NLPIP Lighting Answers

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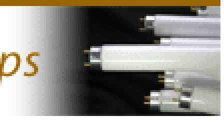
T8 Fluorescent Lamps



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Introduction

In 1981, the 32-watt T8 lamp was introduced in the United States, providing further improvements in 4-foot fluorescent lamps. Today, the T8 lamp is the standard for new construction and is a popular replacement for 34-watt T12 lamps. All major lamp manufacturers market T8 lamps of various wattages, and they are readily available in a variety of linear and U-shaped configurations.

Lighting manufacturers have been improving T8 fluorescent lamps for many years by enhancing key performance characteristics, including light output, efficacy, rated life, maintained light output, and color. This issue of *Lighting Answers* explores these characteristics of T8 fluorescent lamps and brings them together in the context of overall performance. This publication also explores the cost of T8 lamps and how performance characteristics might contribute to price differentials.

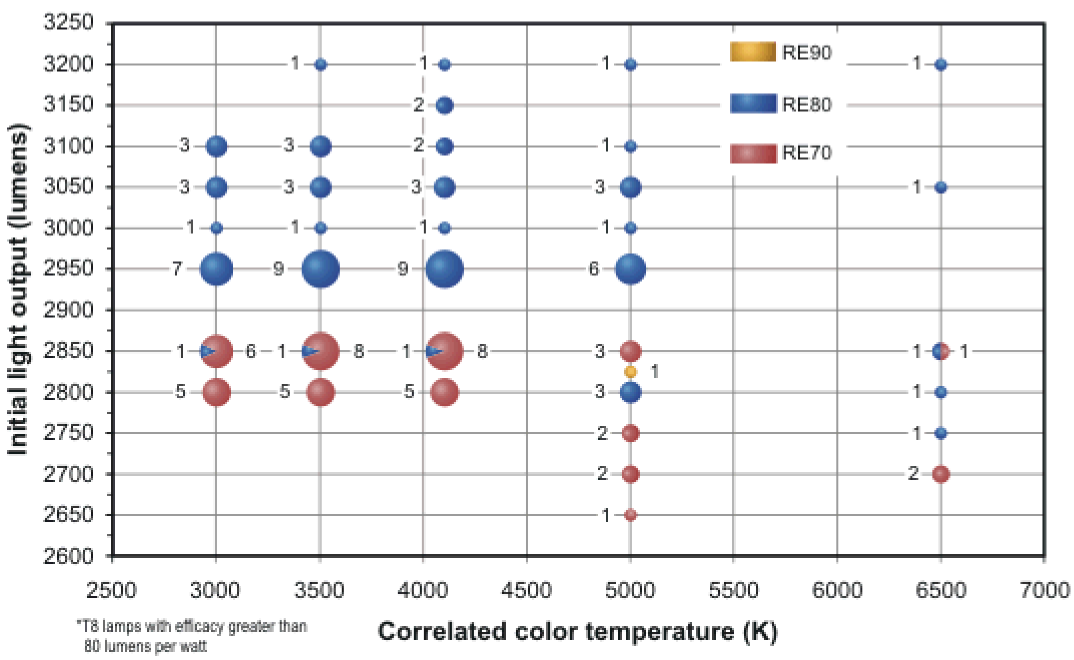
This issue of *Lighting Answers* replaces the 1993 publication of the same title by presenting newer performance data for linear 32-watt T8 lamps. These data were supplied by manufacturers and measured by the National Lighting Product Information Program (NLPIP). The manufacturers' data presented were gathered from catalogs, specification sheets, and

Web sites. The measured data were collected as part of a limited NLPIP testing program. NLPIP examined T8 fluorescent lamps with manufacturer claims of enhanced performance. These lamps are sometimes referred to as "super T8s," "high-performance T8s," or "high-lumen T8s," among other names. NLPIP performed limited measurements of **initial light output**, **spectral power distribution (SPD)**, and electric power during operation. From these data, **lamp efficacy**, **correlated color temperature (CCT)**, **color rendering index (CRI)**, **full-spectrum color index (FSCI)**, and **gamut area (GA)** were calculated. Rated life and maintained light output are discussed; however, they were not tested.

What is the light output of T8 fluorescent lamps?

The amount of light generated by 32-watt T8 fluorescent lamps varies considerably from one lamp model to the next. Figure 1 shows the range of values for rated **initial light output** that are presently published for 121 lamp models by nine manufacturers for different **correlated color temperatures (CCT)**. The number of available models for each rated initial light output is represented by the size of the bubble. For example, at a CCT of 4100 K, there are nine models rated at 2950 initial lumens.

Figure 1. Rated initial light output of T8 fluorescent lamps*



The **color rendering index (CRI)** values of the T8 models shown in Figure 1 are separated into three categories: 70-79, 80-89, and greater than 90. These three categories are commonly referred to by the industry as **RE70**, **RE80**, and **RE90**, respectively. The category into which each lamp model's CRI value falls is indicated by the color of the bubble. For example, at a CCT of 3500 K, there are five RE70 models available with a rated initial light output of 2800 lumens and eight models available with a rated initial light output of 2850 lumens. Figure 1 shows that RE70 models tend to have lower light output than RE80 models. It is also apparent that more RE80 models are available than RE70 or RE90 models, and their rated light output values vary over a much wider range.

As illustrated by the data provided in Figure 1, T8 lamp models are available with light output values at almost every 50-lumen increment between 2800 lumens and 3200 lumens. However, uncertainties in light output measurements can range from 1 to 2% (roughly 50 lumens) across manufacturers, based on proficiency testing as part of the National Voluntary

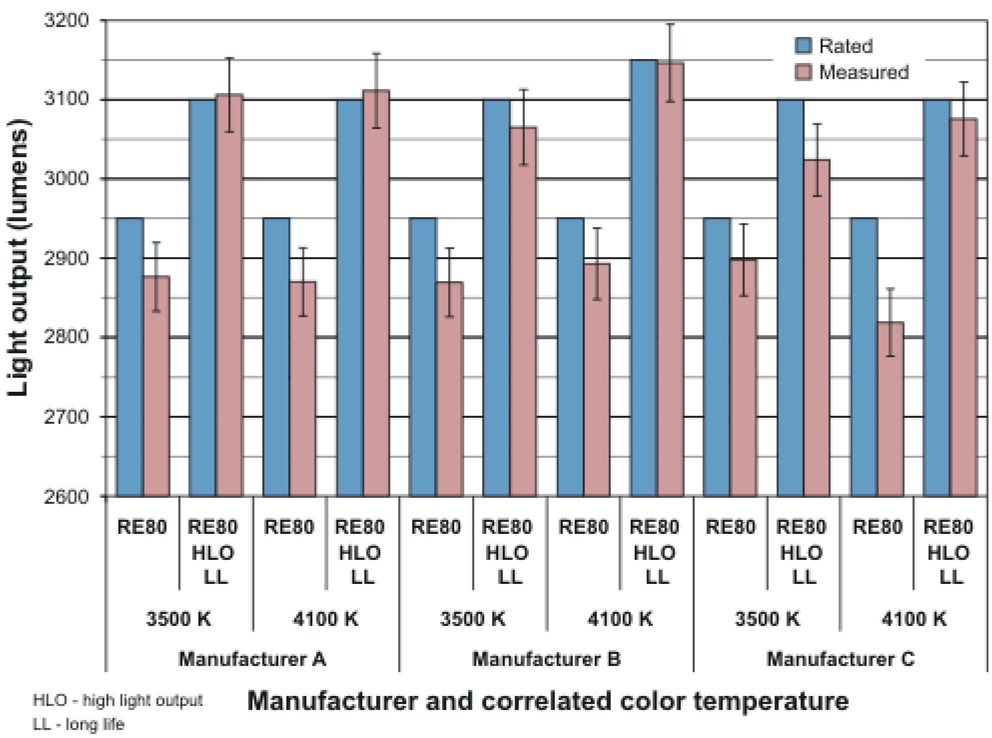
Laboratory Accreditation Program (NVLAP). This program is administered by the National Institute of Standards and Technology (NIST).

NLPIP measured the initial light output of 12 T8 lamp models with CCTs of 3500 K and 4100 K, which are the most common CCTs sold. Three samples of each model were operated on a low-frequency reference ballast following the procedure described by the American National Standards Institute (ANSI C82.3-2002). All lamps tested had rated CRI values between 80 and 89 (RE80), and some lamps had additional enhancements of high light output (HLO) and long life (LL). For details on testing protocols, see Appendix A: Test methods.

Overall, the RE80 lamps tested produced lower light output than their rated values, while most of the **RE80 HLO, LL** lamps tested were near their rated values. In addition, the initial light output of the RE80 HLO, LL lamps averaged 8% higher than the RE80 lamps.

Figure 2 shows the rated and measured light output values, including error bars to show the **combined uncertainty** of the measured values for each lamp model. The combined uncertainty includes the random variability between lamp samples and NLPIP's measurement uncertainty of 1.5% relative to NIST. The measured light output values of the RE80 lamps were, on average, 2.7% lower than their rated values. The measured values for five of the six RE80 HLO, LL lamps were near their rated values. The remaining RE80 HLO, LL model was, on average, 2.5% below its rated value.

Figure 2. Light output of T8 lamps measured by NLPIP



T8 fluorescent lamps are available with a variety of rated light output values. Limited testing by NLPIP found differences between rated and measured light output values. Even if rated and measured light output values were the same, the uncertainties of approximately 1 to 2% would blur the differences between models with similar values of rated light output.

What are the power requirements for T8 fluorescent lamps?

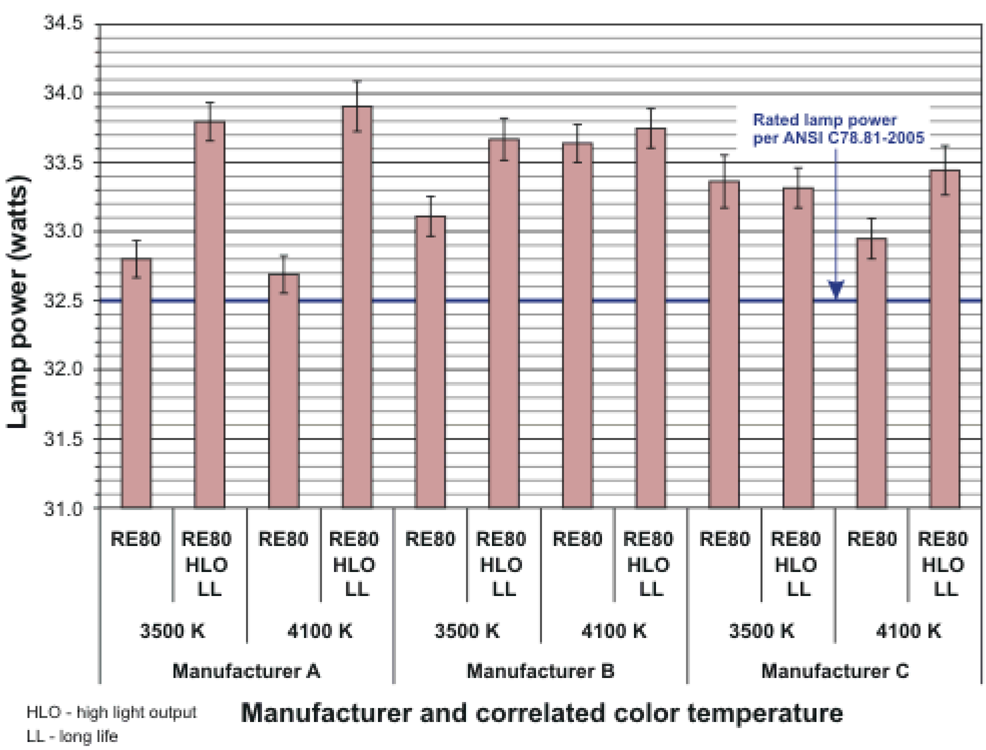
It may be expected that the electric power needed to operate a 32-watt T8 fluorescent lamp will be 32 watts; however, this designation is simply the nominal power of the lamp. The relevant American National Standards Institute (ANSI) document states that the rated lamp power is 32.5 watts under standard test conditions (ANSI C78.81-2005). ANSI further indicates that average lamp power shall not exceed 34.6 watts, which is 6.5% above the rated value. Since this upper limit applies to the average value of the power needed to operate 32-watt lamps, it is possible for individual lamps to exceed 34.6 watts. Since specifiers may select lamps based on efficacy, the variation in lamp power could make calculations of **lamp efficacy** more difficult without knowledge of the actual power and the associated uncertainty for a specific lamp model.

ANSI considers the 4-foot, 32-watt T8 lamp to be a **rapid-start** lamp, but it is commonly operated using an **instant-start** circuit in which the two pins on each end of the lamp are electrically connected or shunted together. Lamps operated on instant-start circuits have lower power than those operated on rapid-start circuits because there is no electrode heating with instant-start operation. However, the difference in lamp power between instant-start and rapid-start operation is not equal to the electrode heating power because the lamp discharge efficiency is lower for instant-start operation.

NLPIP investigated lamp power differences among lamp models. NLPIP selected lamps designated as 32-watt lamps, operated them on a low-frequency reference ballast per ANSI standard C82.3-2002, and measured the electric power needed to operate the lamps. The lamps had **correlated color temperatures (CCT)** of 3500 K and 4100 K, which are the most common CCTs sold. Three samples of each lamp model were measured.

Figure 3 shows the measured power values. The horizontal axis shows the description of each lamp model tested from manufacturers A, B, and C. Error bars show the **combined uncertainty** of the measured values for each lamp model. All measured lamp power values were higher than the ANSI-rated power of 32.5 watts. Five of the lamp models exceeded 33.5 watts, which is 3% above the ANSI-rated value. However, this is within the tolerance described in the ANSI standard (lamp power not to exceed 5% plus 0.5 watts). Specifiers should consider the fact that lamp power can exceed the expected value of 32 watts by more than 5% in any estimation of operating costs.

Figure 3. Power required by T8 lamps measured by NLPIP



In most cases, the measured electric power values for the **RE80 HLO, LL** lamps were higher than the values for the **RE80** lamps, by as much as 1.2 watts. In Question: What is the light output of T8 fluorescent lamps?, NLPIP showed that the light output of the RE80 HLO, LL lamps averaged 8% higher than the RE80 lamps. Therefore, replacing RE80 lamps with RE80 HLO, LL lamps with no change in luminaire layout or **ballast factor** will result in more light output and higher power. Customers who are mostly interested in energy savings should change to a lower ballast factor or change their luminaire layout by using fewer luminaires.

Today, T8 fluorescent lamps are commonly used with high-frequency electronic ballasts. High-frequency operation of fluorescent lamps reduces lamp power for the same light output (Campbell et al. 1953). As stated in the ANSI standard (ANSI C78.81-2005), the lamp power for high-frequency operation is approximately 6% lower than for low-frequency operation, when the lamp is operated as an instant-start lamp. Nevertheless, unknowingly operating a lamp with higher-than-nominal power on a high-frequency electronic ballast will result in an increase in the lighting system's connected load, leading to higher operating costs than expected. For example, the reported input power for a typical two-lamp, high-frequency electronic ballast with a normal ballast factor (0.88) is 58 watts. However, the ballast input power will increase by 3-4% for lamps with 5% higher power than expected (as measured on a low-frequency reference ballast). Specifiers should include the variation in connected load in estimations of operating costs.

How efficacious are T8 fluorescent lamps?

Lamp efficacy is determined by dividing light output by lamp power, resulting in units of lumens per watt (LPW). Determining and comparing lamp efficacy from catalog data is difficult because the actual power needed to operate the lamps is not known (see What are the power requirements of T8 fluorescent lamps?) and because rated light output is given for operation of the lamp at a low frequency of 60 Hz. (T8 lamps are almost always operated on high-frequency electronic ballasts.)

A general perspective on the range of T8 lamp efficacy can be gained by dividing the published light output values by some reference power value. For example, NLPIP selected a lamp power of 32.5 watts, which is the standard value listed for this lamp type (ANSI C78.81-2005). Figure 4 shows these efficacy values, which range from 81 to 99 LPW, for 121 T8 fluorescent lamp models from nine manufacturers. It is likely that the upper limit of this range would decrease slightly if it were based on actual power measurements, which were slightly higher than 32.5 watts in this limited study (Figure 3). Nevertheless, the **RE70** models tended to be at the low end of the range with all of their efficacies below 88 LPW. Figure 4 also shows lower efficacies for some of the **RE80** models at the higher **correlated color temperatures (CCT)** of 5000 K and 6500 K.

Figure 4. Efficacy of T8 fluorescent lamps*

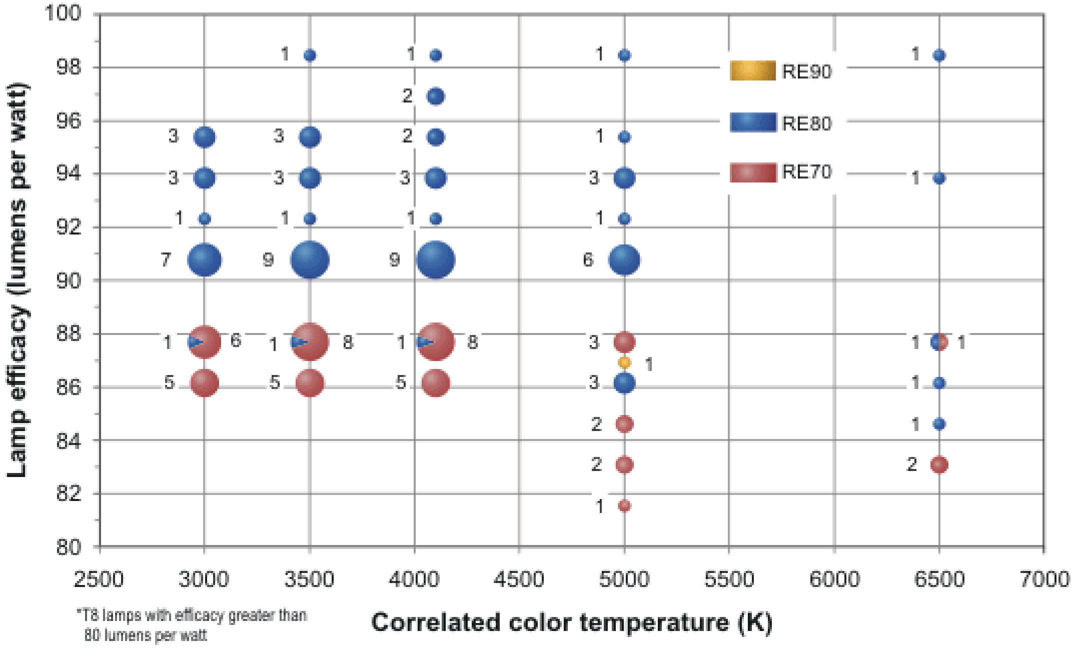
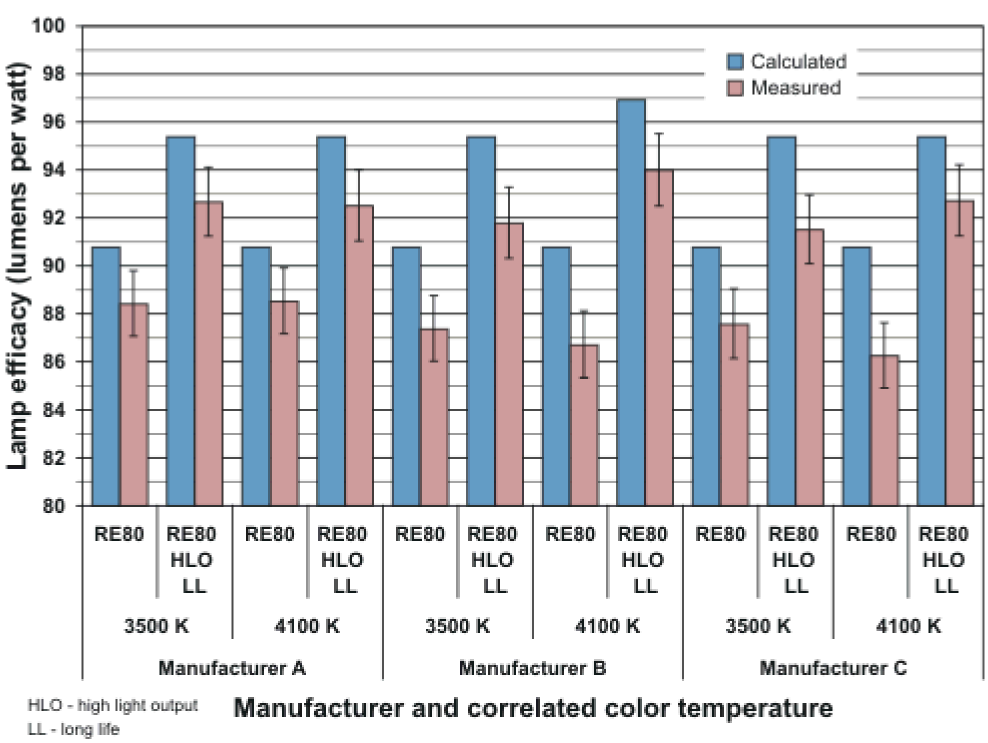


Figure 5 shows the calculated and measured efficacies of the lamps that NLPIP tested. Calculated efficacies were derived by dividing the published light output values by 32.5 watts. NLPIP-measured efficacies were derived from measured light output and power values. The measured efficacies include error bars, which show the **combined uncertainty** of the measured values for each lamp model. The measured efficacies ranged from 86 to 94 LPW, compared to the calculated efficacies that ranged from 91 to 97 LPW. Both RE80 and **RE80 HLO, LL** lamps had measured efficacies that were an average of 3.5% lower than the calculated values. This result is due to measured light output values that were lower than the rated values for RE80 lamps and measured lamp power that was higher than 32.5 watts for all lamps.

Figure 5. Efficacy of lamps tested by NLPIP



The efficacies of the RE80 HLO, LL lamps averaged 5.8% higher than the RE80 lamps. As noted in the previous Questions: [What is the light output of T8 fluorescent lamps?]() and [What are the power requirements of T8 fluorescent lamps?](), both the light output and the input power values of the RE80 HLO, LL lamps were higher than the values for the RE80 lamps. However, the light output values were sufficiently higher to counteract the effect of higher power. The increased efficacies of the RE80 HLO, LL lamps may make them a more attractive choice for new construction or for retrofits in which a ballast change or a luminaire layout change is being made. With a lower **ballast factor** or a luminaire layout change, customers can take advantage of the higher light output of RE80 HLO, LL lamps; they may be able to meet their illuminance requirements and save energy compared to RE80 lamps.

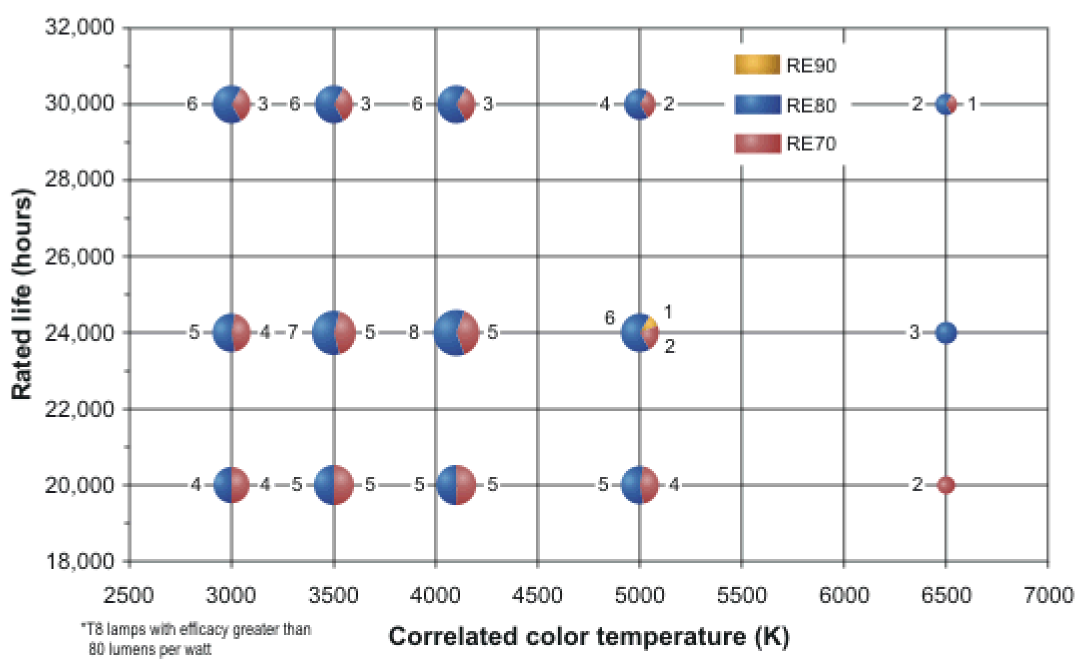
NLPIP testing was conducted using a low-frequency reference ballast as described in American National Standards for Lamp Ballasts-Reference Ballasts for Fluorescent Lamps (ANSI C82.3-2002). T8 lamp efficacy increases by approximately 10% under high-frequency operation (Hitchcock 1983). For more details on testing protocols, see [Appendix A: Test methods]().

What is the life of T8 fluorescent lamps?

Average rated life is the number of hours at which half of a large sample of lamps has failed, which is the median life of the group. The standard operating cycle for this test is 3 hours on, 20 minutes off. The Illuminating Engineering Society of North America (IESNA) defines this procedure in IESNA Approved Method for Life Testing of Fluorescent Lamps (IESNA LM-40-01).

Figure 6 shows the range of average rated life reported by manufacturers for T8 lamp models of different **correlated color temperatures (CCT)**. The size of the bubble represents the number of lamp models available at each of the three rated life values and five CCTs (the actual number of models is shown next to each bubble). The colors of the bubbles represent the **color rendering index (CRI)** of the lamps: **RE70**, **RE80**, and **RE90**. The distributions are nearly the same for the first three CCTs: eight to 10 lamp models are offered with a life rating of 20,000 hours, nine to 13 models have a life rating of 24,000 hours, and nine models have a life rating of 30,000 hours.

Figure 6. Average rated life of T8 fluorescent lamps*

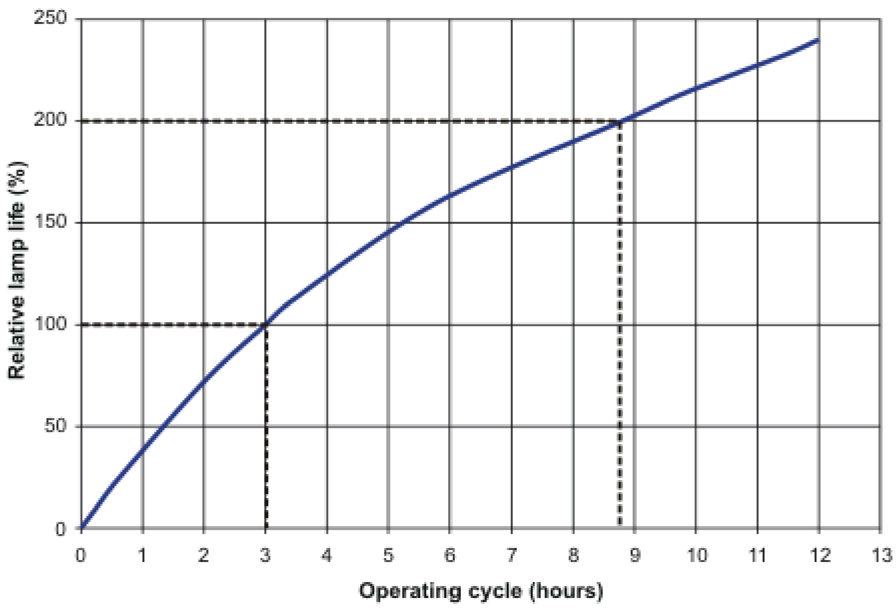


*T8 lamps with efficacy greater than 80 lumens per watt

Specifiers should be aware of several issues concerning the life ratings found in lamp catalogs. First, operating cycles have a large effect on lamp life. The standard operating cycle defined by IESNA of 3 hours on, 20 minutes off provides a common basis to compare results among laboratories performing the same life tests; however, it does not address the wide range of operating cycles that exist in practice. Some manufacturers have addressed this issue by reporting life ratings for operating cycles of 12 hours per start in addition to life ratings for the standard operating cycle.

Figure 7 demonstrates the effect of operating cycle on lamp life. The vertical axis displays relative lamp life, with 100% representing the rated lamp life for the standard operating cycle. Figure 7 shows that for a typical 8-9 hour workday in which lamps are operated continuously, median lamp life may be double the rating reported in the lamp catalogs.

Figure 7. Effect of operating cycle on lamp life



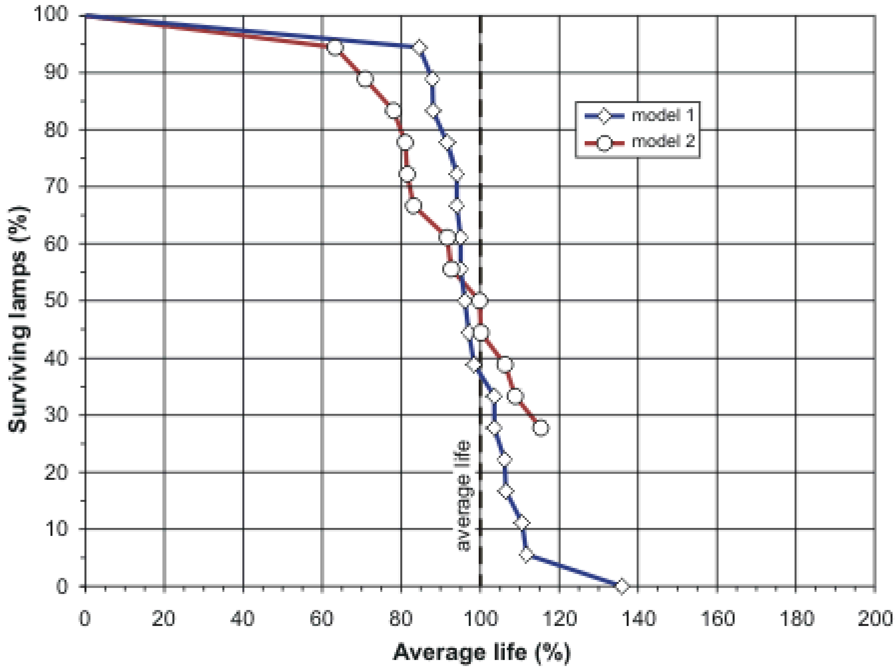
Source: adapted from Vorlander 1950

A second issue that affects average rated life is the type of ballast used to operate the lamps. The life rating for many lamp models is based on operation using **rapid-start** ballasts. For some of these models, the catalog footnotes indicate reductions in rated life by as much as 25% when the lamps are operated using **instant-start** ballasts. In addition, some manufacturers report that the life rating for certain models is based on operation using a specific type of the manufacturer's ballast. When this ballast is not used to operate the lamps, the life rating is reported to be as much as 50% lower, depending on the type of ballast circuitry used. Information about the dependency of lamp life on the choice of ballast is sometimes located only in footnotes and other fine print, so it is important to examine manufacturers' publications carefully.

A third issue to consider is that the rate at which lamps fail has an impact on relamping strategies and, therefore, overall costs. Using a single number, such as rated life, in a cost analysis does not account for differences in failure rates. For a group relamping strategy based on replacing lamps when a certain percentage have failed, the rate of lamp failure directly affects the amount of time before relamping.

Figure 8 shows the results of a previous study conducted by NLPIP for two T8 fluorescent lamp models rated at 20,000 hours. The **standard deviation** for each model provides an estimate of the failure rate. For models with the same average life, a smaller standard deviation (shown as a steep slope) means that most lamp failures will occur closer together and closer to average life compared to models with a larger standard deviation (shown as a shallow slope). For example, model 1 has a smaller standard deviation than model 2 because individual failures are concentrated closer to average life. This means that there is less variability in lamp life for model 1. For typical group replacement strategies model 1 provides more operating time before incurring replacement costs.

Figure 8. Mortality curves for two T8 fluorescent lamp models



The standard deviation, along with a given average life, provides a way to estimate individual lamp failures. For example, consider two T8 fluorescent lamp models with an actual life of 24,000 hours and standard deviations (failure rates) similar to models 1 and 2 in Figure 8. For an office space with 100 lamps, the first lamp failures would be expected to occur before 17,300 hours for model 1 and 11,800 hours for model 2. The twentieth lamp failure, which might be the scheduled point for group relamping, would be expected to occur before 21,600 hours for model 1 and 19,600 hours for model 2. Such differences in failure rate will have a considerable impact on group relamping costs.

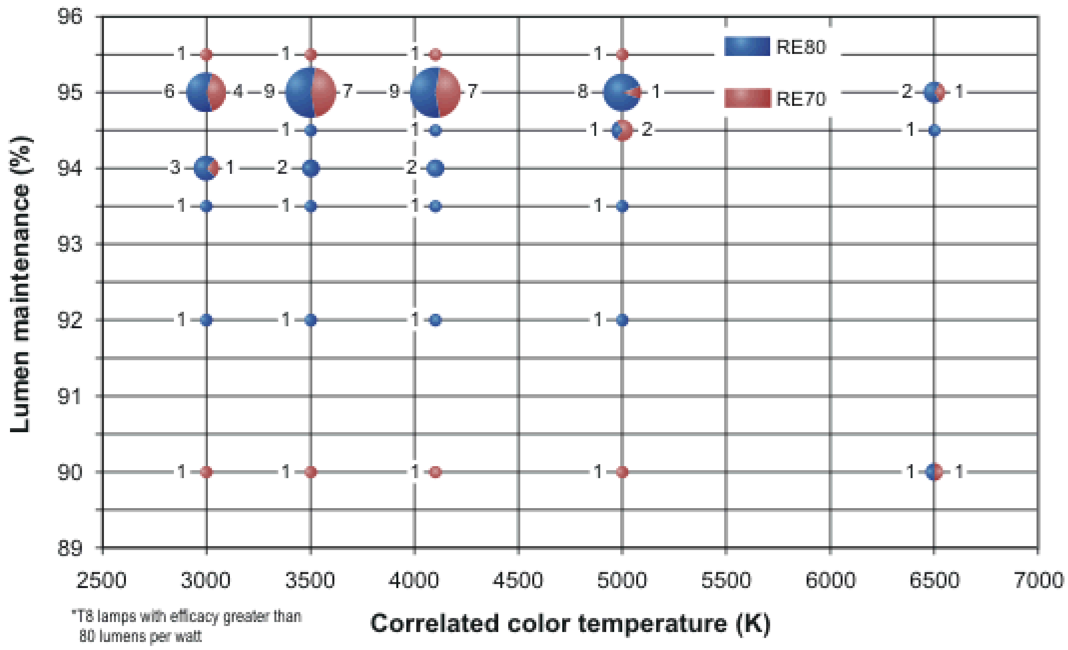
The many factors affecting lamp life make it the lamp attribute with the most uncertainty. Once the effects of operating cycle and ballast choice on lamp life are accounted for, knowledge of a model's standard deviation can be used to estimate individual lamp failures. If manufacturers provided standard deviations, specifiers could make better estimates of actual lamp life to include in lighting cost calculations.

How well do T8 fluorescent lamps maintain light output?

All lamps exhibit some reduction in light output over time. Manufacturers report light output at 40% of rated life as an indicator of maintained light output. This value is close to the average light output over the life of the lamp and is called **mean light output**, mean lumens, or design lumens.

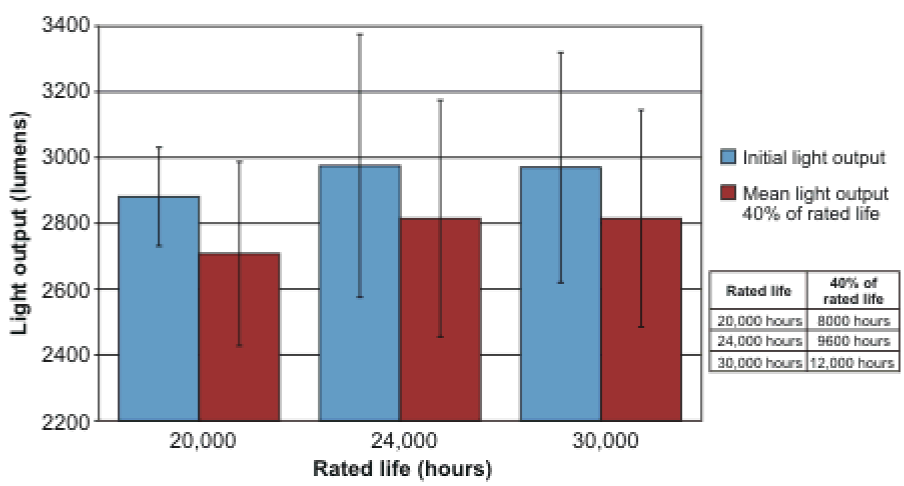
Figure 9 provides an overview of **lumen maintenance** values for T8 fluorescent lamps. Lumen maintenance is the rated mean light output as a percentage of rated **initial light output**. Figure 9 reports lumen maintenance for 86 presently available T8 fluorescent models from five manufacturers; data of rated mean light output were not available from the remaining four manufacturers. The data are separated by **correlated color temperature (CCT)**, with the number of available models indicated by bubble size and labeled next to each bubble. In addition, the colors of the bubbles indicate the range of **color rendering index (CRI)** values to which the models belong. According to manufacturers' data, all T8 models have lumen maintenance over 90%, with three-quarters of the models having lumen maintenance between 94.5% and 95.5%.

Figure 9. Lumen maintenance of T8 fluorescent lamps*



T8 fluorescent lamp models are available with a variety of initial and mean light output ratings. Figure 10 shows a comparison of the rated values of initial and mean light output of 4100 K T8 models, as reported by manufacturers. The range bars in Figure 10 represent the maximum and minimum rated values. With few exceptions, the lumen maintenance of all the models represented in Figure 10 was approximately 95%. However, the range bars show the large variety of rated initial and rated mean light output values that produce the same approximate lumen maintenance percentages. In some cases, models are available with mean light output values that are the same as or higher than the initial light output values of other models.

Figure 10. Light output of 4100 K T8 fluorescent lamps



An important consideration of T8 light output is illustrated in Figure 10 by grouping the data on the horizontal axis by **average rated life**. Many of the lamp models represented in Figure 10 have the same initial and mean light output values, but different life ratings. Therefore, mean light output is measured at different operating times. For the life ratings used in Figure 10, the maximum difference in operating time is 4,000 hours, as shown in the legend. In some cases, lamps are expected to reach their mean light output value at 8,000 hours (1.8 years at 12 hours of operation per day), while others are expected to reach the same mean light output value at 12,000 hours (2.7 years of operation at 12 hours of operation per day).

Another important issue to consider is that the average rated life of a lamp is dependent on the type of ballast used to operate the lamp (see What is the life of T8 fluorescent lamps?). It is unknown how a shorter lamp life will affect lumen maintenance. If ballasts other than those recommended by the lamp manufacturers are used, specifiers should inquire about the impact that those choices may have on mean light output.

What is the color of T8 fluorescent lamps?

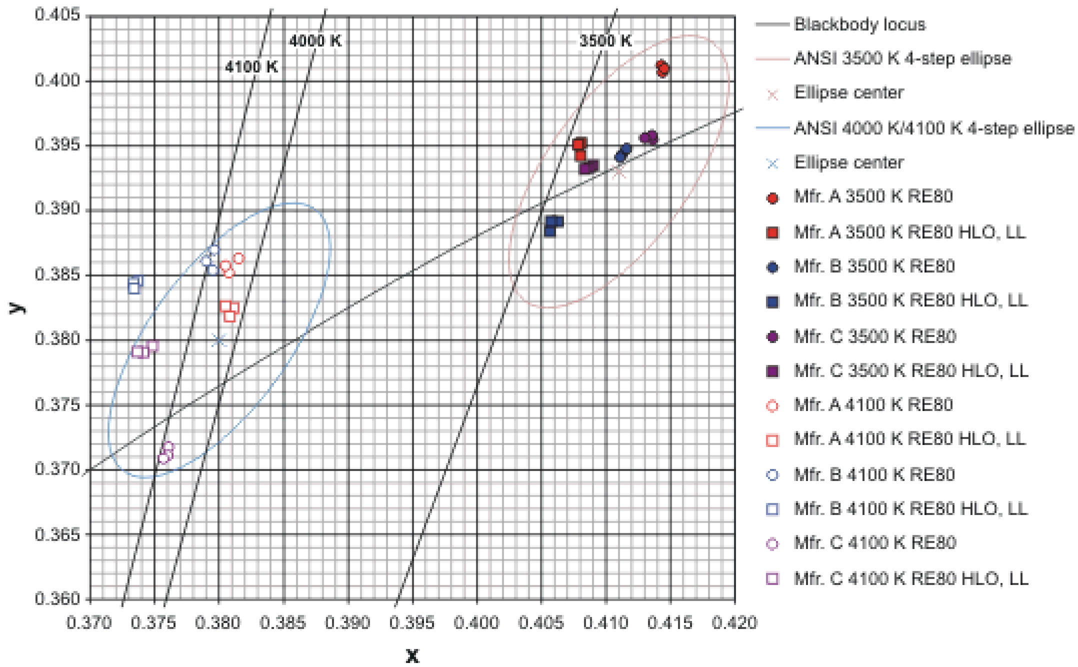
Describing color can be complex. The human eye is selectively and differentially sensitive to a portion of the wavelengths (approximately 380 nm to 780 nm) emitted by light sources. The photoreceptors in our eyes, rods and cones, respond to these wavelengths, and neural processes in the brain create perceptions of color. No single metric fully describes the perceived color of light sources or how lamps render the color of other objects. Different metrics describe different aspects of color such as naturalness, discriminability, and vividness (saturation). For more details on color, see NLPIP report *Lighting Answers: Light Sources and Color*.

Determining the color properties of a light source starts with a measurement of the **spectral power distribution (SPD)**, which provides the physical data needed for colorimetric calculations. The SPD is graphical or tabulated data representing the radiant power emitted by a light source at each wavelength, or narrow bands of wavelengths, in the visible region.

NLPIP tested three T8 lamp samples from each of 12 models and calculated their **chromaticity** coordinates to determine if there were perceptible differences in color. The 12 models consisted of **RE80** and **RE80 HLO, LL** lamps of two **correlated color temperatures (CCT)** (3500 K and 4100 K) from three manufacturers. Figure 11 shows the chromaticity coordinates of these lamps on a portion of the 1931 **CIE** chromaticity diagram. The chromaticity coordinates of the three samples of each model were very close together and would fit within a 1-step **MacAdam ellipse** (not shown in the figure). These small variations suggest that there are no perceived color differences within each lamp model.

The 4-step ellipses for chromaticity tolerance prescribed by the American National Standards Institute (ANSI C78.376-2001) are shown in Figure 11. The chromaticity coordinates of all but one of the lamp models fall within their prescribed ellipses. However, models with chromaticity coordinates that lie at the opposing ends of the ellipses may show perceptible color differences.

Figure 11. Chromaticity coordinates of tested lamps



The concept of **color rendering** describes the effect of a light source on the color appearance of objects. NLPIP evaluated three color-rendering metrics for T8 fluorescent lamps of a given CCT: **color rendering index (CRI)**, a measure of naturalness; **full-spectrum color index (FSCI)**, a measure of discriminability; and **gamut area (GA)**, a measure of vividness. NLPIP found very small differences in these metrics for the models evaluated. For complete details, Appendix B: Color rendering of T8 fluorescent lamps. For more information about CRI, FSCI, and GA, see the NLPIP report *Lighting Answers: Light Sources and Color*.

How can the overall performance of T8 fluorescent lamps be compared?

The decision about which T8 lamp model is best for a particular application can be based on an evaluation of lamp performance attributes and cost. Although cost is a very important part of the selection process, it may be useful to first determine which performance attributes are important for a particular application. Different performance attributes will have varying importance depending on the application. Some organizations, such as the Consortium for Energy Efficiency (CEE), have developed performance criteria to promote the use of certain types of T8 fluorescent lamps. The CEE specification is published in CEE High-Performance T8 Specification (CEE 2006).

Once the important performance attributes for a particular application are determined, specifiers can identify and compare models that meet their needs. Comparisons between T8 lamp models are difficult, however, without knowledge of the uncertainties in the rated values of the lamp attributes, which are not offered by manufacturers. These uncertainties are important in practice because attribute values can overlap, blurring the distinction between similar rated values. Moreover, attribute uncertainties are different for different manufacturers based on their choice of materials, components, and manufacturing processes. With knowledge of the uncertainties associated with the rated values, specifiers could better determine if there are meaningful performance differences among lamp models.

Unknown uncertainties in attribute values, including operating power requirements, undermine confidence in selecting the best lamp model for a particular application. Therefore, specifiers should be careful about paying extra for enhanced attributes that are not well defined.

It should be noted that energy costs dominate the total cost of a lighting system, so higher initial costs could be recouped by making use of even small differences in connected load (see How efficacious are T8 fluorescent lamps?). For details on differences in the cost of T8 fluorescent lamps, see How much do T8 fluorescent lamps cost?

How much do T8 fluorescent lamps cost?

The initial cost of T8 lamps depends mainly on the performance characteristics discussed in the previous sections. For a summary of overall performance, see How can the overall performance of T8 fluorescent lamps be compared? In general, the least expensive 4-foot, 32-watt T8 lamps are **RE70** (having **CRI** values in the 70s), have an **average rated life** of 20,000 hours, a **lamp efficacy** of less than 90 lumens per watt, and a 90-95% **lumen maintenance**. As expected, the cost per lamp generally increases as rated performance increases, with the most expensive lamps typically having better claimed performance in multiple categories. Lamp prices also vary dramatically among suppliers. Table 1 shows an example of how cost increases with better claimed performance and how widely costs can vary between suppliers for the same manufacturer's lamp model. Suppliers A and B, which are nationwide distributors, supplied all lamp models listed.

Table 1. T8 lamp pricing example for one lamp manufacturer

Lamp	Lamp efficacy (LPW)	Average rated life (hours)	Supplier	Price per lamp
RE70	86	20,000	A B	$1.95 $2.03
RE70 LL	86	24,000	A B	$2.66 $3.07
RE80	91	20,000	A B	$3.32 $3.38
RE80 LL	91	24,000	A B	$4.79 $3.80
RE80 HLO, LL	95	24,000	A B	$5.46 $13.24

Table 1 shows that the cost of a **RE80 HLO, LL** lamp from supplier A is 64% higher than a **RE80** lamp from the same source ($5.46 versus $3.32). Since the cost of energy can be as high as 95% of the total cost of lighting, the higher lamp efficacy of the RE80 HLO, LL lamps may provide an opportunity to recoup this higher initial cost. However, the actual power of the RE80 HLO, LL lamps is higher than the actual power of the RE80 lamps (see What are the power requirements for T8 fluorescent lamps?). Therefore, a change in lighting layout or a change to a ballast with a lower **ballast factor** is essential in order to take advantage of the higher lamp efficacy of the RE80 HLO, LL lamps and reap energy cost savings. Table 1 also shows that the price differential between these lamp models from supplier B is over 290%, which may be difficult to recoup in a reasonable length of time.

Of particular interest to those who choose more expensive lamps may be the question of whether the lamps are less expensive in the long run and how quickly any cost savings can be realized. The answer is dependent on many factors including **system efficacy**, the cost of energy, the cost of labor to install or replace lamps, disposal costs, ballast choice, lighting layout, and operating cycle. A detailed analysis of the life cycle cost benefit is needed to accurately evaluate the economics for a specific product choice. A method for analyzing life cycle cost benefits can be found in the IESNA Lighting Handbook, ninth edition (Rea, 2000). Some manufacturers also provide lighting cost calculators. However, an accurate analysis is challenging because of the uncertainties of power and rated life of T8 lamps.

Who makes T8 fluorescent lamps?

Table 2 lists the manufacturers of 4-foot, 32-watt T8 lamps included in this publication and their contact information. Lamps intended for specific applications (such as aquariums, deli cases, etc.) were not considered. Only lamps with efficacies above 80 lumens per watt (as calculated from manufacturers' data) were included in this publication. Nearly all of the T8 lamps discussed in this publication comply with the U.S. Environmental Protection Agency's Toxicity Characteristic Leaching Procedure (TCLP), which is a protocol designed to limit the amount of hazardous materials entering the environment, such as the mercury found in fluorescent lamps. The only lamp included in this publication that is not TCLP-compliant is the one **RE90** lamp available in the market.

Table 2. Manufacturers of T8 fluorescent lamps and contact information

Manufacturer	Web Site	Phone Number
General Electric	www.gelighting.com	800-435-4448
Halco	www.halcolighting.com	800-677-3334
Lumiram	www.lumiram.com	800-354-1044
MaxLite	www.maxlite.com	800-555-5629
OSRAM Sylvania	www.sylvania.com	800-544-4828
Philips Lighting	www.lighting.philips.com	800-555-0050
Technical Consumer Products (TCP)	www.tcpi.com	800-324-1496
USHIO	www.ushio.com	800-838-7446
Westinghouse	www.westinghouselightbulbs.com	888-417-6222

Conclusion

Many models of 32-watt T8 lamps are available with a variety of attributes. In principle, to help specifiers, T8 models could be separated into categories such as "good", "better", and "best" based on overall cost and performance. One way to divide T8 models into such categories would be to search for clear gaps in the reported values or to look for relationships where good performance in one category is associated with good performance in others.

Toward this end, NLPIP suggests that the CRI designations of **RE70** and **RE80** are justified as differentiators for "good" and "better" categories. RE70 models have generally good performance in light output, efficacy, and life, and have the lowest initial cost among T8 fluorescent lamp models. RE80 models could be considered a "better" category because they provide higher light output and efficacy, as shown in Figure 1 and Figure 4. With an appropriate luminaire layout or a lower **ballast factor**, RE80 lamps could provide a modest energy cost savings. The initial cost of RE80 models is marginally higher than RE70 models, but their power requirements are not much different. Since the cost of energy dominates the overall cost of a lighting system, there is little impact on operating costs for this "better" performance category.

A clear separation of RE80 models with enhanced attributes into a "best" (or "super") category is difficult to justify. Some RE80 models with a high light output attribute provide marginally higher efficacy; however, many of these lamps require more power to deliver higher light output. The higher electrical power required by these lamps will lead to a higher connected load and higher energy costs. Therefore, an appropriate luminaire layout or a lower ballast factor is imperative in order to take advantage of the small improvements in efficacy. For models offering a long life attribute, the uncertainties in lamp life are the largest among all the performance attributes, so there is a risk that these lamps may not last as long as expected. This is especially important considering that the initial cost of lamps with both attributes can be 100-300% more per lamp.

Appendix A: Test methods

The purpose of the limited testing in this study was to compare T8 fluorescent lamp models offering substantially different performance characteristics. While many manufacturers offer both **RE70** and **RE80** lamps, there exists a greater variety of RE80 lamps with claims of enhanced performance characteristics, such as high light output (HLO) and long life (LL). Two lamp types were chosen from the RE80 category and tested to compare the measured characteristics with each other and against those reported in manufacturers' catalogs. **RE80 HLO, LL** lamps were compared with RE80 lamps that did not offer those enhancements. Table App-1 lists the trade names and catalog numbers of the lamps that NLPIP tested for this study. NLPIP purchased most of the T8 lamps it tested at local electrical supply stores. Lamps that were not available locally were received from normal production runs directly from the manufacturers.

Table App-1. Trade names and catalog numbers of tested lamps

Manufacturer	Trade Name	Catalog Number
	RE80	
General Electric	ECOLUX®	F32T8/SPX35/ECO F32T8/SPX41/ECO
OSRAM Sylvania	OCTRON® 800	FO32/835/ECO FO32/841/ECO
Philips Lighting	ALTO® Universal	F32T8/TL835/ALTO F32T8/TL841/ALTO
	RE80 HLO, LL	
General Electric	ECOLUX® High Lumen	F32T8/XL/SPX35/HL/ECO F32T8/XL/SPX41/HL/ECO
OSRAM Sylvania	OCTRON® 800 XPS®	FO32/835/XPS/ECO FO32/841/XPS/ECO
Philips Lighting	ALTO>® Advantage	F32T8/ADV835/ALTO F32T8/ADV841/ALTO

The test group consisted of RE80 and RE80 HLO, LL lamps from three manufacturers, in two different **correlated color temperatures (CCT)**, with a sample size of three lamps of each type. This yielded 18 RE80 and 18 RE80 HLO, LL lamps, for a total of 36 lamps. The lamps were seasoned using electronic **instant-start** ballasts for 100 operating hours using the 3-hour-on, 20-minute-off cycle specified in the IESNA Guide to Lamp Seasoning (IESNA LM-54-99). The lamps were placed in an integrating sphere at the Lighting Research Center in Troy, New York, and operated using a standard reference ballast circuit as specified by the American National Standard for Lamp Ballasts-Reference Ballasts for Fluorescent Lamps (ANSI C82.3-2002). Electrical measurements were obtained from the reference circuit in the manner specified by the American National Standards Institute (ANSI), while the integrating sphere and an Optronic Laboratories OL 750 spectroradiometer were used to measure the **spectral power distribution (SPD)** of each lamp.

The light output values of three of the T8 lamps tested for this publication were measured by the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland, for comparison with the data obtained from the integrating sphere at the Lighting Research Center. The NIST data provided a scaling factor that was applied to all light output values for tested lamps reported in this publication.

Appendix B: Color rendering of T8 fluorescent lamps

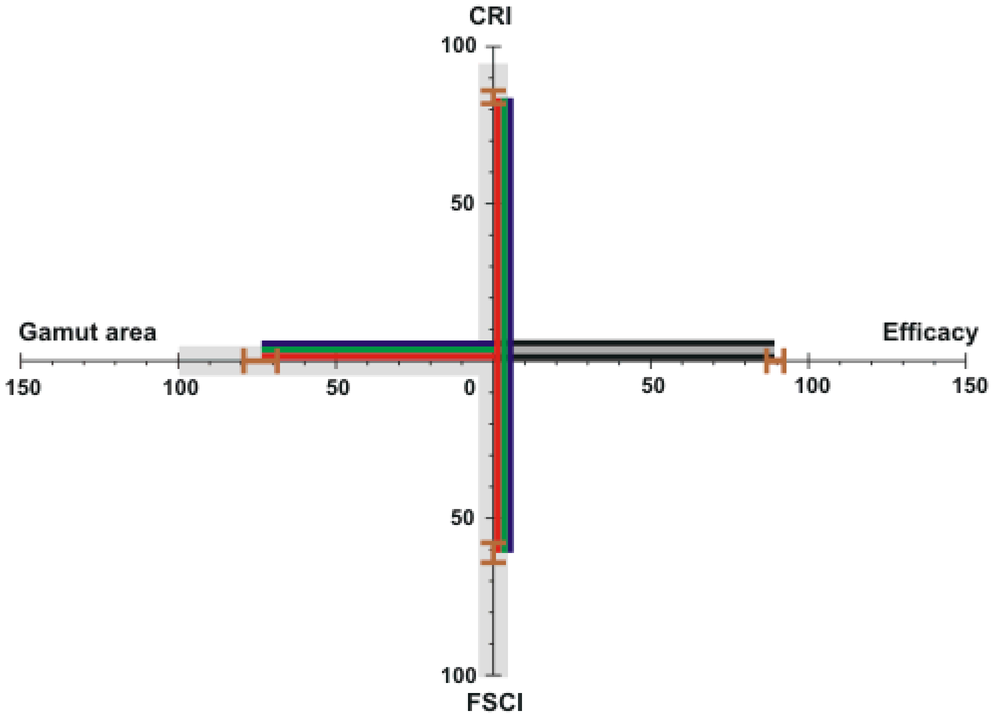
The most widely used metric in the lighting industry, and the one recommended by the **CIE**, is the **color rendering index (CRI)**. CRI is based on the differences in color predicted by the CIE colorimetric system of the light emitted from eight standard color samples when illuminated by the test light source and a reference light source of the same **correlated color temperature (CCT)**. These differences are averaged to produce a single number, the CIE General CRI, which ranges from zero to 100. A cool-white T12 fluorescent lamp using halophosphate phosphors has a CRI of 62. Current T8 fluorescent lamps using rare-earth phosphors have CRI values in the 70s and 80s. Some specialty fluorescent lamps, such as those for museums and deli cases, have CRI values in the 90s, but this typically comes with a sacrifice in **lamp efficacy**.

In order to render subtle differences in the perceived color of objects, a light source must provide radiant power at those particular wavelengths for which the objects have slight differences in spectral reflectance. An equal energy spectrum is an imaginary spectrum that has the same radiant power at all wavelengths; therefore, it would be expected to render colors well. The **full-spectrum color index (FSCI)** is a measure of how much a light source's spectrum deviates from an equal energy spectrum. FSCI values range from zero to 100; an equal energy spectrum has the maximum FSCI value of 100.

A third color-rendering metric is **gamut area (GA)**. GA is a polygon-shaped area enclosed by the **chromaticity** coordinates of the eight CIE standard color samples when illuminated by a given light source. The chromaticities are plotted in CIE 1976 color space. Generally, object colors will appear more vivid, or saturated, when illuminated by a light source with a larger GA. The gamut areas for the T8 fluorescent lamps tested for this publication have been scaled so that an equal energy spectrum has a GA of 100. This scaling facilitates comparisons between GA, CRI, and FSCI.

The NLPIP report *Lighting Answers: Light Sources and Color* introduced a new method to represent values of CRI, FSCI, and GA along with lamp efficacy. Figure App-1 illustrates this method with data for the T8 fluorescent lamps tested by NLPIP, which are of types **RE80** and **RE80 HLO, LL**. The light gray lines in the figure show the values of CRI, FSCI, and GA for an equal energy spectrum. The tri-color bars in the figure show the average values of CRI, FSCI, and GA for all lamps tested, while the gray-and-black bar shows the average value of lamp efficacy. The gold error bars show the **standard deviations** in each of these measured values. These error bars show that there are only small variations in CRI, FSCI, and GA for these models of T8 fluorescent lamps.

Figure App-1. Color and efficacy values for RE80 and RE80 HLO, LL T8 fluorescent lamps tested by NLPIP



Resources

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Credits

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Glossary

Average rated life	The number of hours at which half of a large group of product samples fail under standard test conditions. Rated life is a median value; any lamp or group of lamps may vary from the published rated life.
Ballast factor (BF)	The ratio of the light output of a fluorescent lamp or lamps operated on a ballast to the light output of the lamp(s) operated on a standard (reference) ballast. Ballast factor depends on both the ballast and the lamp type; a single ballast can have several ballast factors depending on lamp type.
Chromaticity	The dominant or complementary wavelength and purity aspects of the color taken together, or of the aspects specified by the chromaticity coordinates of the color taken together. It describes the properties of light related to hue and saturation, but not luminance (brightness).
CIE	Abbreviated as CIE from its French title Commission Internationale de l'Eclairage, the International Commission on Illumination is a technical, scientific, and cultural organization devoted to international cooperation and exchange of information among its member countries on matters relating to the science and art of lighting.
Color rendering	A general expression for the effect of a light source on the color appearance of objects in conscious or subconscious comparison with their color appearance under a reference light source.
Color rendering index (CRI)	A measure of the degree of color shift that objects undergo when illuminated by a lamp, compared with those same objects when illuminated by a reference source of comparable correlated color temperature (CCT). A CRI of 100 represents the maximum value. A lower CRI value indicates that some colors may appear unnatural when illuminated by the lamp. Incandescent lamps have a CRI above 95. The cool white fluorescent lamp has a CRI of 62; fluorescent lamps containing rare-earth phosphors are available with CRI values of 80 and above.
Combined uncertainty	Combined uncertainty is calculated by finding the sum of the squares of sample random variability (standard deviation) and laboratory measurement uncertainty and taking the square root of that sum.
Correlated color temperature (CCT)	A specification of the apparent color of a light source relative to the color appearance of an ideal incandescent source held at a particular temperature and measured on the Kelvin (K) scale. The CCT rating for a lamp is a general indication of the warmth or coolness of its appearance. As CCT increases, the appearance of the source shifts from reddish white toward bluish white; therefore, the higher the color temperature, the cooler the color appearance. Lamps with a CCT rating below 3200 K are usually considered warm sources, whereas those with a CCT above 4000 K usually considered cool in appearance.
Full-spectrum color index (FSCI)	A mathematical transformation of full-spectrum index into a zero to 100 scale, where the resulting values are directly comparable to color rendering index. An equal energy spectrum is defined as having an FSCI value of 100, a "standard warm white" fluorescent lamp has an FSCI value of 50, and a monochromatic light source (e.g., low pressure sodium) has an FSCI value of 0.
Gamut area	A measure of color rendering based upon volume in color space. It is the range of colors achievable on a given color reproduction medium (or present in an image on that medium) under a given set of viewing conditions.

Initial light output	A lamp's light output, in lumens, after 100 hours of seasoning.
Instant start	A method of starting fluorescent lamps in which the voltage that is applied across the electrodes to strike the electric arc is up to twice as high as it is with other starting methods. The higher voltage is necessary because the electrodes are not heated prior to starting. This method starts the lamps without flashing. It is more energy efficient than rapid or preheat starting, but results in greater wear on the electrodes during starting. The life of instant-start lamps that are switched on and off frequently may be reduced by as much as 25 percent relative to rapid-start operation. However, for longer burning cycles (such as 12 hours per start), there may be no difference in lamp life for different starting methods.
Lamp efficacy	The ratio of the light output of a lamp (lumens) to its active power (watts), expressed as lumens per watt (LPW).
Lumen maintenance	The ability of a lamp to retain its lumen output over time. Greater lumen maintenance means a lamp will remain brighter longer. The opposite of lumen maintenance is lumen depreciation, which represents the reduction of lumen output over time. Lamp lumen depreciation factor (LLD) is commonly used as a multiplier to the initial lumen rating in illuminance calculations to compensate for the lumen depreciation. The LLD factor is a dimensionless value between 0 and 1.
MacAdam ellipse	Researcher David L. MacAdam showed that a just noticeable difference (JD) in the colors of two lights placed side-by-side was about three times the standard deviation associated with making color matches between a reference light and a test light)MacAdam 1942, Wyszecki and Stiles 1982). These JNDs form an elliptical pattern of "constant discriminability" in a chromaticity space, centered on the chromaticity of a reference light, known as MacAdam ellipse.
Mean light output	Light output typically evaluated at 40% of rated lamp life. In combination with initial light output, mean light output may be used to estimate lamp lumen depreciation.
Rapid start	A method of starting fluorescent lamps in which the electrodes are heated prior to starting, using a starter that is an integral part of the ballast. Heating the electrodes before starting the lamps reduces the voltage required to strike the electric arc between the electrodes. A rapid-start system starts smoothly, without flashing.
RE70	Designation referring to lamps that use rare-earth phosphors and have color-rendering index values of 70-79.
RE80	Designation referring to lamps that use rare-earth phosphors and have color-rendering index values of 80-89.
RE80 HLO, LL	An RE80 lamp with additional enhancements of high light output (HLO) and/or long life (LL).

RE90	Designation referring to lamps that use rare-earth phosphors and have color-rendering index values equal to or greater than 90.
Spectral power distribution (SPD)	A representation of the radiant power emitted by a light source as a function of wavelength.
Standard deviation	A measure of the average distance of a set of data points from their mean. A set of data points that are all close to their mean will have a smaller standard deviation than a set of points that are further from their mean.
System efficacy	Also referred to as relative system efficacy, system efficacy is a measurement of a system''s ability to convert electricity into light. Measured in lumens per watt (LPW), system efficacy is the ratio of the light output (in lumens) to the active power (in watts).

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