LightingAnswers

Dimming Systems for High-Intensity Discharge Lamps

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NATIONAL LIGHTING PRODUCT INFORMATION PROGRAM

Introduction

Specifying a dimming system for high-intensity discharge (HID) lamps can be confusing, because the information available from dimming system manufacturers on the impact of dimming on light output, lamp color, and *lamp life** sometimes conflicts with the recommendations made by lamp manufacturers. This issue of *Lighting Answers* summarizes information both from dimming system manufacturers and from lamp manufacturers. It also helps explain the technical concerns associated with dimming HID lamps by discussing relevant literature and presenting test results from the National Lighting Product Information Program (NLPIP).

What are the advantages of dimming HID lamps?

The advantages of dimming include energy savings, reductions in peak power demand, and enhanced flexibility for multi-use spaces. A dimming system for HID lamps can save energy because the lamps are dimmed by reducing their input power. Further energy savings may result from reduced demand on the air conditioning system because reducing the input power to the HID lighting system reduces its heat output.

Some dimming systems for HID lamps are used to reduce the input power to the system during periods of peak power demand for the electric utility. By reducing the peak demand for the building, such an application not only saves energy but can reduce demand charges.

A dimming system for HID lamps also offers flexibility. In multi-use spaces such as gymnasiums, the lighting can be adjusted to suit various uses such as sporting events, public assemblies, social functions, and maintenance.

* All terms in *italics* are defined in the glossary on p. 7.

What are HID lamps?

The HID lamp family includes *high-pressure sodium*, *metal halide*, and *mercury vapor* lamps. HID lamps typically consist of a sealed arc tube inside a glass envelope, or outer jacket. The inner arc tube is filled with elements that emit light when ionized by electric current. The mixture of elements within the arc tube is one of the primary distinguishing characteristics of the different types of HID lamps. The inside surface of the outer jacket may be coated with a diffusing material or with phosphors that both diffuse the light and improve the color properties of the lamp. Like fluorescent lamps, HID lamps require ballasts to provide the proper starting voltage and to regulate current during operation.

HID lamps vary in size and input power from a 6-inch, 35-watt lamp used mostly for accent lighting to a 15-inch, 1500-watt lamp used mostly in industrial lighting applications. Figure 1 illustrates the difference in size between a typical HID lamp and a typical incandescent lamp. The energy efficiency of HID lamps varies widely, with lamp *efficacy* ranging from 30 to 150 lumens per watt (LPW). For comparison, a 100-watt incandescent lamp has an efficacy of 17 LPW, and a 32-watt, 4-foot T8 fluorescent lamp has an efficacy of 89 LPW.

Figure 1
A 400-watt metal halide lamp (top) and a 75-watt incandescent lamp (bottom)

Donna Abbott Vlahos

HID lamps require a warm-up period to reach full light output. When shut off, they must cool down before they can be restarted and then must warm up again to reach full light output. The time required for the lamp to restart is called the *restrike time*. Table 1 shows typical warm-up and restrike times for HID lamps, along with some other characteristics.

Their long warm-up and restrike times make HID lamps unsuitable for many applications. However, HID lamps can offer higher lamp efficacy and higher light output than incandescent or fluorescent lamps. HID lamps also are more compact than 4- and 8-foot fluorescent lamps. As a result, their light output is more easily controlled by luminaires. Unlike fluorescent lamps, HID lamp light output is not significantly affected by ambient temperature.

What technologies are used to dim HID lamps?

Presently, HID lamps can be dimmed using two-level or continuous systems. Two-level dimming is technologically simpler and thus less expensive than continuous dimming. Most two-level dimming systems use a *constant-wattage autotransformer* (CWA) ballast; when set to the dimmed setting, the circuit includes an additional capacitor, resulting in a fixed reduction in power and light output.

Three methods are used for continuous dimming of HID lamps. The first uses a variable-voltage transformer to reduce the primary voltage supplied to the ballast, dimming to approximately 60% of rated lamp power. The second method adds a variable reactor to the circuit, which changes the lamp current without affecting the voltage. This allows a wider range of dimming, to approximately 30% of rated power, depending on the lamp and ballast combination. The third method uses solid-state components to change the waveforms of both the current and voltage input to the ballast, dimming to approximately 50% of rated power.

Some dimming systems for HID lamps require special dimming ballasts, whereas others use standard HID ballasts. In both cases, only magnetic ballasts presently are used. Some manufacturers are developing electronic dimming ballasts for HID lamps, which may provide further energy savings and improved dimming performance.

Three types of dimming controls are available: manual (local or remote), automatic (with occupancy sensors or photocells), and time-programmable. Systems are available to control either a single zone or multiple zones.

Table 1
Operating characteristics of HID lamps and ballasts

Lamp Type	Power (watts)	Initial System Efficacy (LPW)*	Lumen Depreciation (%)**	Average Rated Life (hours)	Warm-up Time (minutes)	Restrike Time (minutes)
High-pressure sodium	35–1,000	51–130	9–10	7,500–24,000+	3–4	0.5–1
Mercury vapor	40–1,250	24–60	11–25	12,000–24,000+	5–7	3–6
Metal halide	70–1,500	69–115	20–23	5,000–20,000+	2–5	10–20

* Efficacy calculation includes ballast power.
** Percentage reduction in light output at 40% of rated life.

Figure 2
Light output vs. system input power for a 400-watt, coated metal halide lamp

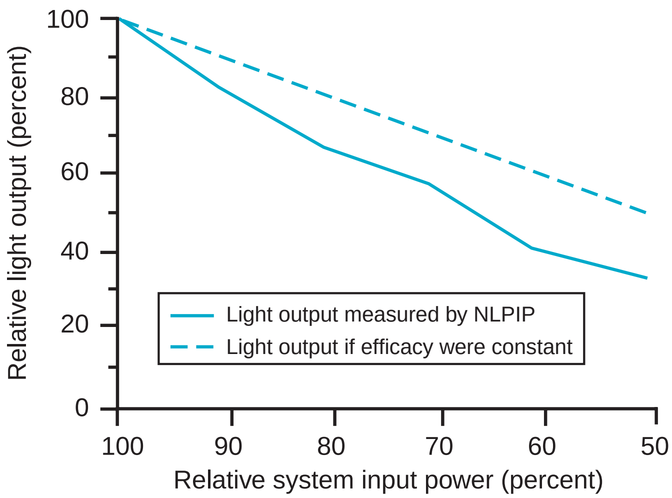


Table 2
Changes in efficacy for a 400-watt, coated metal halide lamp

System Input Power (watts)	Relative Efficacy (%)*
439	100
393	91
354	82
302	79
260	67
247	59

* Relative light output divided by relative system input power.

How does dimming affect light output and system input power?

Reducing the system input power does not proportionally reduce light output. When HID lamps are dimmed, the reduction in light output is greater than the reduction in system input power. Thus, the efficacy decreases as the lamp is dimmed. Figure 2 displays the results of NLPIP's evaluation of a continuous dimming system operating a 400-watt, coated metal halide lamp. Table 2 lists the relative efficacies of this system as NLPIP dimmed the lamp in sequence to approximately 90, 80, 70, 60, and 55% power.

NLPIP also evaluated a two-level dimming system operating a 400-watt, coated high-pressure sodium lamp. For this evaluation, NLPIP switched the system from the high setting (approximately 100% power) to the low setting (approximately 30% power). After the lamp had stabilized at the low setting, its light output was 10% of that at the high setting and the resultant efficacy was 39% of that at the high setting.

According to some dimming system manufacturers, HID lamps used with their systems do not immediately adjust light output when the dimming setting is changed. When these systems are dimmed from full power to minimum power, about half of the total change in light output occurs within a few seconds. It may then take 3 to 10 minutes for the light output to stabilize. With some dimming systems, lamps respond instantly to small changes in input power.

According to some lamp manufacturers, the *lamp lumen depreciation* of metal halide and mercury vapor lamps may increase when the lamps are dimmed, because operation at reduced power increases the blackening of the arc tube due to electrode sputtering. To help limit lamp lumen depreciation of metal halide and mercury vapor lamps, lamp manufacturers recommend that they not be dimmed below 50% of rated power. This recommendation is also important for lamp life and color as discussed on pp. 4 and 5. Lamp manufacturers also state that lamp lumen depreciation of high-pressure sodium lamps is not affected by dimming.

How does dimming affect color?

Of the three HID lamp types, metal halide lamps are the most susceptible to changes in color characteristics when dimmed. Dimming can reduce the arc tube temperature to the point where some of the elements will not ionize, which eliminates the contribution of these elements to the lamp's spectrum. According to some manufacturers, the change in *correlated color temperature* (CCT) is slight when a metal halide lamp is dimmed to 80% of its rated power. However, the CCT increases significantly when the lamp is dimmed below 60%, so that the light produced appears to be more blue.

The effect of dimming on CCT and *color rendering index* (CRI) value is less for phosphor-coated metal halide lamps than for clear lamps. When a clear metal halide lamp is dimmed to 50% of rated power, the CRI value may drop from 65 to 45 and the CCT may increase by 1500 K. When a coated metal halide lamp is dimmed to 50% of rated power, the CRI value may drop from 70 to 60 and the CCT may increase by only 400 K. Figures 3 and 4 show the effects of dimming on the CCTs and CRI values of metal halide lamps. To minimize color shift, some lamp manufacturers recommend that metal halide lamps be operated close to their rated power and never be dimmed below 50% of their rated power.

The CCTs of high-pressure sodium lamps may decrease by 50 to 200 K when they are dimmed; the light appears to be more yellow. CRI values change minimally when high-pressure sodium lamps are dimmed. The color properties of mercury vapor lamps do not change significantly when the lamps are dimmed. For more information about the impact of dimming on lamp color, see the sidebar on p. 5.

How does dimming affect HID lamp life?

Although NLPIP did not test the effect of dimming on lamp life, others have published information and recommendations on HID lamp life. Two recent studies of two-level dimming systems (Smith and Zhu 1993; Gibson 1994), in which the lamps were alternately operated at full power and at reduced power, found no significant change in lamp life. Nevertheless, lamp manufacturers usually caution that operating a lamp continuously at a very low power level reduces lamp life and increases lamp lumen depreciation. For example, manufacturers warn that dimming below 50% of rated power may cut mercury vapor lamp life in half, and may reduce high-pressure sodium and metal halide lamp life by 90%.

Lamp manufacturers recommend that after starting an HID lamp, the dimming system should operate the lamp at full power for 10 to 15 minutes before dimming. One continuous dimming system that NLPIP evaluated met this recommendation by maintaining full power for about 15 minutes each time the lamp was started, regardless of the dimming system's setting. Some metal halide lamp manufacturers also recommend operating the lamps in the base-up position for dimming to limit reduction in lamp life.

Figure 3
Effects of dimming on the CCTs of 400-watt, clear and coated metal halide lamps (Adapted from Gibson 1994)

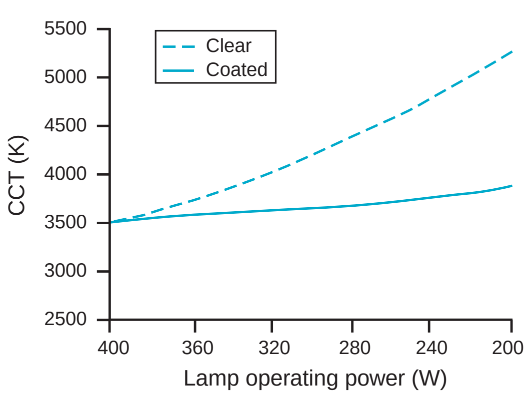
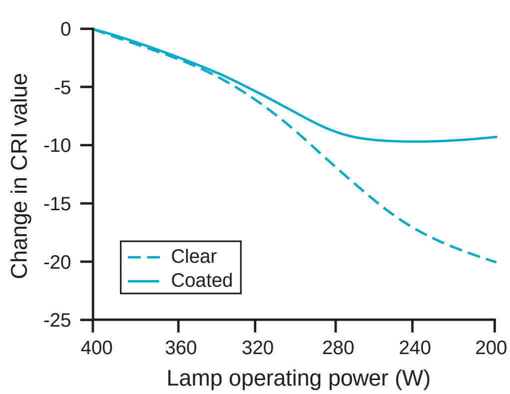


Figure 4
Effects of dimming on the CRI values of 400-watt, clear and coated metal halide lamps (Adapted from Gibson 1994)



During dimming operation, systems should maintain the minimum *open-circuit voltage* established by the American National Standards Institute (ANSI). If this voltage is too low, it may be difficult to restrike the lamp if power is interrupted momentarily.

What applications are best suited for dimming HID lamps?

Two-level dimming systems are particularly useful for parking lots. Lamps can operate at full power during the primary hours of use, after which the system can dim the lamps to the low setting and provide uniform security lighting all night. An added benefit of the use of these systems in parking lots is the reduction of undesired light illuminating the adjoining properties.

For indoor applications, two-level systems can be used effectively with occupancy sensors or timers in spaces such as warehouses. In supermarkets, malls, and other retail applications, dimming the lamps to provide a low level of lighting for after-hours tasks such as maintenance and restocking inventory reduces energy costs during those times. Two-level dimming systems are preferred to automatic on/off controls due to lengthy warm-up and restrike times with on/off systems.

Continuous dimming systems are suited for multi-use applications where flexibility is needed or for applications where a control system is used to regulate the *illuminance*. They are used in airports, industrial buildings, lobbies, classrooms, gymnasiums, ice rinks, sporting arenas, and auditoriums. These systems sometimes use photocells, either to dim lamps based on the availability of daylight, or to compensate for lamp lumen depreciation by dimming the lamps when they are first installed. In the latter application, the system gradually provides more power to maintain a constant illuminance.

High-pressure sodium lamps typically are used in industrial buildings, warehouses, and parking lots. Metal halide lamps often are preferred in locations where color is important, such as supermarkets, gymnasiums, ice rinks, and sporting arenas.

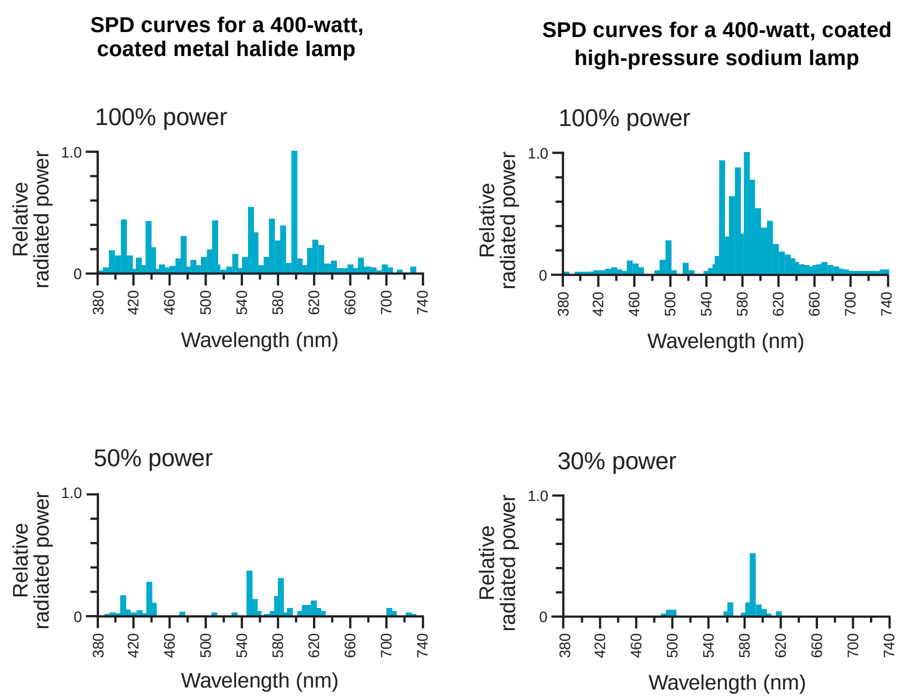
Effect of dimming on the spectral power distribution of HID lamps

A spectral power distribution (SPD) curve illustrates the relative power radiated by a lamp at each given wavelength. NLPIP measured the SPD and CCT for HID lamps operated by two dimming systems at full power and at reduced power.

The two bar charts on the left show the SPD curves for a 400-watt, coated metal halide lamp operated by a continuous dimming system, at 100% and 50% power. When the lamp was dimmed, radiant power was substantially reduced at all wavelengths and the SPD curve resembled that of a mercury vapor lamp. The CCT shifted from 3850 to 4310 K.

The metal halide lamp that NLPIP tested had a sodium-scandium lamp chemistry, which is typical of 400-watt metal halide lamps. The color properties of other metal halide lamp types may be affected differently by dimming.

The two bar charts on the right show the SPD curves for a 400-watt, coated high-pressure sodium lamp operated by a two-level (100% and 30%) dimming system. When the lamp was dimmed, the SPD curve resembled that of a low-pressure sodium lamp, and the CCT shifted from 2070 to 1990 K.



Who manufactures dimming systems for HID lamps?

NLPIP identified six manufacturers of dimming ballasts or controls for HID lamps and sent surveys to all of them. Table 3 summarizes product information from the three manufacturers that responded to the survey.

NLPIP also investigated the costs of dimming systems for HID lamps. Installed costs vary widely, based on the type of dimming system and on the specific details of the application. Specifiers should contact dimming system manufacturers with these details to obtain accurate pricing information.

What warranties are available for these dimming systems?

Some dimming system manufacturers void their warranties if components of their dimming systems are used with controls or ballasts from another manufacturer. Warranties may or may not include the costs of transportation and replacement labor and sometimes include either repair or replacement at the manufacturer's discretion. Some HID lamp manufacturers void their warranties when lamps are operated on a dimming system, unless the dimming system has been approved by the lamp manufacturer.

Table 3
Availability of some HID dimming systems

	Two-Level Dimming							Continuous Dimming						
	Lamp Input Power (watts)							Lamp Input Power (watts)						
	100	150	175	250	400	1000	1500	100	150	175	250	400	1000	1500
High-pressure sodium														
Lutron Electronics Co., Inc.*								•	•		•	•	•	
Peschel Energy, Inc**	•	•		•	•	•		•	•		•	•	•	
Wide-Lite/Control*	•	•		•	•	•					•	•	•	
Mercury vapor														
Peschel Energy, Inc**	•		•	•	•	•		•		•	•	•	•	
Wide-Lite/Control*								•		•	•	•	•	
Metal halide														
Lutron Electronics Co., Inc.*								•	•	•	•	•	•	•
Peschel Energy, Inc**	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Wide-Lite/Control*			•	•	•	•	•			•	•	•	•	•

• Indicates that a dimming system for that lamp wattage was available as of January 1994. Only manufacturers that responded to NLPIP's survey are included.

* Products are available for both 120- and 277-V operation.

** Products are available for 120-, 277-, and 347-V operation.

Glossary

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 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.

constant-wattage autotransformer (CWA) The most common type of ballast used for HID lamps; it maintains a constant power (wattage) supply to the lamp when system input voltage fluctuates.

correlated color temperature (CCT) A description of the color appearance of a light source. The CCT relates the color appearance of the light emitted by a lamp to the color appearance of a reference material heated to a high temperature (measured on the kelvin scale, abbreviated K). As the temperature rises, the color appearance shifts from warm to cool. Lamps with a low CCT (3100 K and lower) appear yellow-white and are described as “warm”; lamps with a high CCT (4000 K and higher) appear blue-white and are described as “cool.”

efficacy The ratio of light output (lumens) to input power (watts), expressed in lumens per watt (LPW).

high-pressure sodium (HPS) A high-intensity discharge lamp type that uses sodium under high pressure as the primary light-producing element. High-pressure sodium lamps produce light with a CCT of approximately 2000 K, although CCTs for lamps with higher CRI values range from 2200 to 2700 K. Standard lamps have a CRI value of 22, others have CRI values from 60 to 80. They are among the most efficacious light sources, with efficacies as high as 150 LPW, although high-pressure sodium lamps with higher CRI values have efficacies as low as 25 LPW.

illuminance The amount of light incident on a surface area. Illuminance is measured in footcandles (lumens/square foot) or lux (lumens/square meter). One footcandle equals 10.76 lux, although for convenience 10 lux commonly is used as the equivalent.

lamp life The median life span of a very large number of lamps. Half of the lamps in a sample are likely to fail before the rated lamp life, and half are likely to survive beyond the rated lamp life. For discharge light sources, such as fluorescent and HID lamps, lamp life depends upon the number of starts and the duration of the operating cycle each time the lamp is started. HID lamp life ratings are based on a 10 hours on, 1 hour off operating cycle, and range from 5,000 to more than 24,000 hours.

lamp lumen depreciation (LLD) The reduction in lamp light output that progressively occurs during lamp life. Phosphor deterioration and blackening of the arc tube contribute to HID lamp lumen depreciation.

mercury vapor (MV) A high-intensity discharge lamp type that uses mercury as the primary light-producing element. Mercury vapor lamps produce light with a CCT from 3000 to 7000 K. Mercury vapor lamps with clear outer bulbs have CRI values from 15 to 25, whereas phosphor-coated lamps have CRI values from 40 to 55. Mercury vapor lamps are less efficacious than other HID lamp types, typically producing only 30 to 65 LPW, but they have longer lamp lives and lower initial costs than other HID lamp types.

metal halide (MH) A high-intensity discharge lamp type that uses mercury and several halide additives as light-producing elements. Metal halide lamps have better color properties than other HID lamp types because the different additives produce more visible wavelengths, resulting in a more complete spectrum. Metal halide lamps are available with CCTs from 2300 to 5400 K and with CRI values from 60 to 93. Efficacies of metal halide lamps typically range from 75 to 125 LPW.

open-circuit voltage The voltage applied across the output terminals of a ballast when no load is connected. This is the voltage applied across a lamp circuit to start the lamp. After starting, the voltage rapidly decreases and stabilizes at the operating voltage.

restrike time The time required for a lamp to restrike, or start, after the lamp is extinguished. Normally, HID lamps need to cool before they can be restarted.

Resources

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Guide to Performance Evaluation of Efficient Lighting Products, 1991

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- *Power Reducers, 1992*
- *Specular Reflectors, 1992*
- *Occupancy Sensors, 1992*
- *Parking Lot Luminaires, 1993*
- *Screwbase Compact Fluorescent Lamp Products, 1993*
- *Cathode-Disconnect Ballasts, 1993*
- *Exit Signs, 1994*
- *Electronic Ballasts, 1994*

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