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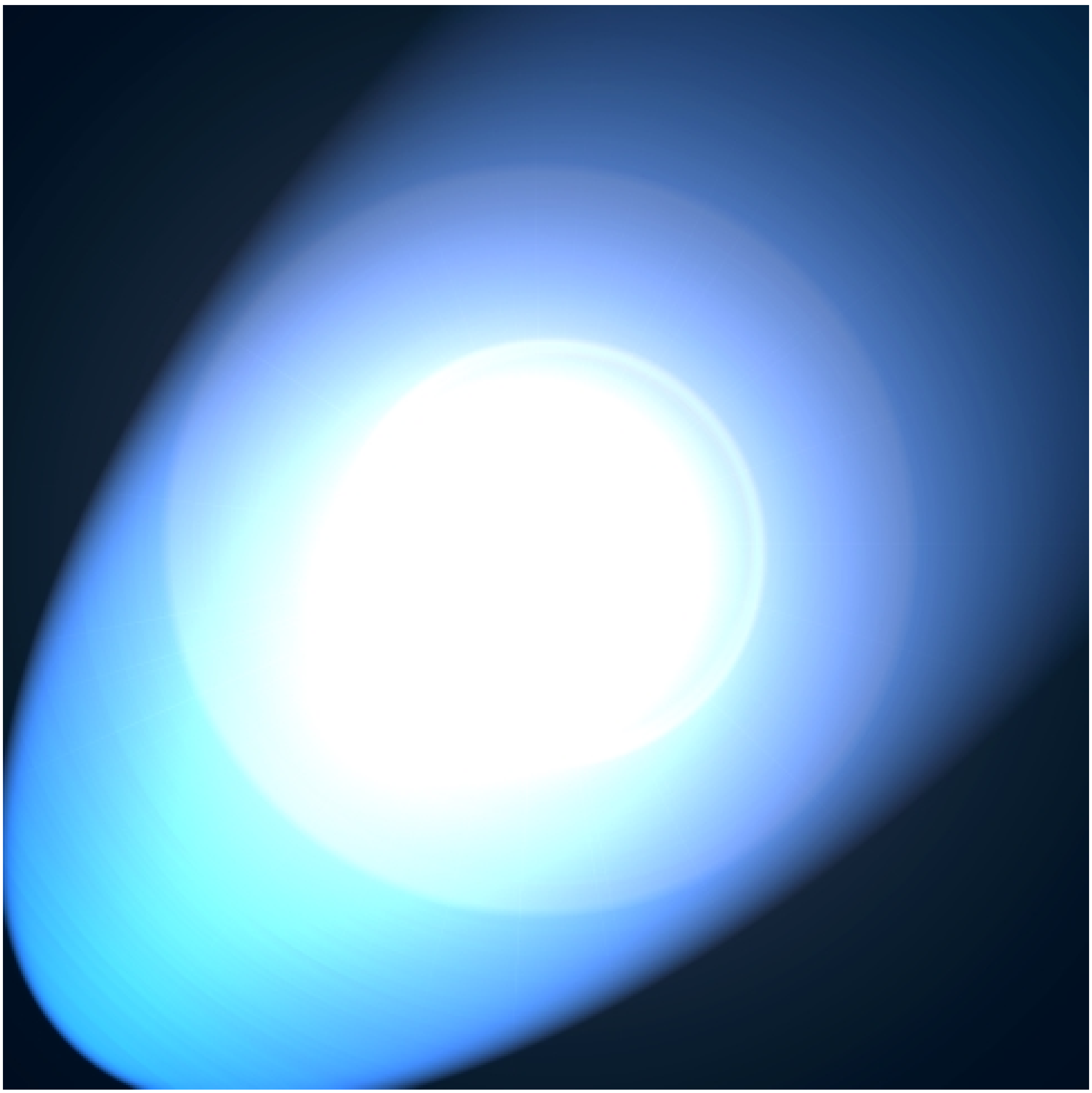
Electronic Ballasts

Non-dimming electronic ballasts for 4-foot and 8-foot fluorescent lamps

Volume 8 Number 1, May 2000



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About NLPIP

The National Lighting Product Information Program (NLPIP) was established in 1990. NLPIP is administered by the Lighting Research Center (LRC), the world's largest university-based center devoted to lighting excellence.

NLPIP's mission is to help lighting specifiers and other lighting decision-makers choose wisely by providing the most complete, up-to-date, objective, manufacturer-specific information available on energy-efficient lighting products. Priority is given to information not available or easily accessible from other sources. NLPIP tests lighting products according to accepted industry procedures or, if such procedures are not available or applicable, NLPIP develops interim tests that focus on performance issues important to specifiers or end-users.

In 1998, NLPIP Online debuted at www.lrc.rpi.edu/nlpip, making the information provided by NLPIP even more accessible to lighting specifiers and other interested people. NLPIP Online includes both PDF files of Specifier Reports and several searchable databases containing manufacturer-reported data and test results.

To help ensure its continued objectivity, NLPIP does not accept funding from manufacturers.

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Volume 8 Number 1 May 2000

Electronic Ballasts

Non-dimming electronic ballasts for 4-foot and 8-foot fluorescent lamps

Manufacturer-Specific Ballast Data and Test Results Online (www.lrc.rpi.edu/nlpip)

Starting with this *Specifier Report*, the National Lighting Product Information Program (NLPIP) will not include tables of manufacturer-supplied and NLPIP-tested data in this PDF file. These data are available in a database through NLPIP Online, a service of the Lighting Research Center (LRC). The Web site explains how to retrieve and print data from the online database.

The Web site also contains a full library of NLPIP publications, including *Specifier Reports, Lighting Answers*, and searchable manufacturers' data and NLPIP test results. When NLPIP tests new ballasts, the data will be updated online.

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Introduction

High-frequency electronic ballasts for fluorescent lighting systems, also called solid-state ballasts, are promoted as providing significant energy savings over magnetic ballasts. As shown in Figures 1 and 2, sales of electronic ballasts in the United States (U.S.) have grown more rapidly than those of any other ballast type in recent years. Their share (by volume) of the overall fluorescent lamp ballast industry grew from 1% in 1988 to 38% in 1998, as shown in Figure 1.

Figure 1. U.S.-Manufactured Ballasts for Fluorescent Lamps, by Quantity of Shipments (Bureau of the Census 1999)

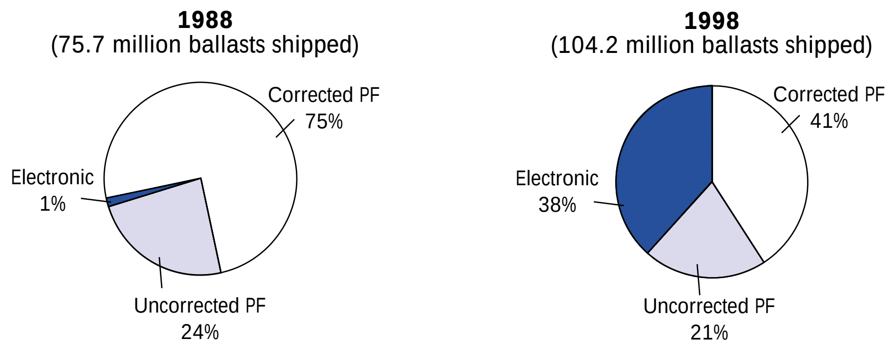
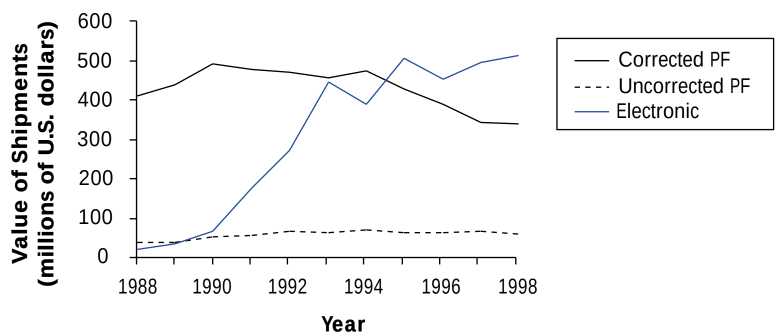


Figure 2. Value of Shipments of U.S.-Manufactured Ballasts for Fluorescent Lamps (Bureau of the Census 1999)



Corrected PF ballasts are magnetic ballasts with a power factor (see p.15) of 85% or greater.

Uncorrected PF ballasts are magnetic ballasts with a power factor less than 85%. This includes many ballasts for compact fluorescent lamps and some ballasts sold for residential applications.

This rapid growth was influenced by both the 1988 amendment to the 1987 National Appliance Energy Conservation Act, which eliminated "high-loss" (older, less efficient) magnetic ballasts and by the U.S. Energy Policy Act of 1992, which increased the use of fluorescent lamps with electronic ballasts (U.S. Congress 1988, 1992). As a result of an October 1999 agreement with ballast manufacturers and energy efficiency advocates, the U.S. Department of Energy (DOE) expects to issue a rule soon that will require the use of electronic ballasts by April 2005 in new construction and renovations of commercial and industrial buildings. The rule will also phase out magnetic ballasts for commercial and industrial buildings completely by 2010.

In December 1991 and again in May 1994, the National Lighting Product Information Program (NLPIP) published *Specifier Reports: Electronic Ballasts*, which provided information about electronic ballasts and performance data for specific manufacturers' products. Since then, new manufacturers have introduced electronic ballasts, and manufacturers represented in the previous report have developed new electronic ballasts.

This new *Specifier Reports: Electronic Ballasts* replaces the previous NLPIP publications by summarizing recent research on non-dimming electronic ballasts for fluorescent lamps. This research addressed ballast reliability and impacts on lamp life, as well as important lamp-ballast compatibility parameters such as glow current, electrode voltage, and electrode preheat time.

This report discusses electronic ballasts for the following types of fluorescent lamps (see the sidebar "Fluorescent Lamp Designations"):

- T5, nominal 4-foot (ft). These lamps require electronic ballasts. T5 lamp-ballast systems are not intended to replace T8, T10, or T12 lamp-ballast systems, because they require different luminaires.
- T8, 4-ft and 8-ft. Most ballasts for T8 lamps are electronic, although a few magnetic ballasts exist for them.
- T10, 4-ft and 8-ft. These lamps can use either magnetic or electronic ballasts.
- T12, 4-ft and 8-ft. Like T10 lamps, T12 lamps can use either magnetic or electronic ballasts. However, major manufacturers of 34-watt (W) T12 lamps state that the lamps are not intended for use with dimming ballasts, ballasts with low power factor, or ballasts with reduced light output (low ballast factor). They also warn that using the lamps on single-lamp ballasts could reduce lamp life. One manufacturer adds that when 34-W lamps are used with electronic ballasts, they might "display erratic starting before end of life."

NLPIP collected data from 12 ballast manufacturers and independently evaluated 74 of the ballasts from the manufacturers for this report. These data appear in an online database (see the sidebar "Manufacturer-Specific Ballast Data and Test Results Online" on p. 3). An online supplement will follow that adds ballast data for T5 lamps.

Fluorescent Lamp Designations

Table 1 shows examples of generic designations for 4-ft and 8-ft fluorescent lamps. The format of the designation is F*xx*T*y*/*zz*, where:

F	=	fluorescent
xx	=	nominal wattage [for lamps 60 inches (in.) or shorter] or length (in inches) from lampholder to lampholder
T	=	tubular
y	=	lamp diameter in eighths of an inch
zz	=	suffix containing additional information about the lamp, such as whether it is a high-output (HO) or energy-saving (ES) lamp.

Table 1. Fluorescent Lamp Designations Used in this Report

Designation	Description	Power (W)	Length [in. (m)]	Diameter [in. (cm)]	Other
F28T5	Nominal 4-ft T5	28	46 (1.16)*	5/8 (1.5)	—
F32T8	4-ft T8	32	48 (1.22)*	8/8 (2.5)	—
F96T8	8-ft T8	59*	96 (2.44)	8/8 (2.5)	—
F40T10	4-ft T10	40	48 (1.22)*	10/8 (3.2)	—
F40T12/ES	4-ft T12	34*	48 (1.22)*	12/8 (3.8)	ES = energy-saving (in this case, a 34-W replacement for a 40-W lamp)
F96T12/HO	8-ft T12	110*	96 (2.44)	12/8 (3.8)	HO = high-output

* Not specified in lamp designation

Background

Types of Ballasts

Ballasts consume electricity while providing the necessary circuit conditions (voltage, current, and wave form) to start and operate fluorescent lamps. Three types of ballasts are sold for commercial applications in the U.S.: magnetic, hybrid, and electronic. Table 2 compares these ballast types. The rest of this report discusses the performance characteristics (such as ballast factor) listed in the table.

Table 2. Comparison of Three Types of Ballasts for 4-Ft Lamps

	Magnetic Ballast	Hybrid Ballast	Electronic Ballast
Number of lamps operated	1–4	1–3	1–4
Starting mode*	PH, IS, RS	RS	IS, RS, PS
Weight (lbs)	3.5	3.5–3.7	0.4–5.0
Lamp operating frequency	60 Hz	60 Hz	20,000–60,000 Hz
System efficacy	Lowest	Higher	Highest
Ballast factor	0.63–0.99	0.80–0.95	0.73–1.30
Ballast efficacy factor (for 4-ft, 2-lamp system)	0.90–1.40	1.10–1.40	1.15–1.56
Total harmonic distortion (%)	most <20, some >20	<20	some <5, most 5–20, some >20
Power factor	most >0.9	>0.9	>0.9
Lamp current crest factor	<1.7	<1.7	<1.7
Lamp flicker index	0.04–0.07	0.04–0.07	<0.01
Operating electrode voltage, rapid-start T8 (V)	2.5–4.4	NA	2.5–4.4
Rated life (years)	10–15	10–20	10–20
Sound rating	A–D	A–B	A–B
Dimming available?	Yes	No	Yes

NA = not applicable
1 lb = 0.45 kg
*IS = instant-start; PH = preheat; PS = programmed-start; RS = rapid-start.

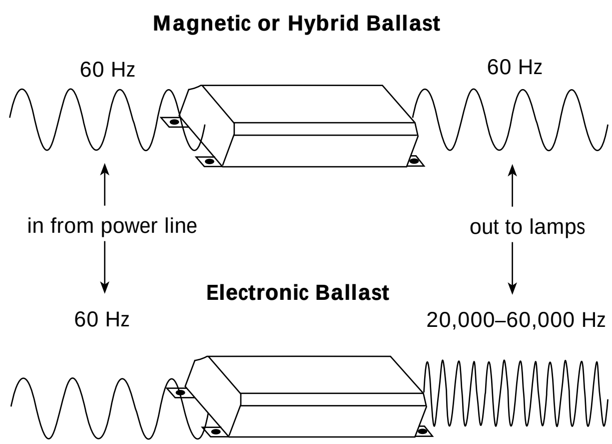
Magnetic Ballasts

Magnetic ballasts are "core-and-coil" electromagnetic ballasts. They contain a magnetic core of several laminated steel plates wrapped with copper windings. Magnetic ballasts usually have greater power losses than electronic ballasts. A lamp-ballast system consisting of a magnetic ballast and two 32-W T8 lamps requires approximately 70 W. Magnetic ballasts operate lamps at line frequency [60 hertz (Hz) in North America] and are usually the least expensive first-cost option for specifiers. Older high-loss magnetic ballasts are approximately 10% less efficient than those manufactured after the National Appliance Energy Conservation Act went into effect in 1990. DOE plans to eliminate magnetic ballasts in new construction and renovation of commercial and industrial buildings by 2005 and phase them out completely by 2010.

Hybrid Ballasts

Hybrid ballasts use a magnetic core-and-coil transformer and an electronic switch for the electrode-heating circuit. Like magnetic ballasts, hybrid ballasts operate fluorescent lamps at line frequency (60 Hz in North America). Hybrid ballasts (also called cathode-disconnect ballasts) disconnect the electrode-heating circuit after they start the lamps. They save approximately 9 W when operating two 32-W T8 lamps compared with magnetic ballasts. Hybrid ballasts cost more than magnetic ballasts, but less than electronic ballasts. For more information about hybrid ballasts, including manufacturer-specific performance data, see *Specifier Reports: Cathode-Disconnect Ballasts*, 1993.

Figure 3. Operating Frequencies (in Hertz) of Ballasts



Electronic Ballasts

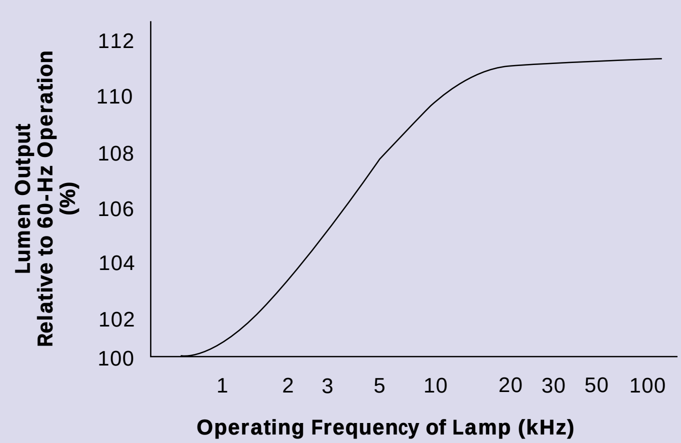
In the early 1980s, advances in solid-state technology allowed ballast manufacturers to replace the core-and-coil transformer with electronic components that operate lamps at 20–60 kHz. These electronic ballasts have approximately half the power loss of magnetic ballasts. Lamp efficacy also increases (by approximately 10–15% compared to 60-Hz operation) when the lamp operates at a frequency above 20 kHz. See Figure 3 and the sidebar "Choice of Frequency for Electronic Ballasts."

Although electronic ballasts are higher in first cost than other ballast types, they can reduce wattage by approximately 10–15 W compared with magnetic ballasts operating two 32-W T8 lamps. Electronic ballasts are also quieter, are often lighter, and virtually eliminate lamp flicker.

Choice of Frequency for Electronic Ballasts

A fluorescent lamp's efficacy relative to 60-Hz operation increases rapidly when the operating frequency changes from 1 kHz to approximately 20 kHz, then increases much more gradually beyond 20 kHz. However, electromagnetic interference (EMI) increases with frequency. To increase efficacy while limiting EMI, electronic ballasts typically operate at a frequency between 20 and 60 kHz.

Figure 4. Lamp Efficacy vs. Frequency
(Adapted from *Lighting Handbook*)



Certifications

Certified Ballast Manufacturers Association (CBM) members participate in a certification program requiring independent laboratory examination and certification. To bear a CBM seal, a ballast must meet or exceed the requirements of specification C82.1 or C82.11 of the American National Standards Institute (ANSI) and meet the safety standards defined by Underwriters Laboratories (see below).

Underwriters Laboratories (UL) sets safety standards for building materials, electrical appliances, and other products. To be UL listed, the ballast must meet all UL safety requirements specified in UL-935.

A "Circle E" label on a ballast indicates that its ballast efficacy factor (BEF) complies with the BEF specified in the 1988 National Appliance Energy Conservation Amendments to the National Appliance Energy Conservation Act of 1987. The label is regulated by the U.S. Federal Trade Commission. Table 4 on p. 10 lists the BEF standards established by the U.S. and Canadian governments.

In Canada, ballasts must meet Canadian Standards Association (CSA) requirements. The CSA can directly certify that a ballast conforms with CSA standards or can rely on certification by other laboratories such as UL.

The C-UL listing mark applies to products for the Canadian market. Products with this mark are certified by UL to conform to Canadian safety requirements.

Lamp-Ballast Starting Methods

Ballasts use one of three general methods, defined by the American National Standards Institute (ANSI), to start fluorescent lamps: preheat, instant-start, or rapid-start. Programmed-start ballasts are similar to rapid-start ballasts, but are emerging as a separate technology, and so are discussed separately below. Lamp manufacturers design many fluorescent lamps for use with more than one type of ballast. For example, some rapid-start lamps work with all types of ballasts. Table 3 lists the most common effects of mismatching ballast and lamp types. Manufacturer catalogs and the ballast or lamp products themselves usually list the starting method; always check to make sure that a particular lamp-ballast combination is recommended by both manufacturers.

Table 3. Effects of Mismatching Ballast and Lamp Types

	Preheat Ballast	Instant-Start Ballast	Rapid-Start or Programmed-Start Ballast
Preheat lamp	normal operation	unreliable starting; shortened lamp life	unreliable starting
Instant-start lamp	most will not start	normal operation	most will not start
Rapid-start lamp	normal operation	usually shortened lamp life	normal operation

Preheat

Preheat (also called switch-start) ballasts for linear fluorescent lamps are all magnetic ballasts. In preheat operation, the ballast heats the lamp electrodes for several seconds to approximately 1470–1830° Fahrenheit (F) [800–1000° Celsius (C)]. After the electrode is preheated, the starter switch opens to apply a voltage of approximately 200–300 volts (V) across the lamp to start it. Preheat ballasts might cause the lamp to flash on and off for a few seconds before finally staying lit. None of the ballasts in this report use this starting method.

Instant-Start

Instant-start ballasts were developed to start lamps without delay or flashing. Instead of heating the electrodes prior to starting, instant-start ballasts supply a high initial voltage (over 400 V for 4-ft lamps; higher for longer lamps) to start the lamp. The high voltage is required to initiate the discharge between the unheated electrodes. Instant-start ballasts do not provide supplemental heating voltage to the electrodes either before or during operation, so instant-start ballast systems have lower power losses than rapid-start ballast systems.

Frequent switching reduces lamp life with all starting methods, but instant-start systems are believed to reduce lamp life more than preheat systems because starting a lamp without first heating the electrodes accelerates degradation of the electrodes' emissive coating.

Rapid-Start

To extend lamp life while preventing lamps from flashing, manufacturers developed rapid-start ballasts. They have a separate set of windings that provides a low voltage (about 3.5 V) to the electrodes, heating them to approximately 1470°F (800°C) in 1 to 2 seconds (s) (Waymouth 1971). Electrode heating reduces the amount of voltage required to start the lamp. While heating the electrodes, rapid-start ballasts apply 200–300 V to start the lamp. Rapid-start ballasts supply the electrode heating voltage even after the lamp has started, which requires 1.5–2 W of additional power for each lamp. Rapid-start ballasts start lamps with a brief delay but without flashing.

Programmed-Start

Manufacturers are developing new rapid-start technologies that control the starting process better, which should further extend lamp life. These new technologies are called programmed-start, modified rapid-start, or controlled rapid-start. Most of these ballasts wait until after the electrodes are heated to apply the starting voltage. ANSI is developing a standard definition of programmed-start technology.

Performance Characteristics

Ballast Factor

Ballast factor (BF) is the ratio of the light output of a lamp or lamps operated by a specific ballast to the light output of the same lamp(s) operated by a reference ballast. BF can be used to calculate the actual light output of a specific lamp-ballast combination when designing a fluorescent lighting system. Magnetic ballasts usually have BFs between 0.93 and 0.98. Electronic ballasts have BFs ranging from 0.73 to 1.50, providing a wide choice of light output levels for a system.

A fluorescent lamp's light output depends on the current flowing through the lamp, which is controlled by the ballast. A lamp's rated light output is determined when the lamp is operated on a reference ballast at line frequency. When lamps are operated at high frequencies (20–60 kHz), less current is required to produce the same light output because the lamps operate more efficiently.

Reference Ballasts

ANSI also provides a standard (ANSI C82.3-1983) for reference ballasts used in tests for BF, rated light output, and so on. They are different from commercially available magnetic and electronic ballasts such as those discussed in this report. Reference ballasts are designed and manufactured specifically to provide stable reference conditions for testing ballasts and lamps. They always operate at line frequency (60 Hz in North America); have constant impedance for long periods of time over a wide range of operating current; and are relatively uninfluenced by temperature or magnetic surroundings.

Ballast Factor, Ballast Efficacy Factor, and System Efficacy Relationships

These three potentially confusing terms show different aspects of a lamp-ballast system and are described using different calculations. However, both BEF and system efficacy are based in part on BF.

$$\text{BF} = \frac{\text{light output of the lamps with the test ballast}}{\text{light output of the lamps with a reference ballast}} \quad \frac{\text{(lumens)}}{\text{(lumens)}}$$

$$\text{BEF} = \frac{\text{BF} \times 100}{\text{power}} \quad \frac{\text{(percent)}}{\text{(watts)}}$$

$$\text{System efficacy} = \frac{\text{system light output}}{\text{power}} \quad \frac{\text{(lumens)}}{\text{(watts)}}$$

Because rated light output is measured on a reference ballast, ballast factor can also be calculated as follows:

$$\text{BF} = \frac{\text{light output of the lamps with the test ballast}}{\text{number of lamps} \times \text{rated light output of one lamp}} \quad \frac{\text{(lumens)}}{\text{(lumens)}}$$

System light output can be calculated based on rated light output, number of lamps, and ballast factor, which allows a calculation of system efficacy without measuring system light output:

$$\text{System efficacy} = \frac{\text{rated light output} \times \text{number of lamps} \times \text{BF}}{\text{power}} \quad \frac{\text{(lumens)}}{\text{(watts)}}$$

Ballasts with extremely high BFs could reduce lamp life and accelerate lumen depreciation because of high lamp current. Ballasts with extremely low BFs also could reduce lamp life because they reduce lamp current (see “Instant-Start Operation” on p. 19).

For ballasts that can operate different types of lamps, BF is typically different for each lamp type. BFs of different ballasts should only be compared if the ballasts are operating the same lamp type. Generally, BF decreases as more lamps are added to a lamp-ballast system. Manufacturer-reported BF in the online database is reported separately for each number and type of lamp operated by a given ballast.

The Certified Ballast Manufacturers Association (CBM) uses ANSI standards to certify ballasts. Electronic ballasts that carry the CBM seal have a minimum BF of 0.85. For more information about ballast certification, see the “Certifications” sidebar on p. 8.

Ballast Efficacy Factor

Ballast efficacy factor (BEF), sometimes called ballast efficiency factor, is the ratio of ballast factor (as a percentage) to power (in watts). BEF is a relative measurement of the system efficacy of the fluorescent lamp-ballast combination. BEF comparisons should be made only among ballasts operating the same type and number of lamps because BEF depends on the type and number of fluorescent lamps that a ballast is operating. Typical BEFs for different ballast types are shown in Table 2 on p. 6.

Both the U.S. and Canadian governments have set minimum BEF standards for some 4-ft and 8-ft fluorescent lamp ballasts. These standards are summarized in Table 4.

Table 4. U.S. and Canadian Standards for Ballast Efficacy Factor

			BEF (minimum)	
Lamp Type	Ballast Input Voltage (Volts)	Total Nominal Lamp Power (W)	U.S. Standard (%/W)	Canadian Standard (%/W)
Two F32T8	120	64	NS	1.25
	277	64	NS	1.23
	347	64	NA	1.20
One F40T12	120	40	1.81	1.81
	277	40	1.81	1.81
	347	40	NA	1.75
Two F40T12	120	80	1.06	1.06
	277	80	1.05	1.05
	347	80	NA	1.02
Two F96T12	120	150	0.57	0.57
	277	150	0.57	0.57
	347	150	NA	0.56
Two F96T12/HO	120	220	0.39	0.39
	277	220	0.39	0.39
	347	220	NA	0.38

NA = not applicable
NS = no standard

System Efficacy

A lighting system's efficacy is the ratio of the light output to the power, measured in lumens per watt (LPW), for a particular lamp-ballast system. For fluorescent lighting systems, system efficacy ranges from approximately 60–100 LPW. Table 5 lists typical system efficacies, ballast factors, and annual energy costs for some lamp and ballast combinations. As the table shows, electronic ballasts perform well in terms of both efficacy and operating costs.

Table 5. Typical Efficacies and Annual Energy Costs of Different Lamp-Ballast Combinations

	Power (W)[a]	Ballast Factor [a]	Efficacy (LPW)[a]	Increase in Ballast Price ($US)[b]	Annual Energy Costs ($US)[c]
Ballast and Two 4-Ft 32-W T8 Lamps (120V)					
Magnetic	70	0.94	78	base case	24.50
Hybrid	61	0.86	82	4	21.35
Electronic instant-start, low ballast factor	51	0.71	81	0	17.85
Electronic instant-start, normal ballast factor	63	0.95	87	7	22.05
Electronic rapid-start	62	0.88	82	9	21.70
Ballast and Two 4-Ft 34-W T12 Lamps (F40T12/ES) (120V)					
Magnetic	72	0.87	68	base case	25.20
Hybrid	66	0.88	75	18	23.10
Electronic instant-start, low ballast factor	52	0.73	79	16	18.20
Electronic rapid-start	62	0.88	79	14	21.70

[a] These data are based on information from the California Energy Commission (1993) and assume operation under ANSI test conditions.

[b] Increase in ballast price is with respect to the cost of a magnetic ballast. These figures are based on price quotations from Albany, New York, area distributors in February 2000. Actual prices vary, depending on volume purchased, local market conditions, and distribution channel.

[c] Actual energy costs assume 3500 operating hours per year (9.6 hours per day) and an energy cost of $0.10/kWh.
Annual energy cost = [power (W) × annual operating hours × $/kWh] ÷ 1000.
No lamp replacement or other maintenance costs are included.

Ballast Life

Some of the first electronic ballasts on the market had high early-failure rates, leading to the perception that the technology was unreliable. As a result, some lighting specifiers and users still hesitate to use electronic ballasts, especially when new products are introduced. Documenting the reliability of any manufacturer's product is difficult because manufacturers continually change their product designs, component suppliers, and manufacturing processes. Furthermore, testing strategies for ballast life are not well established and are costly and time consuming to implement.

NLPIP presents the following information on ballast life and reliability so that lighting specifiers and users can better understand issues related to ballast life. Most defective ballasts fail soon after installation, so specifiers should closely evaluate the manufacturer's warranty (see the sidebar "Ballast Warranty"). Ballast life depends on input voltage, ambient temperature, and the ballast's operating temperature, among other variables.

Ballast Warranty

The warranty period for electronic ballasts ranges from 3 to 5 years. In their warranties, ballast manufacturers sometimes warn that the warranty will not apply if the product is not installed in accordance with the National Electrical Code, the standards of Underwriters Laboratory, and the American National Standards Institute. Manufacturers might also require that specific instructions for ballast storage, installation, use, and maintenance be followed. Some ballast manufacturers state that they will pay labor expenses for replacing defective ballasts.

Input Voltage

Electronic ballasts use semiconductor devices such as transistors and diodes that are more sensitive than magnetic components to variations in input voltage. There are two general categories of variations: long-term and short-term (transient).

Depending on the configuration of a building's electrical distribution, voltage supplied to a ballast might be consistently above or below the ballast's rated input voltage. Traditionally, electronic ballasts have been designed to meet their rated life with input voltage variations of ±10%. Some ballast manufacturers claim reliability for a range of up to ±20%.

Transient spikes, surges, swells, and sags are brief compared to long-term fluctuations, but more extreme. To protect components from transient voltage fluctuations, electronic ballast designs can use filters and voltage limiters at the ballast input. Ballast life depends on the design and quality of these components and the degree to which the ballast is exposed to transient fluctuations.

Ballast Reliability

In addition to functioning within a reasonable range of temperatures and voltages, the ideal ballast design would also tolerate:

- fewer lamps than the ballast was designed for
- the wrong lamp type
- a failed lamp in the circuit
- open or short circuits

Manufacturers must often choose between better reliability and lower costs.

Based on the factors that affect ballast life, some manufacturers evaluate the reliability of their electronic ballasts by stress testing, including:

- high-temperature
- ballast partial-load and no-load
- low- and high-input voltage
- susceptibility to voltage fluctuation and distortion
- rapid-cycle testing

This testing can help ensure the reliability of a new ballast design or of a component that has been changed in or added to an old ballast design.

Some ballast manufacturers use the "mean time between failures" (MTBF) of components to predict ballast life. The predicted MTBF for the ballast, which is based on the failure probabilities of individual components, is determined by the shorter-life components such as electrolytic and film capacitors. Although components' MTBF can help manufacturers estimate ballast life, its results might not conform to field data, as it does not account for component assembly or the other conditions discussed above.

One study reports the results of field testing more than 30,000 electronic ballasts installed in 67 buildings (Abesamis et al. 1990). The ballasts were from three manufacturers, with at least 4000 ballasts from each. None of the ballasts had been installed for more than approximately 3.5 years at the time of the report, which would be well within the warranty period of most of the electronic ballasts in this report. During that time, the defect rates for two of the manufacturers were 1.0% and 0.5%. The defect rate for the third manufacturer was much higher (6.3%), but these ballasts used special dimming resistors to operate at partial light output, so are probably not comparable to standard electronic ballasts. Magnetic ballasts typically have failure rates of 0.5% (Houghton et al. 1992).

Class "P" and UL-Listed Ballasts

In the U.S., the 1965 National Electrical Code required ballasts for indoor use to incorporate protective devices that prevent ballast overheating. To implement this safety requirement, UL established the Class "P" standard for indoor ballasts. The 1984 National Electrical Code required that all ballasts for indoor use be Class "P" ballasts. When a Class "P" ballast's case temperature reaches 230°F (110°C), a heat-sensitive device opens a switch that interrupts power to the ballast, thereby preventing overheating and a possible fire. Some ballasts can automatically resume operation when the ballast case cools to a temperature below 185°F (85°C). Under normal operation, the ballast case temperature for UL-listed ballasts should not exceed 194°F (90°C).

Operating and Ambient Temperatures

High temperatures can damage electronic components. For safety reasons, UL specifies a maximum ballast case operating temperature of 194°F (90°C).

In addition to the operating temperature of the ballast case itself, most manufacturers specify a maximum ambient temperature for the ballast. A higher ambient temperature leads to a higher ballast operating temperature. If the ambient temperature exceeds the maximum listed by the manufacturer, the ballast warranty might become void. The online database includes the maximum ambient temperatures specified by the manufacturers.

Lamp-Ballast Interaction Effects

Input Voltage

Nearly all ballasts are designed to operate lamps with input voltage within ±10% of the designed operating voltage. Outside this range, lamps might not operate properly.

The light output from lamps operated by magnetic ballasts and some electronic ballasts varies with the input voltage: the higher the voltage, the higher the light output. Other electronic ballasts are designed to keep light output relatively constant despite voltage fluctuations. Specifiers should check with the ballast manufacturer to see whether a ballast has this feature. This light output regulation, however, can conflict with planned utility voltage reductions, which sometimes are implemented to reduce peak demand; if the utility reduces the supply voltage, the ballast draws more current to maintain light output, defeating the utility's objective.

Ambient Temperature

Ambient temperature affects both light output and power of fluorescent lamp-ballast systems. Each fluorescent lamp-ballast system has an optimum ambient temperature at which it produces maximum light output. Higher or lower temperatures reduce light output.

For indoor applications, overheating lamps is more common than underheating because lamps are usually enclosed in luminaires that trap heat. As shown in Figure 5, light output peaks at a higher ambient temperature for electronic ballasts than for magnetic ballasts, so lamps usually operate closer to their optimum temperature in an enclosed luminaire with an electronic ballast.

Magnetic ballasts typically heat luminaires more than electronic ballasts because they have greater power losses — in other words, more of their power is converted to heat. Similarly, lamps themselves are slightly cooler with electronic ballasts because the lamp power is lower. As a result, light output can be reduced by as much as 20% for lamps operated in 2-ft by 4-ft lensed luminaires with magnetic ballasts, whereas light output is reduced by only 10% when using electronic ballasts in the same luminaire.

Figure 5. Performance of a Magnetic and an Electronic Ballast Operating an F32T8 Lamp (Adapted from Bleeker and Veenstra 1990)

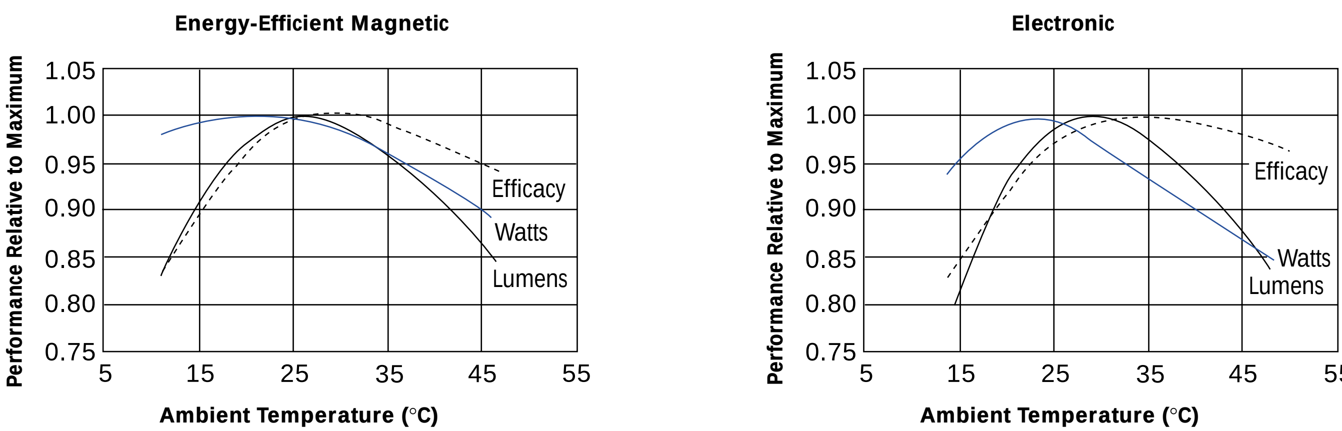


Figure 5 on p. 14 shows that power also is reduced at temperatures above the optimum. Nominal power ratings for fluorescent lamp-ballast systems are derived from testing in open-air conditions, yielding higher power values than the actual power of a system in an enclosed luminaire. Systems that use magnetic ballasts operate at higher temperatures than those that use electronic ballasts, so the relative reduction in power (compared with rated value) is greater. Thus, using rated power values to predict the energy savings that could be achieved by converting from magnetic to electronic ballasts can lead to overestimates of savings, because the actual difference in power between the two systems is less in a luminaire than it is under open-air conditions.

Power Quality

Power quality describes the potential of a specific electronic device to distort the sinusoidal shape of the voltage waveform or change the phase relationship between the voltage and current. Electromagnetic interference (EMI) also affects power quality, as explained on p. 16. A device with minimal effect on power quality neither distorts the supply voltage nor affects the voltage-current phase relationship. See *Lighting Answers: Power Quality*, 1995, for a complete discussion. NLPIP evaluated power quality for electronic ballasts by measuring power factor and current total harmonic distortion (THD).

Power Factor

Power factor is defined as the ratio of power (in watts) to apparent power [in volt-amperes (VA)]. Apparent power is the product of root-mean-square (rms) voltage and rms current. Power factor ranges from 0–1. A power factor of 1 means that the voltage and current waveforms are in phase and neither waveform is distorted. In other words, when the power factor is 1, apparent power and power are equal.

The primary cause of low power factor in magnetic ballasts is the inductance of the ballast transformers, which causes a phase shift between current and voltage. It can be corrected by using an appropriate capacitor, either within the ballast itself or elsewhere in the building's power system. Low power factor in electronic ballasts is primarily due to the THD caused by a non-linear load, which is more difficult and expensive to correct.

Root-Mean-Square (rms)

Root-mean-square is the effective value of a periodic quantity such as an alternating current or voltage wave. It is calculated by averaging the squared values of the amplitude over one period and taking the square root of that average.

Total Harmonic Distortion

Both current and voltage waves should be sinusoidal. Any distortion of the current wave shape distorts the voltage in the electrical distribution system, thus reducing power factor. Distorted currents could also interfere with the operation of electronic equipment (both nearby and remote); cause improper operation of power grid protective devices (fuses, circuit breakers, and relays); interfere with nearby communications circuits; and overheat motors, transformers, capacitors, and neutral conductors. For more information, see *Lighting Answers: Electromagnetic Interference Involving Fluorescent Lighting Systems*, 1995, and *Lighting Answers: Power Quality*, 1995.

A distorted waveform is made up of the main sinusoidal wave (called the *fundamental*) and one or more harmonic waves. A harmonic wave has a frequency that is an integer multiple of the fundamental. For example, a distorted 60-Hz current wave might contain harmonics at 120 Hz (called a second-order harmonic), 180 Hz (third-order harmonic), and other multiples of 60 Hz. Highly distorted current waveforms contain numerous harmonics. The even harmonic components (second-order, fourth-order, and so on) tend to cancel each other's effects, but the odd harmonics tend to add in a way that rapidly increases distortion because the peaks and troughs of their waveforms often coincide.

Definitions of terms used to characterize harmonic distortion vary; the sidebar "Definitions and Standards for Harmonic Distortion" describes some of these differences. NLPIP uses the term *current total harmonic distortion (THD)*.

All ballasts that NLPIP tested for this report had THD of less than 19%. Because current THD is expressed as a percentage of the fundamental, an electronic ballast equal in THD to a magnetic ballast, but operating at lower power, lowers distortion current levels in the system.

Electromagnetic Interference

Most electronic devices can generate EMI. Incorrectly grounding a ballast can increase EMI. EMI can be either radiated through the air or conducted through the power supply wiring.

The U.S. Federal Communications Commission (FCC) and the Canadian government limit the amount of radiated EMI that fluorescent lighting systems may produce at frequencies from 30 to 1000 MHz (USFCC 47 CFR 18, ICES-005).

Definitions and Standards for Harmonic Distortion

Current THD is a measure of the amount of distortion in a current's wave shape: the higher the THD value, the greater the distortion. American National Standards Institute (ANSI) Standard C82.11 sets a limit of 32% current harmonic factor (see the definition below) for electronic ballast systems. The Federal Energy Management Program, which issues energy-efficiency guidelines for federal buildings, specifies THD of 20% or less. Similarly, many utilities only include ballasts that have THD of less than 20% in their energy-efficiency programs.

$$\text{NLPIP and IEEE THD} = \sqrt{\frac{I_2^2 + I_3^2 + I_4^2 + \ldots + I_{33}^2}{I_1^2}} \times 100$$

where

I_1 = fundamental current
I_2 = current in second harmonic
I_3 = current in third harmonic
I_4 = current in fourth harmonic
etc.

ANSI, CSA, and IEC define THD as the ratio of the harmonic content to the rms value of the periodic current (all of the harmonic components including the fundamental), which is expressed as

$$\text{ANSI, CSA, and IEC THD} = \sqrt{\frac{I_2^2 + I_3^2 + I_4^2 + \ldots + I_{33}^2}{I_1^2 + I_2^2 + I_3^2 + I_4^2 + \ldots + I_{33}^2}} \times 100$$

Unlike the definition used by NLPIP and IEEE, this definition always results in a THD less than 1.0.

Both definitions of THD measure harmonics only up to the 33rd harmonic (2000 Hz), because harmonics at higher frequencies are usually a small percentage of the total current.

Harmonics that are odd triple multiples of the fundamental frequency (3rd, 9th, 15th, 21st, ...) have the greatest potential impact on electrical systems because this current flows on the neutral conductor and might overload it. ANSI C82.11 also sets limits for odd triple multiples and other harmonics.

In this report, NLPIP uses the THD definition of the Institute of Electrical and Electronic Engineers (IEEE 519–1992) because that is how ballast manufacturers typically report it. This definition coincides with the definition of *harmonic factor* used by ANSI, the Canadian Standards Association (CSA), and the International Electrotechnical Commission (IEC).

FCC and the Canadian government limit the amount of conducted EMI that fluorescent lighting systems may produce to 1000 microvolts for industrial and commercial applications and 250 microvolts for consumer applications (USFCC 47 CFR 18, ICES-005). All fluorescent lighting systems sold in the U.S. must meet either the commercial or the consumer FCC limits, but most electronic ballasts meet only the less stringent commercial standards.

Some electronic ballasts have been designed specifically to reduce potential radiated interference with infrared remote control systems, which typically operate between 33 and 42 kHz or between 50 and 60 kHz (NEMA 1999).

Physical Characteristics

Electronic ballasts for 4- and 8-ft lamps have similar physical characteristics, with some variations in design that could have important ramifications for a particular application. For example, electronic ballasts have either metal or plastic casings. Plastic casings are lighter and less expensive than metal casings but do not conduct heat as well. Therefore, a ballast with a plastic casing might run slightly warmer than a similar ballast with a metal casing.

Dimensions

Although electronic ballasts can be smaller than magnetic ballasts, most ballasts for T8, T10, and T12 lamps are designed to have the same “footprint” (locations of bolt-holes) as magnetic ballasts to simplify retrofitting. Ballasts for T5 lamps are often smaller. Ballast lengths in this report range from 8.3 to 13.3 in. [21.1 to 33.8 centimeters (cm)], and widths range from 1.6 to 3.2 in. (4.1 to 8.1 cm). Most of the ballasts measure 9.5 × 2.4 in. (24.1 × 6.1 cm) and either 1.5 in. (3.8 cm) or 1.6 in. (4.1 cm) high. The online database includes ballast dimensions provided by the manufacturers.

Weight

Most electronic ballasts are lighter than magnetic ballasts. Magnetic ballasts for linear fluorescent lamps average approximately 3.5 pounds (lb) [1.6 kilograms (kg)]. Of the weights reported by manufacturers for electronic ballasts in this report, most ranged from 0.4–3.0 lb (0.2–1.4 kg). The online database contains ballast weights provided by the manufacturers.

Some electronic ballasts are filled with a potting material that adds significant weight to the ballast. In fact, potted electronic ballasts are sometimes mistaken for magnetic ballasts because they weigh as much.

Sound

Magnetic ballasts sometimes produce a humming noise caused by vibration of the laminated magnetic core. Electronic ballasts are usually significantly less noisy because they are made of different materials than magnetic ballasts and operate at high frequencies.

Ballasts are rated from “A” to “F” based on their noise level. The rating does not directly indicate the amount of noise the ballast generates, but instead defines the range of ambient sound levels in which people will not notice the ballast noise. While manufacturers use the same ranges, there is no standard describing the method of measurement or application of the rating. Table 6 shows the average sound levels, in acoustic decibels (dB), for noise ratings “A” through “F.”

Table 6. Ballast Noise Ratings

Noise Rating	Average Ambient Sound Level (dB)
A	20–24
B	25–30
C	31–36
D	37–42
E	43–48
F	49 and higher

“A”-rated ballasts are for indoor applications such as offices, and noisier “B”-rated ballasts are intended for outdoor applications or indoor spaces such as warehouses where noise is not as bothersome. Most electronic ballasts have a noise rating of “A.”

Although electronic ballasts are usually quieter than magnetic ballasts, other factors can amplify the vibration and noise generated by a ballast, such as the mounting method, location of the ballast in the fixture, and even loose parts in the fixture.

Flicker

Operating fluorescent lamps on alternating current modulates the light output. When the modulation is perceptible, it is called *flicker*. For fluorescent lamps operated at line frequency (60 Hz in North America), the phosphors are refreshed 120 times per second, resulting in 120-Hz light output oscillation. Flicker at this relatively low frequency is a suspected source of eyestrain and headaches. Electronic ballasts that operate lamps at a frequency of 20 kHz or higher refresh the phosphors so rapidly (40,000 times per second) that the light modulation is imperceptible.

Flicker index is the industry-recognized measure for perceptible light modulation, and ranges from 0.00–1.00. Higher values indicate an increased possibility of flicker. Flicker indexes for fluorescent lamps operated by magnetic ballasts range from approximately 0.04–0.07, not perceptible by most people. Most electronic ballasts have flicker indexes below 0.01.

Lamp Life Considerations

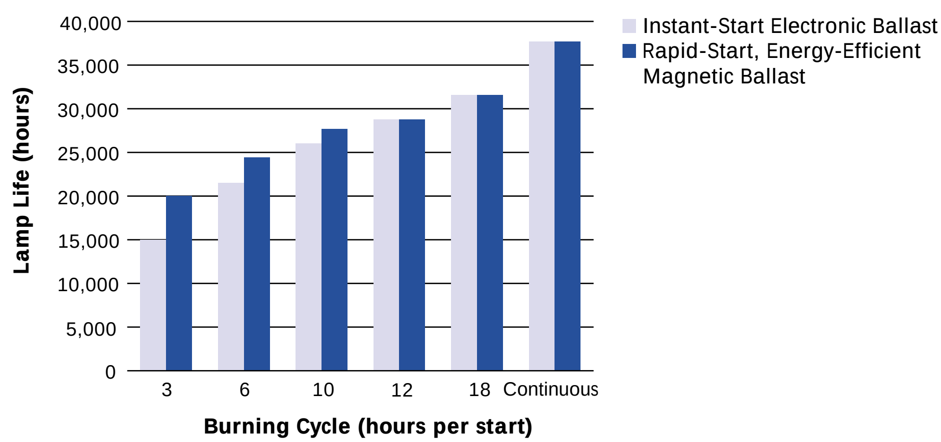
Lamp Current Crest Factor

Lamp current crest factor (CCF), the ratio of peak lamp current to rms lamp current, describes the wave shape of the lamp current. A high CCF indicates that the current wave shape has high peaks that can reduce lamp life. The CCF of a sine wave is 1.41. ANSI Standard C82.11 (ANSI 1993) recommends a maximum CCF of 1.7. Lamp CCF is determined by the ballast; most lamp manufacturers void their warranties when lamps are operated on ballasts with CCFs greater than 1.7.

Instant-Start Operation

Many electronic ballasts operate lamps in an instant-start mode. Instant-start ballasts have lower total power than rapid-start ballasts because they do not heat the lamp electrodes before or during lamp operation. However, because the starting voltage is applied to cold electrodes, instant-start ballasts can reduce lamp life (more than rapid-start ballasts do) at short burning cycles. Some lamp manufacturers state that when lamps are operated on instant-start ballasts for an average of 3 hours per start, their life might be 25% shorter than when operated on rapid-start ballasts. For longer burning cycles (12 hours or more per start), the difference in lamp life diminishes (see Figure 6).

Figure 6. Effect of Burning Cycle on T8 Lamp Life (Adapted from GTE Products Corporation 1988)



Average lamp life versus hours on during burning cycle (number of hours on, 20 minutes off)

Some instant-start ballasts are designed to have low ballast factor to further reduce power, which reduces lamp current. Lower lamp current results in lower electrode temperatures, which might cause electrode sputtering and reduce lamp life. To respond to the concerns about low-ballast-factor, instant-start ballasts, some lamp manufacturers state that they have changed their electrode design to reduce the required lamp current (Sardinsky and Hawthorne 1993).

Shut-Off Circuits

When a small-diameter fluorescent lamp such as a T5 fails, the ballast might deliver excess power in an attempt to operate the failed lamp. The excess power increases the temperature near the electrode, particularly when delivered by an instant-start ballast (which is capable of high sustained lamp voltages). Temperatures can reach as high as 660°F (350°C) at the lamp tube, cracking or melting it and damaging the lamp base, socket, or other luminaire components. A circuit that shuts off the starting voltage when the lamp fails prevents this problem. Some ballast manufacturers include a shut-off circuit in all electronic ballasts. Members of the National Electrical Manufacturers Association are discussing this issue, but have yet to resolve it.

Rapid-Start Operation

The rapid-start method has several operating characteristics that affect lamp life. Glow current, lamp preheat time, electrode temperature, and electrode voltage affect the rate at which the lamp electrodes' emissive coatings evaporate or the amount of electrode sputtering that occurs.

Glow Current

Reduced lamp life and increased end darkening of fluorescent lamps are related to the loss of the electrodes' emissive coating during starting. Glow current flows away from electrodes during the preheat time and reflects the degree to which the emissive coatings are lost during lamp starting before the electrodes have reached operating temperature. High glow current increases lamp end darkening and reduces lamp life.

Ideally, the glow current should be zero. For a high-frequency rapid-start system, ANSI C82.11 limits the average value of the rms glow current to a maximum of 25 milliamps.

Lamp Preheat Time

Lamp preheat time is the length of time a rapid-start ballast heats the electrodes before starting the lamp. A short electrode preheat time might cause insufficient heating, which results in electrode sputtering and reduces lamp life. For rapid-start electronic ballasts for 40-W lamps, ANSI C82.11 recommends that the preheat time be at least 500 milliseconds (ms), or equal to or greater than 90% of the preheat time of a "corresponding" rapid-start magnetic ballast.

Electrode Temperature and Electrode Voltage

Lamps operated by rapid-start, magnetic ballasts have an average electrode temperature of approximately 2000°F (1100°C) during lamp operation, whereas lamps operated by rapid-start electronic and hybrid ballasts have average electrode temperatures of approximately 1100°F (600°C) (Verderber et al. 1985). Although this lower temperature reduces evaporation of the emissive coating, lamp electrode sputtering might increase, reducing lamp life. Electronic ballast designs can result in average lamp electrode temperatures of around 1800°F (1000°C), helping to achieve rated lamp life.

During operation, rapid-start ballasts (except for hybrid ballasts) continue to provide low electrode voltage (about 3.5 volts rms) to heat the electrodes. Because electrode temperature is difficult to measure directly, electrode voltage (referred to as "cathode heating voltage" by ANSI) is used as a related parameter in lighting standards. Electrode voltage that is either too high or too low can reduce lamp life. ANSI C78.1 establishes the acceptable range of electrode voltages for several different types of lamps (see Table 7 on p. 21). ANSI has not yet established electrical specifications for ballasts for T5 lamps. Lamp manufacturers might not warrant lamp life if the electrode voltages are not within ANSI recommendations.

Table 7. ANSI-Recommended Electrode Voltages (Cathode Heating Voltages) for Rapid-Start Lamps

	Electrode Voltage (V)	
Lamp Type	Minimum	Maximum
F32T8	2.5	4.4
F40T10	2.5	4.0
F40T12	2.5	4.0
F40T12/ES	2.5	4.0
F96T12/HO	3.0	4.0

R_H/R_C

In addition to preheat time and electrode-heating voltage, the LRC has found evidence to support the use of another indicator of lamp and ballast compatibility for rapid-start electronic systems (Davis and Ji 1998). R_H/R_C is the ratio of hot electrode resistance to cold electrode resistance for each lamp-ballast system. An R_H/R_C value of 4.25 equates to a lamp electrode temperature of 1300°F (700°C), which lamp experts consider the minimum temperature for proper lamp starting. The relationship between R_H/R_C and electrode overheating is not yet known. Some lamp manufacturers recommend an upper limit of 6.25, which equates to a lamp electrode temperature of 1925°F (1050°C).

The LRC's research indicates that if the R_H/R_C ratio is too low, it could reduce lamp life. However, other factors within the lamp influence lamp life, such as the amount of emissive material on the lamp electrodes, the quality of the electrodes, and different fill gas types or pressures.

If glow current (see "Glow Current" on p. 20) is too high, R_H/R_C cannot be measured, as explained in the sidebar "Measuring R_H/R_C". High glow current by itself might damage the electrodes more than insufficient heating would.

Measuring R_H/R_C

Because the resistance of the tungsten used in lamp electrodes is related to its temperature, R_H/R_C (the ratio of hot electrode resistance to cold electrode resistance) can be used to calculate the approximate temperature of the electrode just before a lamp is started (Hammer 1995).

Cold electrode resistance can be measured using an ohmmeter capable of measuring resistances of a few ohms. Hot electrode resistance cannot be measured directly. It must be calculated by measuring the voltage applied to the electrode and the electrode current just before the lamp starts. Several similar methods of measuring this hot electrode resistance have been developed.

NLPIP used a measurement technique similar to Mortimer (1996) to measure R_H/R_C for this report. The R_C was measured at a room temperature of 77±2°F (25±1°C). For the R_H measurement, the electrode-heating voltage and electrode-heating current were measured immediately before the lamp's transition from glow to arc. NLPIP calculated the R_H value and the R_H/R_C ratio based on these values. If the lamp has a high glow current, it complicates the measurement of R_H because it is difficult to distinguish between electrode-heating current (which is required to calculate R_H) and lamp glow current.

Ballast Installation and Disposal

Most electronic ballasts are the same size and shape as magnetic ballasts, so they can directly replace these ballasts. The color coding and number of wires in most electronic ballasts are also the same as magnetic ballasts, with a few exceptions. Some ballasts do not supply wires, but have color-coded “stab-in” connectors. The contractor must supply 18 American Wire Gauge (AWG) solid copper wire for installation. NLPIP tested ballasts with stab-in connectors from Motorola and JRS and found that the wires were easy to insert into these ballasts.

All ballasts manufactured in the U.S. since 1978 are free of polychlorinated biphenyls (PCBs). They can be disposed of in municipal landfills under federal environmental regulations (U.S. Environmental Protection Agency 1994), although state and local regulations vary. Specifiers should check with their local landfills for pertinent regulations. Most ballasts contain lead solder, which is not yet regulated but might be in the future.

Related Technologies

PLC Transmitters and Electronic Ballasts

Interference from high-frequency electronic ballasts can disrupt some power-line carrier (PLC) signals. PLC systems transmit high-frequency (50–500 kHz) signals via a building’s power lines. The signals control devices such as synchronized clocks or contain voice transmissions such as intercom messages. Some commercial and residential energy management systems also use PLC devices. Specifiers should consult the manufacturers of both the PLC device and the electronic ballast to ensure compatibility.

Building Automation Systems

A building automation system is a computer network that integrates the controls of a building’s various electrical and mechanical systems, such as heating, lighting, and security systems. However, high initial and maintenance costs, apparent complexity, and concerns about interoperability of lighting and other building systems have limited the widespread use of building automation systems. Some manufacturers advertise their ballasts as compatible with them. For more information, refer to *Lighting Answers: Building Automation Systems*, 1997, or contact manufacturers directly.

Dimming Ballasts

Manufacturers also make magnetic and electronic dimming ballasts. These ballasts dim fluorescent lamps by reducing the lamp current; products are available that claim to dim reliably to as low as 0.5–2.5% of full light output. Most dimming ballasts are electronic. The performance characteristics described in this report apply to both dimming and non-dimming electronic ballasts.

Dimming ballasts allow adjustable light levels. The ballasts save energy (and therefore money) because the power of a dimming ballast decreases as the ballast dims. However, the installed costs for these ballasts and their associated control systems are higher than for non-dimming electronic ballasts. For detailed information, see *Specifier Reports: Dimming Electronic Ballasts*, 1999.

Additionally, specifiers are concerned about how dimming ballasts affect lamp life and the compatibility of the lamp, dimming ballast, and control. For example, 34-W, energy-saving fluorescent lamps could have reduced life when dimmed and generally should not be used with dimming ballasts unless recommended by the ballast manufacturer.

Performance Evaluations

This NLPIP report covers only non-dimming electronic ballasts for 4-ft and 8-ft lamps. The online database (www.lrc.rpi.edu/nlpip) contains both the data supplied by manufacturers and the results of NLPIP testing. Table 8 on p. 25 provides contact information for the manufacturers. Table 9 on p. 26 lists the types of electronic ballasts available from manufacturers that responded to NLPIP's requests for information. Ballasts are grouped in Table 9 by their input voltage. (Input voltage is the designed operating voltage of the ballast. In the U.S., ballasts are designed to operate at either 120 V or 277 V; in Canada, at either 120 V or 347 V.)

The online database contains manufacturer-reported data for ballasts for 4-ft and 8-ft T8, T10, and T12 lamps. NLPIP-tested data for 4-ft and 8-ft T8 lamp ballasts are also in the online database. Manufacturer-reported and NLPIP-tested data on ballasts for T5 lamps will be added to the database when testing is complete.

NLPIP Testing Procedure

NLPIP tested two-lamp F32T8, four-lamp F32T8, and two-lamp F96T8 electronic ballasts. Three samples of each of 74 ballast models were requested from manufacturers. Additionally, one sample of each model was purchased through a distributor, if it was available. NLPIP tested two of the ballasts supplied by the manufacturers plus the purchased ballast, for a total of three tests for each product.

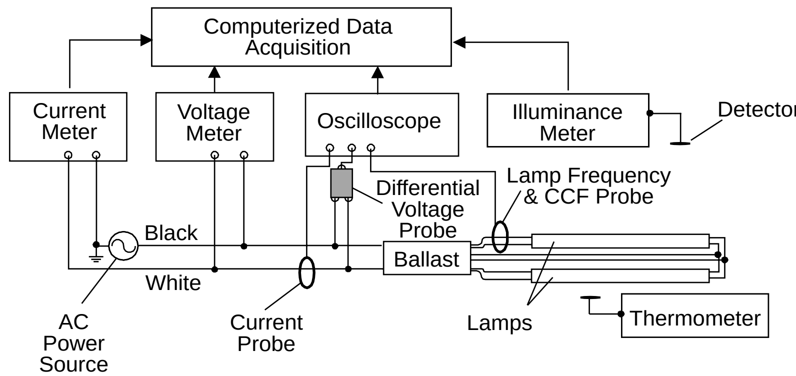
NLPIP testing was conducted at the LRC's laboratory in Watervliet, New York, from July 1999 through November 1999. Only products received by July 31, 1999, were tested. NLPIP evaluated the following characteristics of these ballasts: operating frequency, power, power factor, THD, lamp current crest factor, ballast factor, ballast efficacy factor, and R_H/R_C. NLPIP used Version 5.1 of National Instruments' LabVIEW software throughout testing to control, monitor, and acquire data from the test equipment.

The NLPIP-measured data reported in the online database are the mean data for each product. No substantial differences were noted between the performance of the manufacturer-submitted products and the NLPIP-purchased products.

NLPIP's electrical testing apparatus is illustrated in Figure 7 on p. 24. NLPIP used the following lamps while testing electrical characteristics and ballast factor: OSRAM SYLVANIA F32T8-35K, Philips F32T8/TL741, and General Electric F96T8SP35 Trimline. NLPIP used the following lamps while testing R_H/R_C: OSRAM SYLVANIA T8 F032/741, Philips F32T8/170, and General Electric F32T8-SP35. NLPIP tested the lamp brands as follows:

- OSRAM SYLVANIA lamps with two-lamp F32T8 ballasts
- Philips lamps with four-lamp F32T8 ballasts
- General Electric lamps with two-lamp F96T8 ballasts

Figure 7. Apparatus for NLPIP's Electrical Characteristics Testing



Ballast Factor

NLPIP used two reference ballasts and a calibrated ballast to determine the ballast factor of the tested ballasts: two WPI Power Systems variable linear reactors (model number 20758a) for two-lamp systems and a MagneTek Triad (model number B432I2ORh) secondary reference ballast, calibrated by Intertek Testing Services, for four-lamp systems. Illuminance measurements for both test and reference systems were obtained on the same testing rack, as shown in Figure 7.

NLPIP measured the ballast factor (BF) for 4-ft lamp ballasts. Eight-foot lamps require a higher starting voltage than NLPIP's power supply could provide, so NLPIP did not measure BF for them.

For two-lamp systems, the ballast factor of each test ballast was calculated as follows:

$$\text{BF} = \frac{\text{light output of the lamps with the test ballast}}{\text{light output of the lamps with a reference ballast}}$$

For four-lamp systems, the use of a calibrated ballast instead of a reference ballast required a different calculation for ballast factor:

$$\text{BF} = \text{BF of calibrated ballast} \times \left(\frac{\text{light output of the lamps with the test ballast}}{\text{light output of the lamps with the calibrated ballast}} \right)$$

Test lamps were seasoned for at least 100 hours. The ambient temperature at a point not more than 3 feet from the lamps and at the same height as the lamps was maintained at 77±2°F (25±1°C). Before testing each day, the lamps were operated for at least 20 minutes. During the testing, NLPIP used relays to switch from the reference ballast to the test ballast without extinguishing the arc. In a very few cases, the lamp was extinguished for a very short period during the switching; these lamps were restabilized for an additional 5 minutes. The input voltage was maintained at 120±0.12 V.

Results

NLPIP's testing found that the ballasts' operating frequency ranged from 20–46 kHz. For all 74 tested ballasts, power factor was 0.98 or greater and THD was less than 19%. Lamp CCF was 1.7 or less for 64 of the ballasts; 10 ballasts had lamp CCF values between 1.7 and 1.9.

NLPIP found 30 ballasts with lower power than the manufacturer-supplied data and 36 ballasts with higher power. However, none of the ballasts varied by more than 6% of the manufacturer-supplied value. Forty-eight ballasts had higher BF (up to 22% higher) than the manufacturer-supplied data, and only seven ballasts had lower BF. NLPIP did not measure BF for ballasts for F96T8 lamps.

All ballasts for two F32T8 lamps had BEFs greater than or equal to 1.387, which exceeds the Canadian minimum standard of 1.250. All ballasts for four F32T8 lamps had BEFs ranging from 0.819 to 0.888. NLPIP did not calculate BEF for ballasts for F96T8 lamps.

Eight ballasts had glow currents that exceeded 25 milliamperes (mA), which is the maximum glow current specified in ANSI C82.11 for rapid-start systems. Some glow currents were as high as 100 mA.

NLPIP tested R_H/R_C for the 10 rapid-start ballasts. However, high glow current complicates the measurement of R_H because it is difficult to distinguish between electrode-heating current (which is required to calculate R_H) and lamp glow current. Therefore, the online database reports R_H/R_C only for the two systems with glow current below 25 mA.

Some of the rapid-start systems also started lamps much faster than the ANSI-recommended minimum of 500 ms. A few rapid-start systems started in less than 100 ms, which is comparable to instant-start systems.

Ballasts with high glow currents typically have a short start time. The combination of high glow current and short preheat time might shorten lamp life.

Table 8. Manufacturer Contact Information

Company	Phone	Web Site
Advance Transformer	800-322-2086	www.advancetransformer.com
FIT Electronics	403-252-2828	NA
Howard Industries	601-442-0033	www.howard-ballast.com
JRS Technology	607-748-4800	www.jrstechnology.com
LG Industrial Systems U.S.A.	888-544-7872	www.lgisusa.com
MagneTek	615-316-5100	www.magnetek.com/ballast
MaxLite SK America	973-256-3330	www.maxlite.com
Motorola Lighting[1]	800-654-0089	www.motorola.com/ies/MLI
Philips Lighting	800-555-0050	www.lighting.philips.com
PowerLighting[2]	800-533-7290	www.powerlighting.com
OSRAM SYLVANIA	800-255-5042	www.sylvania.com/ballast
Toshiba Lighting	847-229-8900	www.toshiba-lighting.com

NA = not available
[1] Acquired by OSRAM SYLVANIA in April 2000
[2] Now SLI Lighting

Table 9A. Availability of Electronic Ballasts

Lamp Length	4 Feet											
Lamp Type	F32T8				F32T8/HO		F40T10			F40T12		
Number of Lamps	1	2	3	4	1	2	1	2	3	1	2	3
Manufacturers of 120-V Electronic Ballasts												
Advance Transformer	•	•	•	•	•	•	•	•	•	•	•	•
FIT Electronics		•	•	•								
Howard Industries	•	•	•	•								
JRS Technology		•										
LG Industrial Systems U.S.A.	•	•	•	•						•	•	
MagneTek	•	•	•	•			•	•	•	•	•	•
Maxlite SK America		•	•	•							•	
Motorola Lighting[1]	•	•	•	•			•	•	•	•	•	•
Philips Lighting	•	•	•	•						•	•	•
PowerLighting[2]	•	•	•	•						•	•	•
OSRAM SYLVANIA	•	•	•	•								
Toshiba Lighting	•	•	•	•								
Manufacturers of 277-V Electronic Ballasts												
Advance Transformer	•	•	•	•	•	•	•	•	•	•	•	•
FIT Electronics		•		•								
Howard Industries	•	•	•	•								
LG Industrial Systems U.S.A.	•	•	•	•						•	•	
MagneTek	•	•	•	•			•	•	•	•	•	•
Maxlite SK America		•	•	•							•	
Motorola Lighting[1]	•	•	•	•			•	•	•	•	•	•
Philips Lighting	•	•	•	•						•	•	•
PowerLighting[2]	•	•	•	•						•	•	•
OSRAM SYLVANIA	•	•	•	•								
Toshiba Lighting	•	•	•	•								
Manufacturers of 347-V Electronic Ballasts												
Advance Transformer	•	•	•	•				•			•	
MagneTek	•	•	•	•								
Motorola Lighting[1]	•	•	•	•								
PowerLighting[2]	•	•	•	•								
OSRAM SYLVANIA	•	•	•	•								

[1] Acquired by OSRAM SYLVANIA in April 2000
[2] Now SLI Lighting

Table 9B. Availability of Electronic Ballasts

Lamp Length	4 Feet							8 Feet											
Lamp Type	F40T12/ES			F40T12/ES/HO		F40T12/HO		F96T8		F96T8/HO		F96T12		F96T12/ES		F96T12/ES/HO		F96T12/HO	
Number of Lamps	1	2	3	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Manufacturers of 120-V Electronic Ballasts																			
Advance Transformer	•	•	•				•	•	•	•	•	•	•	•	•		•		•
FIT Electronics																			
Howard Industries								•	•										
JRS Technology																			
LG Industrial Systems U.S.A.	•	•						•	•				•		•		•		•
MagneTek	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•		•
Maxlite SK America									•										
Motorola Lighting[1]	•	•	•				•	•	•			•		•	•				
Philips Lighting								•	•			•	•						•
PowerLighting[2]	•	•	•					•	•			•	•	•	•		•		•
OSRAM SYLVANIA								•	•				•		•		•		•
Toshiba Lighting							•		•				•						
Manufacturers of 277-V Electronic Ballasts																			
Advance Transformer	•	•	•				•	•	•	•	•	•	•	•	•		•		•
FIT Electronics																			
Howard Industries								•	•										
LG Industrial Systems U.S.A.	•	•						•	•				•		•		•		•
MagneTek	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•		•
Maxlite SK America									•										
Motorola Lighting[1]	•	•	•				•	•	•			•		•	•				
Philips Lighting								•	•			•	•						•
PowerLighting[2]	•	•	•					•	•			•	•	•	•		•		•
OSRAM SYLVANIA								•	•				•		•		•		•
Toshiba Lighting							•		•				•						
Manufacturers of 347-V Electronic Ballasts																			
Advance Transformer		•						•	•										
MagneTek								•	•										
Motorola Lighting[1]																			
PowerLighting[2]								•	•			•	•	•	•				
OSRAM SYLVANIA									•										

Sample Table

To see the data, please visit the NLPIP Web site (www.lrc.rpi.edu/nlpip). The online database contains both manufacturer-reported data and NLPIP test results. After specifying the voltage, lamp type, and number of lamps (as well as optional selection criteria), you can select the columns you want displayed for all ballasts that meet the criteria you specified. This example shows what all the manufacturer-reported data for a few 120-V ballasts for two F32T8 lamps might look like.

Open-circuit voltage. The voltage across the ballast output terminals (to which a lamp is normally connected) under no-load (open-circuit) conditions.

Power factor. The ratio of power (in watts) to apparent power (in rms volt-amperes).

Glow current (for rapid-start and programmed-start ballasts only). The current that flows from the lamp electrodes while the lamp starting voltage is applied, but before the lamp starts (p. 20).

Power. The input power (in watts) for a lamp and ballast combination.

			Electrical Characteristics								
										Operating Electrode Voltage	
Manufacturer	Trade Name	Catalog Number	Starting Method	Power (W)	Power Factor	Current THD (%)	Open-Circuit Voltage (V)	Min. Electrode Preheat Time (ms)	Glow Current (mA)	Min. (V)	Max. (V)
Company A	ABC	1234	IS	76	>0.99	<10	600	NA	NA	NA	NA
Company B	DEF	5678	RS	61	>0.99	<10	NS	NS	NS	NS	NS
Company C	GHI	9101	PS	60	>0.95	<20	450	NA	NA	2.5	4.0

NA = not applicable
NS = not supplied by manufacturer

Current THD (total harmonic distortion). A measure of the degree to which the current wave shape deviates from sinusoidal, expressed as a percentage (p. 15).

Min. operating electrode voltage (for rapid-start ballasts only). The minimum voltage that the ballast supplies across each lamp electrode while the lamp is operating.

Starting method. Electronic ballasts use one of three methods to start fluorescent lamps: instant-start, rapid-start, or programmed-start (p. 8).

Min. electrode preheat time (for rapid-start ballasts only). The length of time (in milliseconds) that the electrodes are heated before the lamp starts (p. 8).

Max. operating electrode voltage (for rapid-start ballasts only). The maximum voltage that the ballast supplies across each lamp electrode while the lamp is operating.

Lamp operating frequency. The frequency of the current supplied by ballasts during lamp operation. Lamp operating frequency is discussed in the sidebar on p. 7.

BF (ballast factor). The ratio of the light output of a fluorescent lamp operated by a particular ballast to the light output of the same lamp operated by a reference ballast under standard testing conditions.

BEF (ballast efficacy factor). The ratio of the ballast factor (as a percentage) to the power (in watts). For example, if the ballast factor of a ballast is 0.88 and its power is 33 W, the ballast's BEF is 88 ÷ 33 = 2.67%/W.

Sound rating. The range of ambient sound levels in which people will not notice the noise generated by the ballast. Table 6 on p. 18 contains the average sound levels corresponding to sound ratings "A" through "F."

Lamp current. The current flowing between the lamp electrodes during operation.

Rated life. The number of years expected to pass before half of a large number of ballasts fail under normal operating conditions.

Electrical Characteristics			Physical Characteristics					Photometric Characteristics		Life/Reliability						
			Dimensions													
Lamp Current (mA)	Lamp CCF	Lamp Operating Frequency (kHz)	h (in.)	w (in.)	l (in.)	Sound Rating	Unit Weight (lb)	BF	BEF (%/W)	Rated Life (yr)	Min. Start Temp. (° F)	Max. Temp. (° F)	Rh/Rc	Warranty (yr)	Listed/ Certified By	Price ($US)
265	<1.7	>20	1.625	2.375	9.500	A	2.2	1.18	1.55	15–20	0	167	NA	5	UL, CSA, CBM	20–24
NS	<1.5	45	1.500	1.700	9.500	A	0.9	0.88	1.43	NS	50	158	NS	5	UL, CSA	NS
370	<1.7	>20	1.625	2.375	9.500	A	2.7	0.91	1.52	15–20	0	167	NA	5	UL, CSA	NS

Lamp CCF (current crest factor). The peak lamp current divided by the root-mean-square (rms) lamp current. CCF ranges from 1.0 to infinity. ANSI requires CCF to be less than 1.7; lamp manufacturers usually will not warranty their lamps if operated on ballasts with lamp CCFs greater than 1.7.

Min. start temp. The minimum ambient temperature at which the ballast reliably starts lamps.

Max. ballast case temp. The maximum temperature of the ballast case for which the manufacturer's life rating is valid.

R_H/R_C. The ratio of hot electrode resistance to cold electrode resistance for a particular lamp-ballast system. The ratio is part of an equation that allows the researcher or designer to estimate the temperature of the electrode just before a lamp is started (p. 21).

Warranty period. Warranty is discussed in the sidebar on p. 12.

Listed or certified by. Certifications are discussed in the sidebar on p. 8.

Retail price. The cost of a single ballast, as reported by the manufacturer. Most manufacturers provide discounts for large orders.

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