	3.2	2.7	3.2	0	1.4	3.4	2.8	2.8	1.3	1.9	1.5	2.7	1.3	2.8	3.5	0	2.9	1.4	1.9	1.4	3.0
	100	to	3.6	2.8	3.6	0	1.4	3.0	3.1	3.2	1.4	1.9	1.4	2.7	1.3	2.8	3.5	0	3.3	1.5	1.9	1.4	3.4
	110	4.0	4.0	2.7	4.0	0	1.4	4.3	3.4	3.4	1.8	1.9	1.4	2.7	1.3	2.8	3.9	0	3.6	1.5	1.9	1.3	3.8
Lamp Current Crest Factor	90		1.8	1.3	1.4	1.9	1.4	-	2.2	1.5	1.5	1.3	1.4	1.9	1.5	1.5	1.6	1.9	1.6	1.5	1.3	2.0	1.8
	100	1.7 max	1.9	1.4	1.4	1.8	1.4	-	2.2	1.6	1.5	1.3	1.4	1.9	1.6	1.5	1.6	1.9	1.6	1.5	1.3	2.0	1.8
	110		2.0	1.4	1.6	2.1	1.4	-	2.2	1.6	1.6	1.3	1.4	1.8	1.7	1.5	1.6	2.0	1.6	1.5	1.3	2.0	1.8
Light Output (lm)	90		5020	5040	4290	4220	4570	-	4520	4490	4120	4580	4480	4650	4330	5080	4150	4160	4390	4000	4730	4000	4900
	100		5060	5060	4750	4870	5140	6623	5060	4480	4640	5180	5040	5270	4860	5100	4610	4830	4420	4500	5310	4580	4970
	110		5290	5090	5180	5680	5650	-	5600	4490	5100	5600	5530	5800	5320	5120	5030	5580	4420	4960	5850	5100	5290
Ballast Factor		.925	.880	.865	.812	.832	.878	1.132	.865	.765	.793	.886	.862	.900	.830	.872	.788	.826	.756	.769	.908	.783	.864
Light Output Regulation (%)	90	-25	-2	0	-10	-13	-11	-	-11	0	-11	-12	-11	-12	-11	0	-10	-14	-1	-11	-11	-13	-2
	110	+25	+3	+1	+9	+17	+10	-	+11	0	+10	+8	+10	+10	+9	0	+9	+16	0	+10	+10	-11	+4
Flicker (%)	100		21	2	1	18	1	-	9	0	1	1	1	6	20	2	1	18	0	1	0	20	30
System Efficacy (lm/W)	90		67	72	80	83	83	-	81	74	81	82	83	78	84	75	78	83	77	81	83	80	65
	100		64	71	79	84	84	67	81	73	82	83	84	79	84	74	78	83	76	81	84	80	61
	110		63	70	78	83	84	-	80	72	82	82	84	80	83	73	77	83	74	81	85	79	60

APPENDIX B

Tables B-1 and B-2 are the data collected for seven static controllers operating two-lamp 40-watt and 34-watt rapid-start T-12 fluorescent systems, respectively. The data are the average values measured for three controllers of each type.

TABLE B-1
STATIC CONTROLS FOR 40WATT F40 LAMPS

Characteristic	Core-Coil	Controller 1	2	3	4	5	6	7
Power (W)	94	62	62	59	46	41	45	62
Power Factor (%)	98	66	94	94	60	80	85	94
Light Output (lm)	6100	4090	4050	3820	2990	2300	2660	4000
Filament Voltage (V)	3.6	2.3	3.6	3.5	2.4	3.6	3.5	3.6
Flicker (%)	30	31	29	28	38	33	29	28
Current Crest Factor	1.6	1.7	1.7	1.7	1.9	1.8	1.8	1.7
Harmonics (%)								
2nd	2	3	1	4	3	1	3	2
3rd	11	30	25	28	38	42	37	26
5th	10	4	12	12	3	11	12	12
System Efficacy (lm/W)	65	66	65	65	65	56	59	65
Relative Change (%)								
Power	0	-34	-34	-37	-51	-56	-52	-34
Light Output	0	-33	-34	-37	-51	-62	-56	-34
Efficacy	0	+2	0	0	0	-14	-9	0
Lamp Wall Temperature (°C)	40	37	37	37	36	35	35	37

TABLE B-2
STATIC CONTROLS FOR 34WATT F40 LAMPS

Characteristic	Core-Coil	Controller 1	2	3	4	5	6	7
Power (W)	77	50	53	52	37	36	38	53
Power Factor (%)	90	53	72	69	48	74	75	70
Light Output (lm)	5150	3400	3100	2900	2400	1830	2130	3040
Filament Voltage (V)	3.5	1.8	3.5	3.5	2.0	3.6	3.5	3.5
Flicker (%)	13	20	46	46	29	33	36	48
Current Crest Factor	2.0	1.7	2.5	2.5	1.8	2.5	2.3	2.6
Harmonics (%)								
2nd	4	1	94	92	14	50	62	96
3rd	24	32	23	24	39	34	30	26
5th	16	2	11	10	3	8	6	12
System Efficacy (lm/W)	67	68	58	56	65	51	56	57
Relative Change (%)								
Power	0	-35	-31	-32	-52	-53	-51	-31
Light Output	0	-34	-40	-44	-53	-64	-59	-41
Efficacy	0	+1	-13	-16	-3	-24	-16	-15
Lamp Wall Temperature (°C)	34	30	29	29	28	26	26	30

APPENDIX C

Tables C-1 and C-2 list the data collected for thirteen fluorescent lighting control systems, for 40-watt and 34-watt F40 fluorescent lamps, respectively. Controllers 1 to 5 are systems that control the lighting of fluorescent lamps operated with standard core-coil ballasts at 60 Hz. Controllers 6 through 13 are electron ballasts that have internal circuitry which permits them to directly dim the fluorescent lamps.

TABLE C-1
DYNAMIC CONTROLS FOR 40 WATT F40 LAMPS

Characteristic	Light Level	Core-Coil Ballast	Controller					Solid-State Ballasts							
			1	2	3	4	5	6	7	8	9	10	11	12	13
SYSTEM INPUT															
Power (W)	max	94	94	100	100		105	83	82	90	121	71	136	67	138
	mid		73	80	50		73	50	47	48	59	47	93	46	100
	min		38	48	17		47	22	19	16	41	29	53	28	62
Power Factor (%)	max	97	98	91	94		96	99	93	96	96	89	94	90	92
	mid		86	52	61		89	98	89	97	93	87	94	86	90
	min		71	66	63		88	97	75	87	88	82	88	79	86
Harmonics 3rd (%)	max	12	10	35	33	12	13	9	13	16	9	36	17	31	12
	mid		35	52	54	19	31	3	24	11	21	42	17	36	12
	min		42	53	56	24	27	9	50	24	28	51	22	44	12
BALLAST INPUT															
Voltage (V)	max	120	117	119	119	120	277								
	mid		95	92	87	90	234								
	min		91	87	84	84	222								
Power (W)	max	94	91	100	98	94	104								
	mid		59	63	47	73	65								
	min		31	48	15	53	38								
Light Output (lm)	max	6100	5910	6410	6180	6100	5880	5690	5950	6210	9048	5290	11120	5210	11200
	mid		3960	4740	3390	4900	3990	2660	2780	2890	3500	3530	7270	3570	7620
	min		2010	3070	602	3560	1830	360	390	430	2060	1820	3300	1980	4000
Filament Voltage (V)	max	3.5	3.4	3.4	3.4	3.5	3.3	3.3	3.3	4.6	2.5	3.5	2.0	3.2	2.0
	mid		2.7	3.0	2.5	2.4	2.8	4.1	3.8	3.1	2.8	3.1	2.1	3.2	2.0
	min		2.7	2.4	2.5	2.5	2.8	3.0	3.1	4.5	2.8	2.7	2.2	3.0	2.1
System Efficacy (lm/W)	max	65	63	64	62	65	56	69	73	69	75	75	82	78	81
	mid		55	59	68	67	53	53	59	61	59	75	78	78	76
	min		54	65	37	66	39	16	21	27	50	63	62	71	65
Dimming Range (%)	max		100	100	100	100	100	100	100	100	100	100	100	100	100
	mid		67	74	55	80	68	47	47	47	39	67	65	69	68
	min		34	48	10	59	31	6	7	7	23	34	30	38	36

TABLE C-2
DYNAMIC CONTROLS FOR 34 WATT F40 LAMPS

Characteristic	Light Level	Core-Coil Ballast	Controller 1	2	3	4	5	6	7	9	Solid-State Ballasts 10	11	12	13
SYSTEM INPUT														
	max	80	81	92	93		94	72	69	103	62	110	58	113
Power (W)	mid		84	69	70		82	48	46	80	42	76	42	81
	min		78	37	37		68	23	21	58	27	45	25	51
	max	93	94	83	87		92	99	92	95	88	94	86	92
Power Factor (%)	mid		96	55	58		88	99	89	94	85	90	82	88
	min		93	45	50		85	96	76	92	79	86	76	85
	max	20	15	47	50	15	10	6	14	10	37	17	32	12
Harmonics 3rd (%)	mid		24	54	58	18	26	2	26	14	44	19	37	12
	min		32	57	62	22	30	8	40	14	52	24	44	12
BALLAST INPUT														
	max	120	118	120	120	120	271							
Voltage (V)	mid		97	90	92	70	242							
	min		88	74	76	66	222							
	max	80	80	92	90	79	93							
Power (W)	mid		65	66	62	50	73							
	min		55	36	33	38	58							
	max	5150	5110	5250	5410	5150	5110	5060	5100	8090	4480	9250	4420	9350
Light Output (lm)	mid		4470	3120	3690	3530	4350	2780	2830	5830	2960	6070	3000	6350
	min		3860	1950	2050	2690	3520	420	480	3570	1420	2880	1560	3220
	max	3.6	3.5	3.5	3.5	3.6	3.3	2.8	2.8	2.1	3.2	1.6	3.3	1.7
Filament Volt (V)	mid		2.8	2.6	2.6	1.9	2.9	3.1	3.1	2.2	3.1	1.7	3.3	1.6
	min		2.5	2.1	2.2	1.9	2.7	3.0	3.1	2.3	2.7	1.7	3.0	1.7
	max	64	63	57	58	65	54	70	74	79	72	84	76	83
System Efficacy (lm/W)	mid		53	52	53	71	53	58	62	73	70	80	71	78
	min		49	53	55	71	52	18	23	62	53	69	62	63
	max		100	100	100	100	100	100	100	100	100	100	100	100
Dimming Range (%)	mid		87	69	68	69	85	55	55	72	66	66	68	68
	min		76	37	38	52	69	8	9	44	32	31	35	34

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