Fluorescent Dimming Ballast Study Report

Submitted to:

Sacramento Municipal Utility District

SMUD™

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About the Customer Advanced Technologies Program…

SMUD's Customer Advanced Technologies (C.A.T.) program works with customers to encourage the use and evaluation of new or underutilized technologies. The program provides funding for customers in exchange for monitoring rights. Completed demonstration projects include lighting technologies, light emitting diodes (LEDs), indirect/direct evaporative cooling, non-chemical water treatment systems, daylighting and a variety of other technologies.

For more program information, please visit:
https://www.smud.org/en/business/save-energy/rebates-incentives-financing/customer-advanced-technologies.htm

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1. Executive Summary

Fluorescent lighting is the most prevalent type of lighting in commercial buildings, and linear fluorescent lighting accounts for 81% of non-residential interior lighting [1]. As of January 1, 2014, new California Title 24 Building Energy Efficiency Standards will require the majority of new commercial interior lighting systems to be dimmable and have a high degree of dimming control resolution. These requirements will likely result in the widespread use of continuous dimming fluorescent ballasts. Thus, there will be a growing need to better understand the relationships between fluorescent dimming ballast input power, input control signal, and light output. Although ballasts are available in many different configurations, ballasts selected for this performance comparison study have the following characteristics:

1.   Full range continuous dimming
2.   Four wire controls (0-10 Vdc)
3.   Compatible with 4 ft. T8 fluorescent lamps (25 Watt and 32 Watt)
4.   Designed to operate 2 lamps and 3 lamps

Past field research efforts have provided evidence of performance anomalies in fluorescent dimming ballasts with regard to the relationship between the input control signal and the input power. These anomalies may have a negative effect on energy savings. This report explores the issue of performance anomalies through a comprehensive dimming ballast research study in order to identify typical ballast performance characteristics for products that are compatible with 4 ft. T8 fluorescent lamps. The product list is representative of the majority of the dimming ballast market and includes both two and three lamp models (Figure 1 and Figure 2). Technical ballast performance information is generally not publicly available, and was obtained directly from manufacturer contacts. This report is written to provide all relevant information while preserving manufacturer anonymity. It should be noted that the data presented in this report are self-reported by the manufacturing companies and have not been independently tested.

Although the trends of input signal to power consumption within the input control signal ranges of 20% to 70% are consistent with general expectations, there were some noteworthy findings:

*   Almost all products exhibited control deadbands – instances where changes in the control signal voltage resulted in no corresponding changes in light output or power consumption. These tended to occur at the lowest settings (i.e. 0-2 Vdc) and at the highest settings (9-10 Vdc). One product (Brand B) exhibited a deadband in the range of 7.5 to 10 Vdc.

*   Ballasts from one manufacturer (Brand A) exhibited a significant performance anomaly: the power consumption with an input signal of 7 Vdc was substantially higher than with a control signal of 7.5 Vdc. This is significant, as many users choose to use 70% of maximum output for energy conservation and demand response programs. The performance anomaly seen in Brand "A" products represents approximately one-third of the available market options (for products that met the criteria used in this study).

These findings indicate a need for careful review of ballast performance characteristics when developing specifications or choosing products for specific project applications. This is particularly important for electricians or control technicians tasked with commissioning lighting controls. A thorough understanding of fluorescent ballast performance characteristics and lighting control systems will be instrumental in achieving energy savings and end user satisfaction.
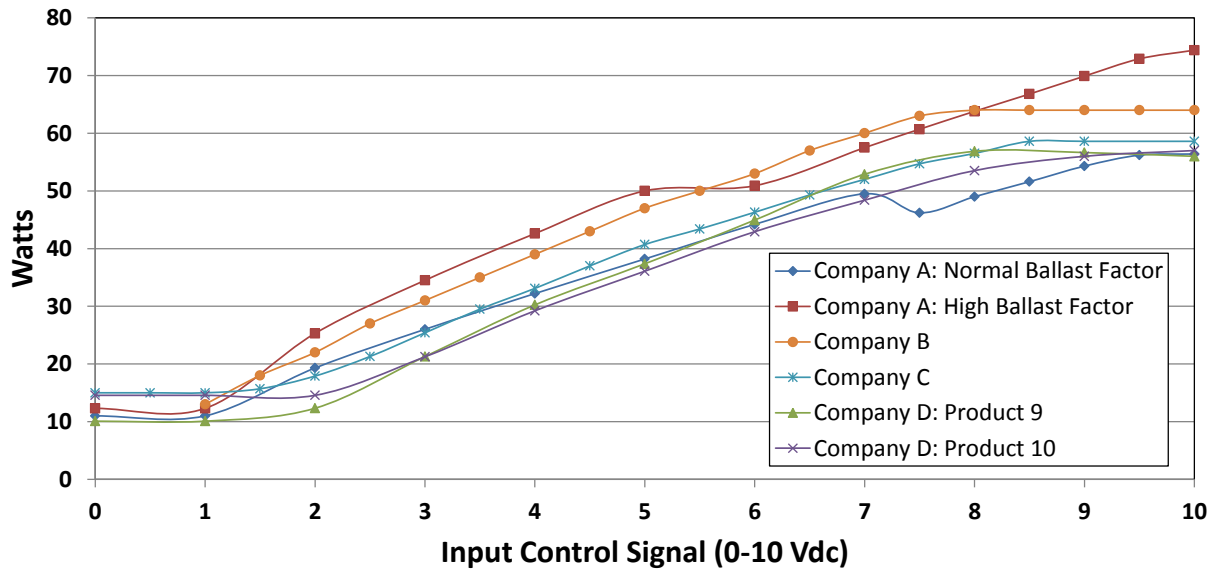
Dimming Ballast Summary: 2-Lamp

Figure 1: Summary for 2-Lamp, 277 V Dimming Ballasts
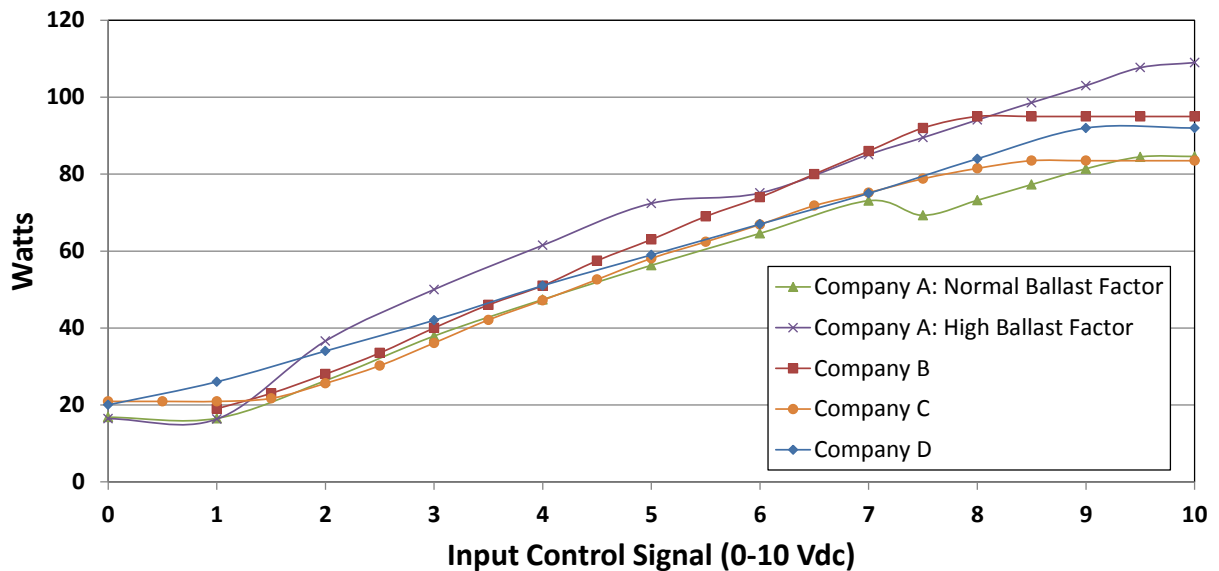
Dimming Ballast Summary: 3-Lamp

Figure 2: Summary for 3-Lamp, 277 V Dimming Ballasts

2. Introduction

2.1   Background

Dimming ballasts are a quickly-growing sector of energy efficient lighting technologies. These ballasts are incorporated into four types of lighting control strategies: Daylight Harvesting, Occupancy, Task Tuning and Demand Response.

- Daylight Harvesting controls use a combination of daylight and electric lighting to meet building lighting needs. This is achieved by constantly measuring the total amount of light in a space and adjusting the electric light levels to meet the desired illumination level.

- Occupancy systems dim lighting through the use of occupancy sensors (in lieu of turning the lights off completely). This strategy is used for applications where completely turning off the lights during business hours may not be acceptable. Applications for occupancy systems include corridors, stairwells, classrooms, warehouses, and assembly areas.

- Task Tuning allows end users to precisely adjust the desired illumination levels. These systems are typically used in applications such as large open floor plan cubicle offices where occupants have the capability to control the light fixtures directly over their individual cubicles.

- Demand Response ballasts use dimming functions to lower the light levels during peak hours, specifically upon request from the local utility. Demand response ballasts generally can be controlled remotely via the internet and may be connected with control systems that accept open automated demand response (OpenADR) protocols.

These control strategies can be used in combination in order to provide customized and more efficient lighting solutions. Dimming ballast adoption has steadily increased since the ballasts were introduced to the market, and there will likely be a substantial increase in dimming ballast implementation after the updated release of California Title 24 building code in January 2014.

Title 24 is the building code portion of the California Code of Regulations. This encompasses many aspects of California building standards including the electrical, plumbing, and fire codes. One of these sections is the Energy Code, which creates standards for improving energy efficiency and reducing energy consumption. The next update to the building code includes higher requirements for lighting control systems that use dimming ballast functions to improve energy efficiency. Specifically, the code calls for an increase in ballast dimming granularity for advanced multi-level lighting controls, which favors full range dimming. This allows for "precise and non-interruptive adjustment of lighting to match the available day lighting, and provide dimming and demand response function throughout the building [2]."

Continuous dimming ballasts enable a full range of dimming levels by adjusting the amplitude of the current flowing through the lamp. The power is reduced as current is reduced, thereby dimming the light. Ballast granularity is the number of dimming steps, with the least granular meaning a single dimming step and the most granular meaning full range dimming. The energy code update specifies that dimming ballasts with one intermediate light level step in addition to

On/Off will be either increased to three intermediate level steps or increased to continuous dimming. This allows for "precise and non-interruptive adjustment of lighting to match the available day lighting, and provide dimming and demand response function throughout the building[2]." The release of the new California Building Energy Code is creating a shift towards continuous dimming ballasts. All dimming energy savings rely on the reduction of ballast operating power while lights are dimmed. The relationship between dimming levels and power savings are not always linear but there is expectation for a regular trend. However, there is some evidence of irregular performance anomalies at specific dimming levels on continuous dimming ballasts. For example, there may be a linear power reduction as the ballast dims from 100% to 70% of the maximum light output, followed by no power reduction until 60% of the maximum, after which the linear power reduction trend resumes. It is important to understand the true nature of dimming ballast performance as California approaches the new energy code dimming ballast standards.

2.2   Assessment Objectives

The goal of this study was to understand full range dimming ballast performance for a comprehensive list of ballasts that best represent the market. These findings are presented as a tool that can be used to shape future energy efficiency programs through understanding of common continuous dimming ballast performance behavior.

2.3   Methodology

ADM developed a search criterion to refine the scope of this study to similar ballast products from multiple companies. We began with a focus on full range dimming. This ballast type was presented for investigation because it provides the best control in energy efficient lighting systems that are likely to be used with the new code standards. There are several dimming range limits within continuous dimming ballasts. In general, it is common to see ballasts that dim from 100%-20% and from 100%-5%. Ballasts that have dimming functions similar to 100%-20% are becoming a smaller portion of the market in favor of the 100%-5% option. Only one company included a 100%-20% dimming range product line in their product catalog but this ballast has since been discontinued. The market shift towards widest range dimming leaves only the 100%-5% option. These are not exact dimming ranges, as there are small differences between similar ballasts in a product line which can depend on the number of lamps and other factors. Additionally, some companies produce ballasts that dim from 100%-3%, which fits into the same widest range dimming ballast category.

Four wire controls are the most popular analog method used today. These controls have separate wires powering the ballast and controlling the light levels. The advantage to this method is that the light level input signal can be provided by any type of control system. The standard input signal is a 0-10 Volt (Vdc) direct current signal with Class 2 wiring. Other ballast controls include two wire, three wire, and Digitally Addressable Lighting Interface (DALI). Two and three wire systems use phase control to change light levels. Two wire controls send the AC signal across the ballast power input wire using a power line carrier signal, and three wire controls use a third dedicated wire for AC signals. DALI controls include a digital value storing

component which is used for combining ballasts into location groups for zoning control [3]. Four wire ballasts are the best standard for comparison due to their popularity and adherence to standard 0-10 V control signal practices. A wiring diagram of a four wire ballast is provided in Figure 3.
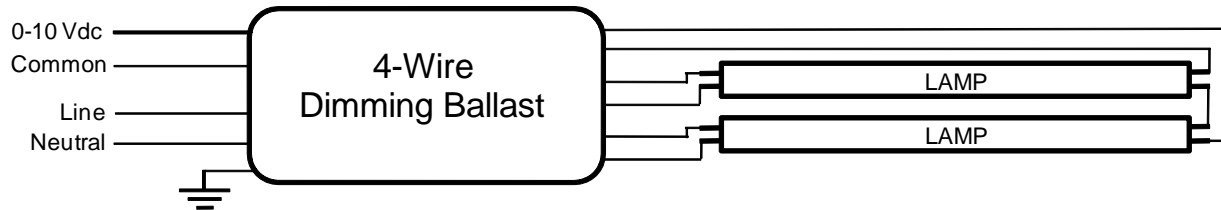
Figure 3: Wiring Diagram of Four Wire Dimming Ballast

While there is some variation in the type of lamps used in commercial applications, the majority of dimming ballasts are designed for 4 ft. T8 lamps. Two common wattages for 4 ft.T8 linear fluorescent lamps are 25 Watts and 32 Watts. Ballast specification information identifies the number and lamp wattage that the ballast can power, and some ballast models can support multiple lamps. Some companies have product lines of ballasts that include a range from one through four lamp options. The most common ballast types offered by the major ballast manufacturing companies are 2-lamp and 3-lamp ballasts.

Ballasts used for this performance comparison study have the following characteristics:

1. Full range continuous dimming
2. Four wire controls (0-10 Vdc)
3. Compatible with 4 ft. T8 fluorescent lamps (25 Watt and 32 Watt)
4. Designed to operate 2 lamps and 3 lamps

ADM's staff built a network of contacts with each company that allowed us to engage in conversations about dimming ballast specifications and other ballast information. During this process we validated our product list, identified their most popular ballasts, and inquired about light output, power input, input control signal relationships, and costs. The ballast performance tests were conducted with lamps recommended for use by the ballast manufacturer. No independent performance tests were conducted as part of this research.

3. Products Evaluated

ADM started with a list of the six major ballast manufacturers. The approach towards every company was to determine all combinations of 25 W and 32 W, 2-lamp and 3-lamp, 100%-20% dimming and 100%-5% dimming, T8 ballasts produced. We anticipated that multiple ballasts would fit each criteria and decided to rank each ballast by popularity to form a list of the most used ballasts on the market. Popularity was based on feedback from manufacturer's representatives. We found that most companies did not have dimming ballasts that fit into each combination of research criteria, and two of those companies did not manufacture dimming ballasts that met certain criteria that allowed them to be included in this study. This narrowed the product list down to four companies because not all of the six ballast companies investigated offered a continuous dimming ballast with four wire controls. We also discovered that the only identified 100%-20% dimming range ballast had been discontinued. We compiled a list of products for those four remaining companies and represent them anonymously as Company A, B, C, and D in Table 1. Ballast factor (BF) is the ratio of the lumen output of a fluorescent lamp for an evaluated ballast to the lumen output of the lamp on a reference ballast. The reference ballast is set up and calibrated according to ANSI (American National Standards Institute) test procedures.

Table 1: Condensed Product List

	Model	Dimming Range	Watts	# of Lamps	Voltage	Additional Options
Company A	1	100%-3%	32 W	2	120-277	Normal Ballast Factor
	2	100%-3%	32 W	2	120-277	High Ballast Factor
	3	100%-3%	32 W	3	120-277	Normal Ballast Factor
	4	100%-3%	32 W	3	120-277	High Ballast Factor
Company B			25 W			
	5	100%-5%	32 W	2	120-277	
			25 W			
	6	100%-5%	32 W	3	120-277	
Company C	7	100%-5%	32 W	2	120-277	
	8	100%-5%	32 W	3	120-277	
Company D	9	100%-3%	32 W	2	120-277	
	10	100%-5%	32 W	2	120-277	
	11	100%-5%	32 W	3	120	
	12	100%-5%	32 W	3	277	

Price quotes for each of the researched ballasts from local distributors when purchased in quantities of 100 are shown in Table 2.

Table 2: Ballast Price Quotes Based on Quantities of 100

	Model #	# of Lamps	Unit Cost
Company A	1	2	$66.73
	2	2	$71.56
	3	3	$71.56
	4	3	$73.95
Company B	5	2	$105.18
	6	3	$133.11
Company C	7	2	$48.75
	8	3	$53.88
Company D	9	2	$39.00
	10	2	$52.00
	11	3	$33.50
	12	3	$33.50

4. Results

This section presents summaries of the data collected from the ballast manufacturers. Additional tables of data are presented in the Appendix.

4.1 Company A

The four models from Company A are a normal and high ballast factor option for 2-lamp and 3-lamp ballasts. The 2-lamp normal ballast factor model (Figure 4) has a linear power trend from input control signal from 9.5 Vdc down to 7.5 Vdc. As the input signal is decreased to 7 Vdc the input power increases. This is an unexpected anomaly that should be conveyed to customers so that they can appropriately control the signal and conserve energy by an expected amount. Input power resumes a linear trend from an input signal of 7 Vdc down to 1 Vdc. No additional power savings occur below a 1 Vdc input signal. Deadbands in the power versus input signal occur below 1 Vdc and above 9.5 Vdc.

Power vs. Control Signal

*Figure 4: Company A Model 1: Power Input vs. Input Control Signal;
2-Lamp, Normal Ballast Factor*

The light output versus control signal data (Figure 5) show a somewhat linear light output trend with input signals from 9 Vdc down to 1 Vdc. Deadbands in the light output versus input signal occur below 1 Vdc and at 9 Vdc and above.

Light Output vs. Control Signal

Figure 5: Company A Model 1: Light Output vs. Input Control Signal;
2-Lamp, Normal Ballast Factor

The 2-lamp high ballast factor model (Figure 6) shows a linear trend with input signals from 10 Vdc down to 6 Vdc. As the input signal is decreased from 6 Vdc down to 5 Vdc there is almost no reduction in power consumption. Input power resumes on a linear trend as the input signal drops from 5 Vdc down to 1 Vdc. The lower deadband occurs at 1 Vdc and below.

Power vs. Control Signal

Figure 6: Company A Model 2: Power Input vs. Input Control Signal;
2-Lamp, High Ballast Factor

The light output versus control signal data (Figure 7) show a somewhat linear light output trend with input signals from 9 Vdc down to 1 Vdc.

Light Output vs. Control Signal

Figure 7: Company A Model 2: Light Output vs. Input Control Signal;
2-Lamp, High Ballast Factor

The 3-lamp normal ballast factor model (Figure 8) shows a linear trend from input control signal 9.5 Vdc down to 7.5 Vdc. As the input signal is decreased to 7 Vdc the input power increases. This is an unexpected anomaly that should be conveyed to customers so that they can appropriately control the signal and conserve energy by an expected amount. Input power resumes a linear trend from an input signal of 7 Vdc down to 1 Vdc. No additional power savings occur below a 1 Vdc input signal. Deadbands in the power versus input signal occur below 1 Vdc and above 9.5 Vdc.
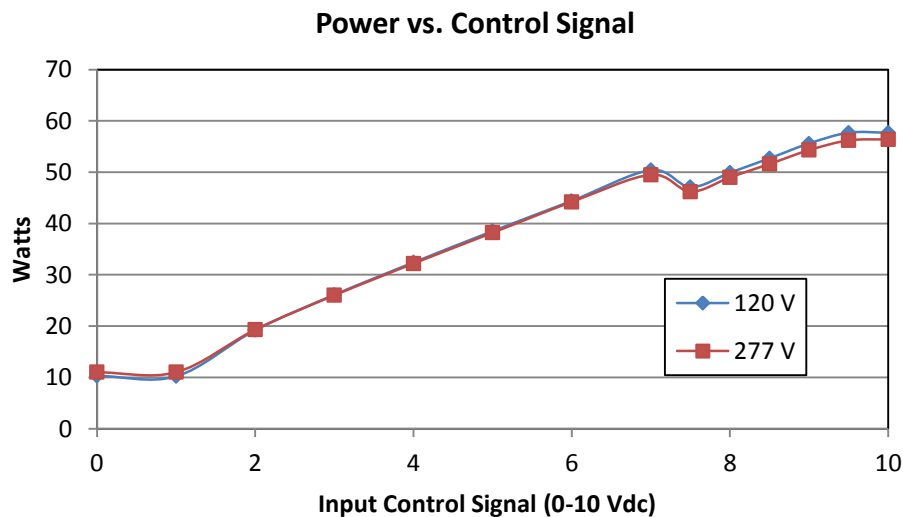
Power vs. Control Signal

Figure 8: Company A Model 3: Power Input vs. Input Control Signal;
3-Lamp, Normal Ballast Factor

The light output versus control signal data (Figure 9) show a somewhat linear light output trend with input signals from 9 Vdc down to 1 Vdc. The lower deadband occurs at 1 Vdc and below.

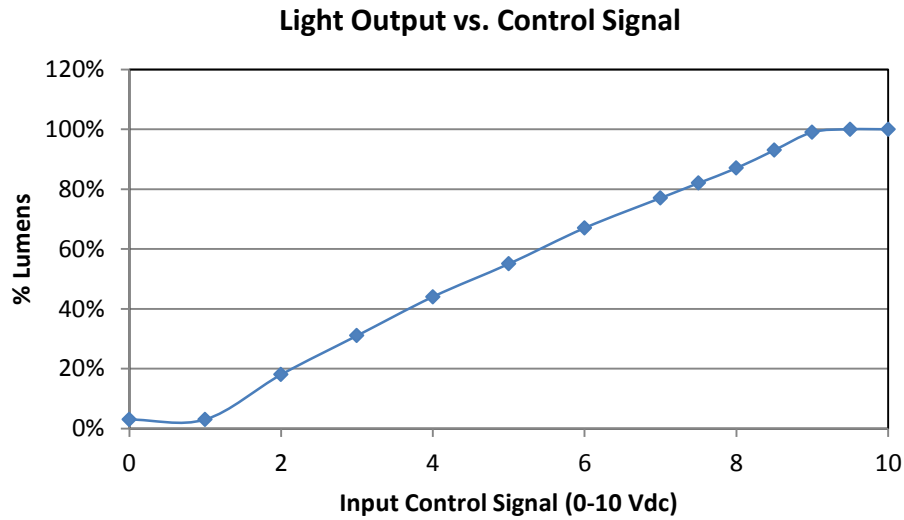**Light Output vs. Control Signal**
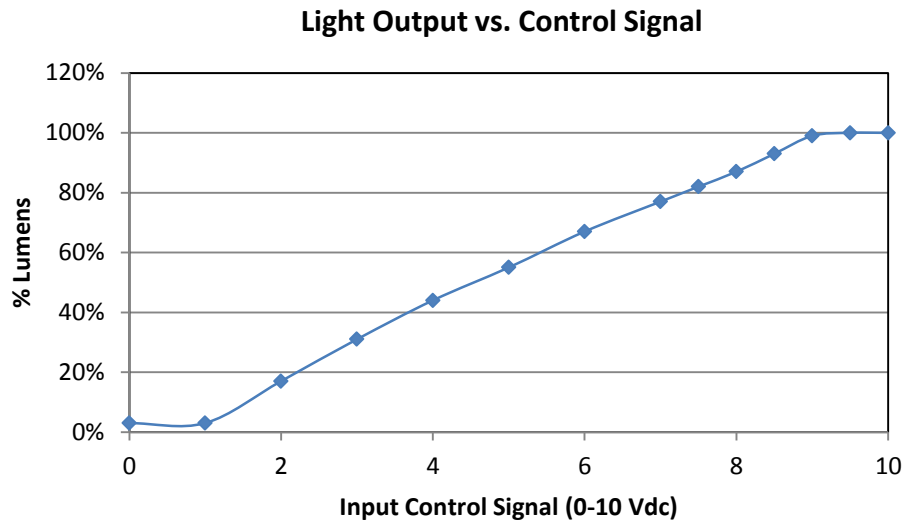
Figure 9: Company A Model 3: Light Output vs. Input Control Signal;
3-Lamp, Normal Ballast Factor

The 3-lamp high ballast factor model (Figure 10) shows a linear trend with input signals from 10 Vdc down to 6 Vdc. As the input signal is decreased from 6 Vdc down to 5 Vdc there is almost no reduction in power consumption. Input power resumes on a linear trend as the input signal drops from 5 Vdc down to 1 Vdc. The lower deadband occurs at 1 Vdc and below.
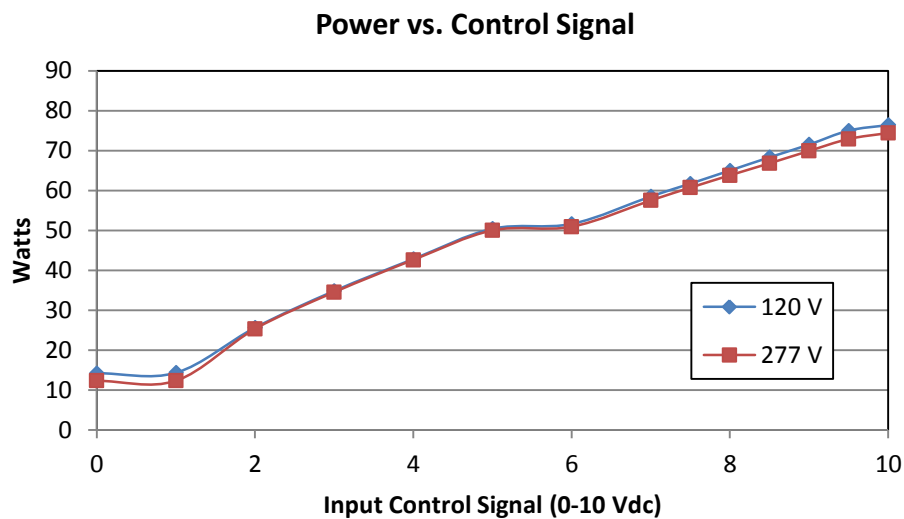
Power vs. Control Signal

Figure 10: Company A Model 4: Power Input vs. Input Control Signal;
3-Lamp, High Ballast Factor

The light output versus control signal data (Figure 11) show a somewhat linear light output trend with input signals from 9.5 Vdc down to 1 Vdc.
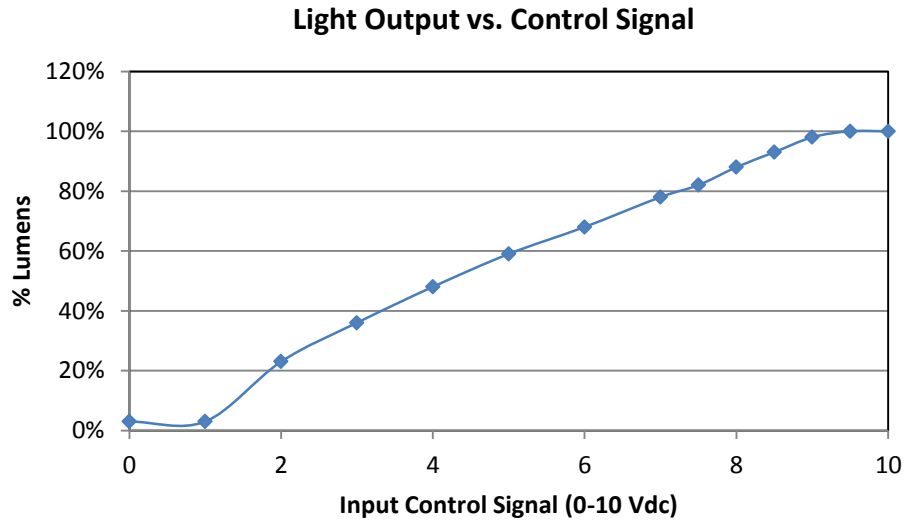
Light Output vs. Control Signal

Figure 11: Company A Model 4: Light Output vs. Input Control Signal;
3-Lamp, High Ballast Factor

4.2   Company B

The two models from Company B are a 2-lamp and a 3-lamp dimming ballast. The 2-lamp model (Figure 12) has a somewhat linear input power trend with input signals from 7.5 Vdc down to 1 Vdc. Deadbands in the power versus input signal occur below 1 Vdc and at 8 Vdc and above.
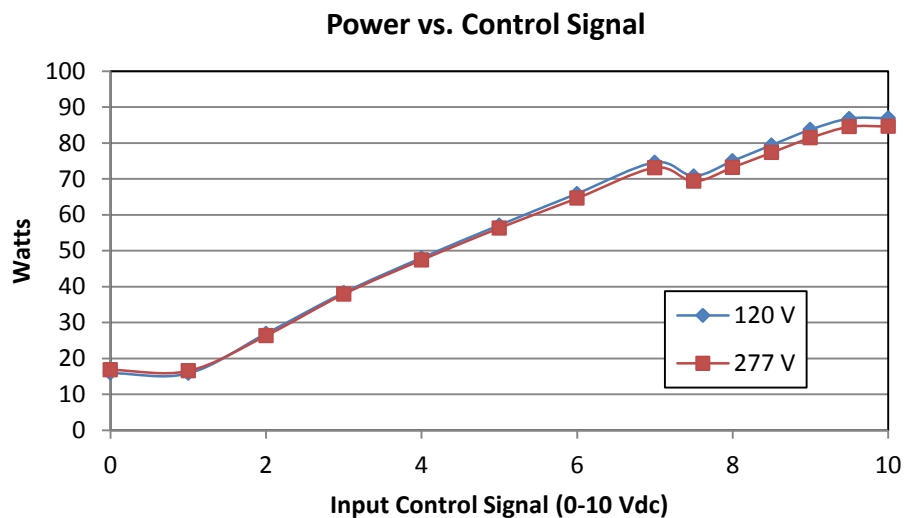
Power vs. Control Signal

Figure 12: Company B Model 5: Power Input vs. Input Control Signal; 2-Lamp

The light output versus control signal data (*Figure 13*) show a somewhat linear light output trend with input signals from 8 Vdc down to 1 Vdc.

Light Output vs. Control Signal

Figure 13: Company B Model 5: Light Output vs. Input Control Signal; 2-Lamp

The 3-lamp model (Figure 14) has a somewhat linear input power trend with input signals from 8 Vdc down to 1 Vdc. Deadbands in the power versus input signal occur below 1 Vdc and at 8 Vdc and above.

Power vs. Control Signal

Figure 14: Company B Model 6: Power Input vs. Input Control Signal; 3-Lamp

The light output versus control signal data (*Figure 15*) show a somewhat linear light output trend with input signals from 8 Vdc down to 1 Vdc.

Light Output vs. Control Signal

Figure 15: Company B Model 6: Light Output vs. Input Control Signal; 3-Lamp

4.3   Company C

The two models from Company C are a 2-lamp and a 3-lamp ballast. Both have no differentiation in power input with input signals from 10 Vdc down to 8.5 Vdc. The 2-lamp model (Figure 16) has a somewhat linear input power trend with input signals from 8.5 Vdc down to 1.5 Vdc. The lower deadband occurs at 1.5 Vdc and below. The upper deadband occurs at 8.5 Vdc and above.
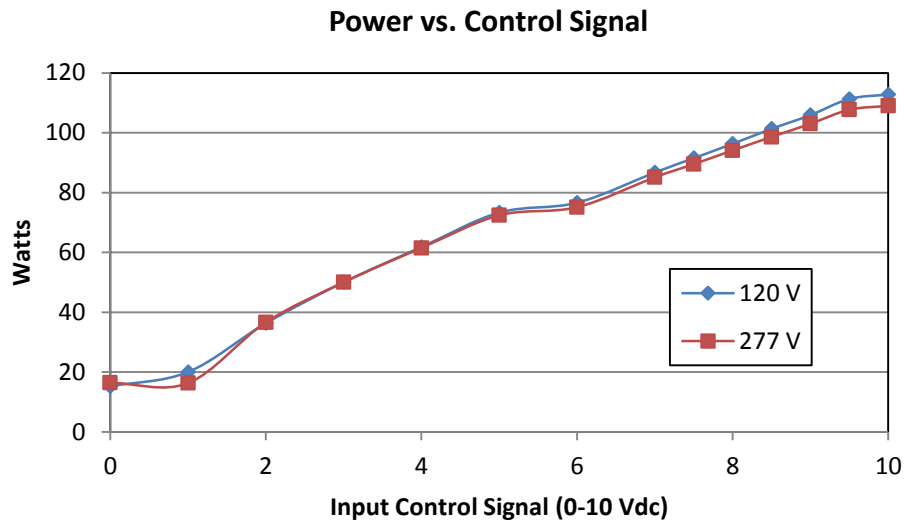
Power vs. Control Signal

Figure 16: Company C Model 7: Power Input vs. Input Control Signal; 2-Lamp

The light output versus control signal data (Figure 17) show a somewhat linear light output trend with input signals from 8.5 Vdc down to 1.5 Vdc.

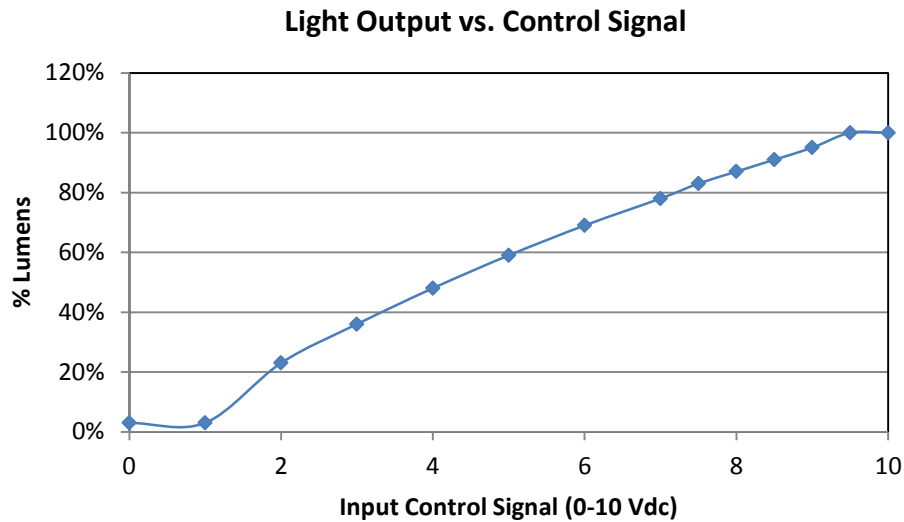**Light Output vs. Control Signal**

Figure 17: Company C Model 7: Light Output vs. Input Control Signal; 2-Lamp

The 3-lamp model (Figure 18) shows a somewhat linear input power trend with input signals from 8.5 Vdc down to 1.5 Vdc. The lower deadband occurs at 1.5 Vdc and below. The upper deadband occurs at 8.5 Vdc and above.
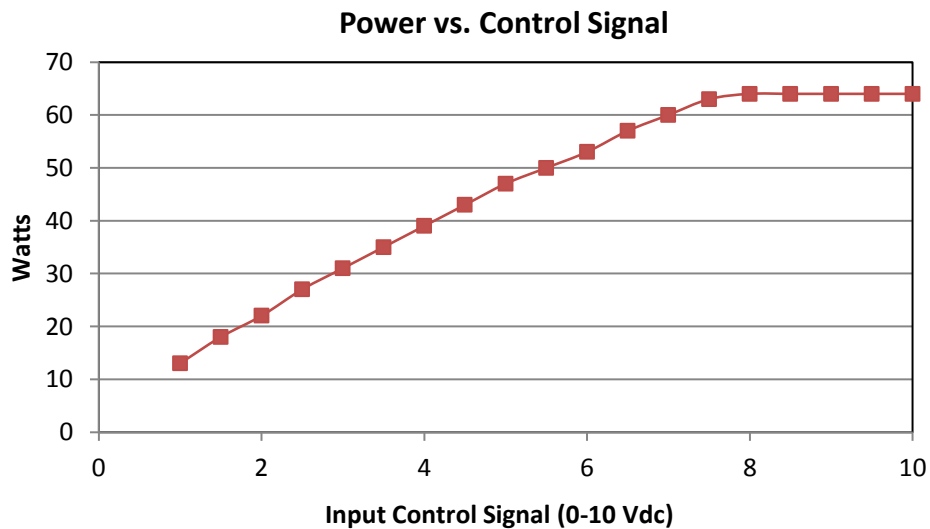
Power vs. Control Signal
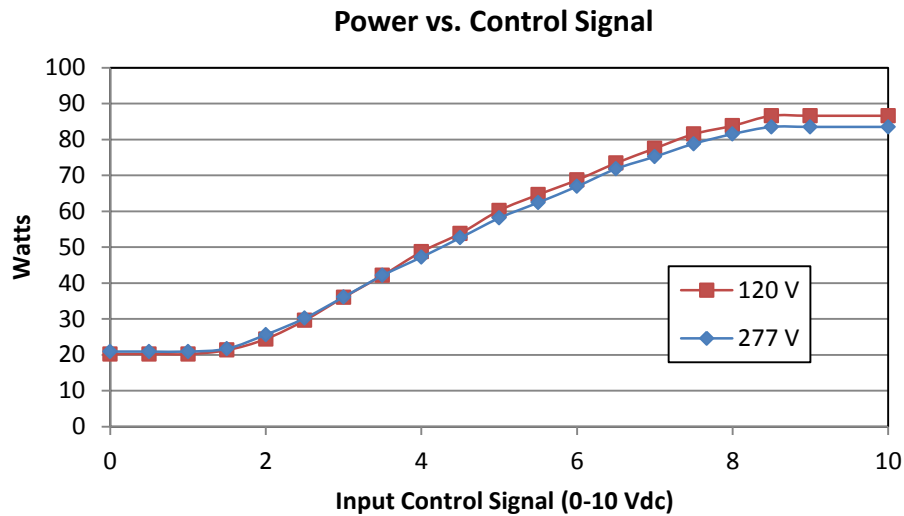
Figure 18: Company C Model 7: Power Input vs. Input Control Signal; 3-Lamp

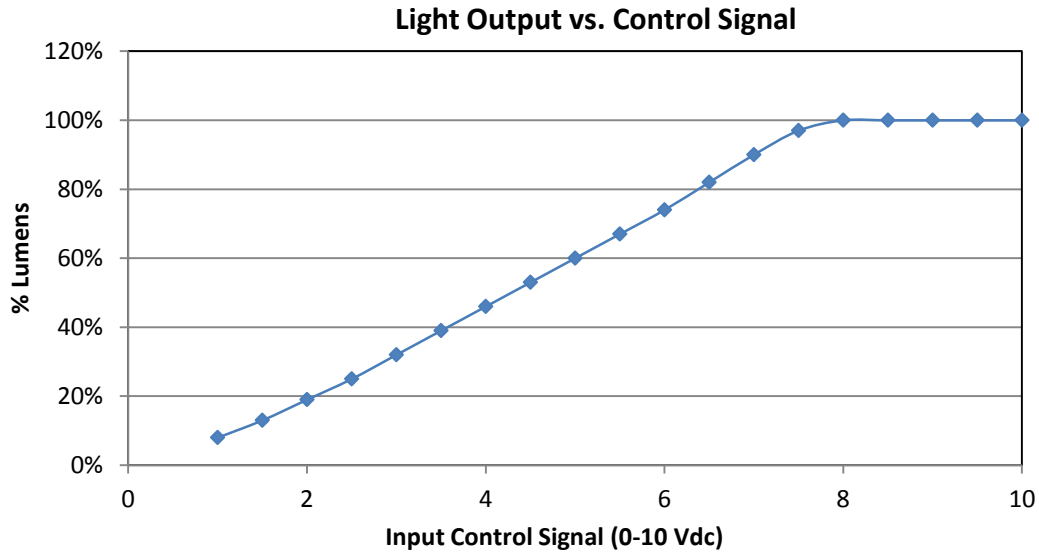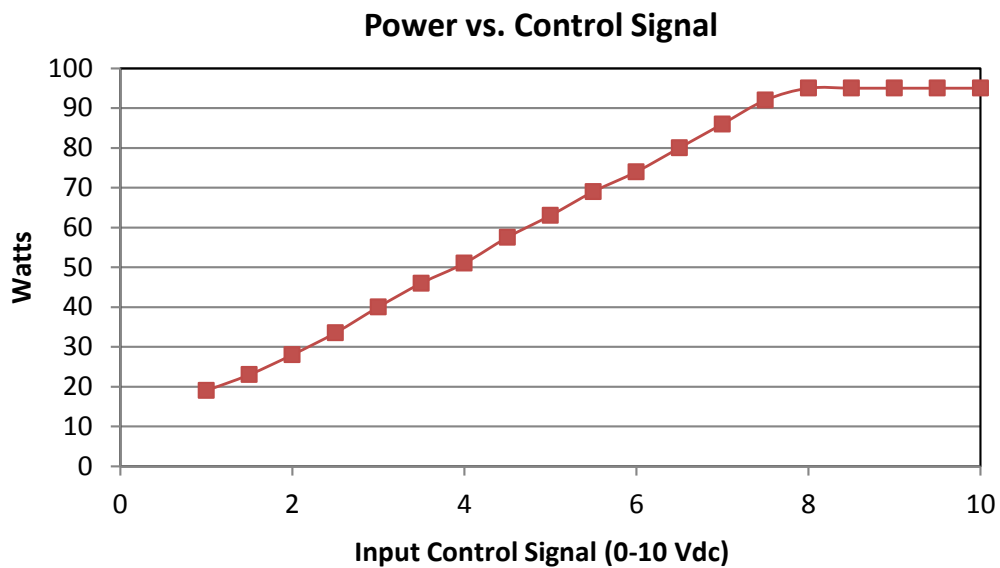The light output versus control signal data (Figure 19) show a somewhat linear light output trend with input signals from 8.5 Vdc down to 1.5 Vdc. Deadbands in the light output versus input signal occur below 1 Vdc and at 8.5 Vdc and above.

Light Output vs. Control Signal

Figure 19: Company C Model 8: Light Output vs. Input Control Signal; 3-Lamp

4.4   Company D

The four models from Company D are multiple 2-lamp and 3-lamp ballasts. Model 9 is a 2-lamp, dimming range from 100% to 3% ballast (Figure 20). It shows a somewhat linear input power trend with input signals from 8 Vdc down to 2 Vdc. The lower deadband occurs at 2 Vdc and below. The upper deadband occurs at 8 Vdc and above.

Power vs. Control Signal
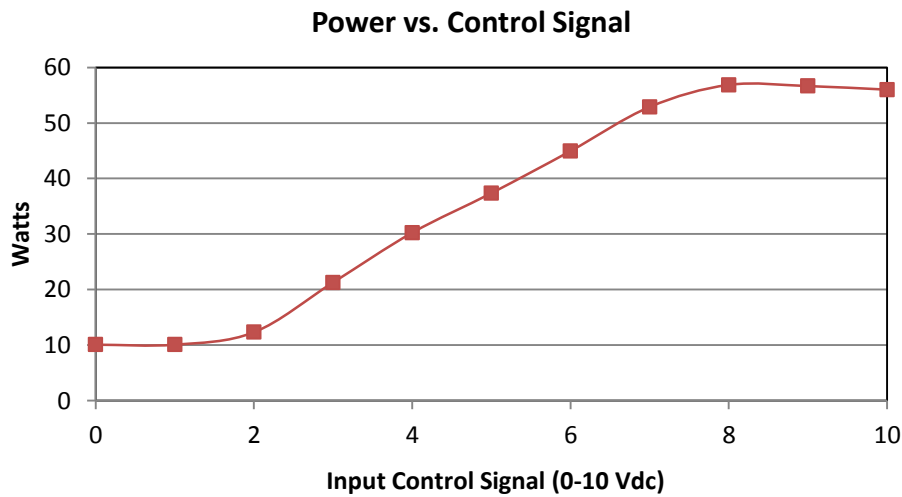
Figure 20: Company D Model 9: Power Input vs. Input Control Signal; 2-Lamp, 100%-3%

The light output versus control signal data (Figure 21) show a somewhat linear light output trend with input signals from 8 Vdc down to 1 Vdc. Deadbands in the light versus input signal occur below 1 Vdc and at 8 Vdc and above.
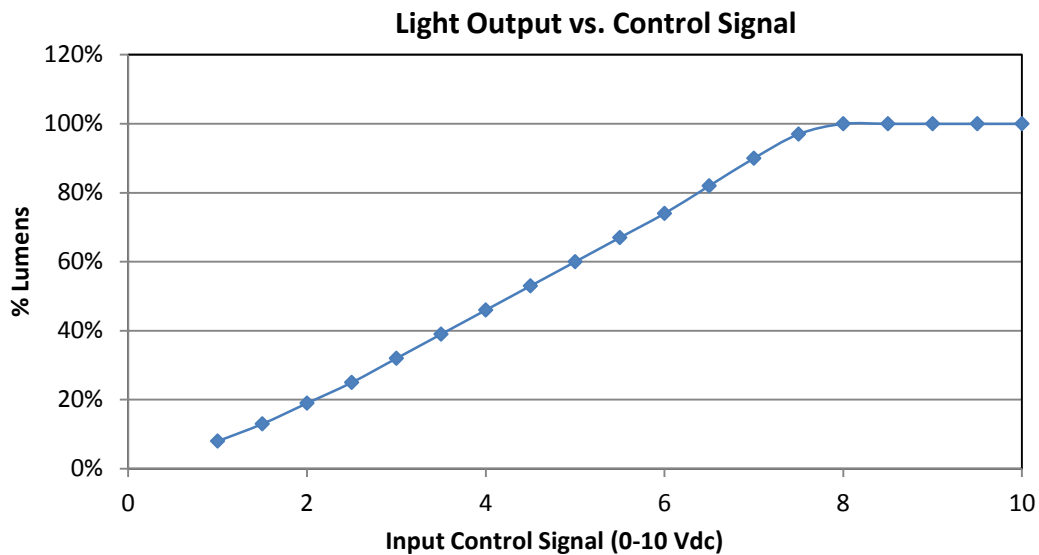
Light Output vs. Control Signal
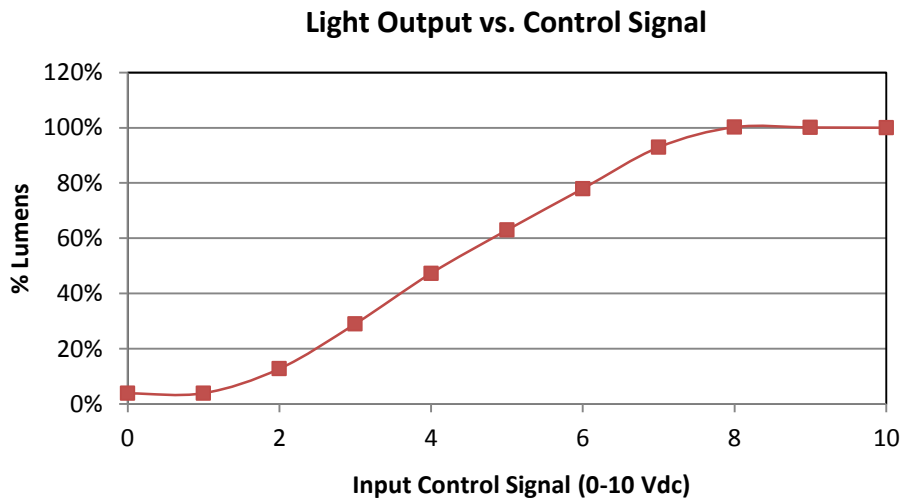
Figure 21: Company D Model 9: Light Output vs. Input Control Signal; 2-Lamp, 100%-3%

Model 10 is a 2-lamp, dimming range from 100% to 5% ballast (Figure 22). It shows a somewhat linear input power trend with input signals from 9 Vdc down to 2 Vdc. The lower deadband occurs at 2 Vdc and below.
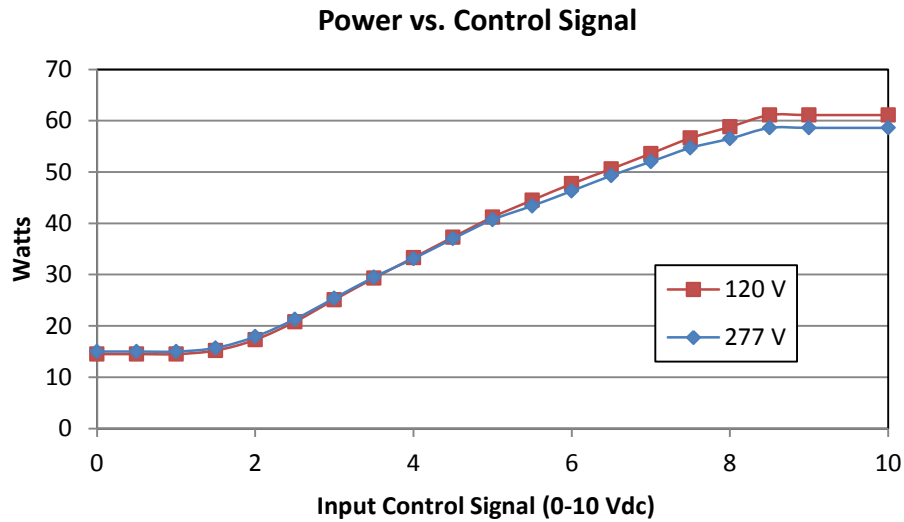
Power vs. Control Signal
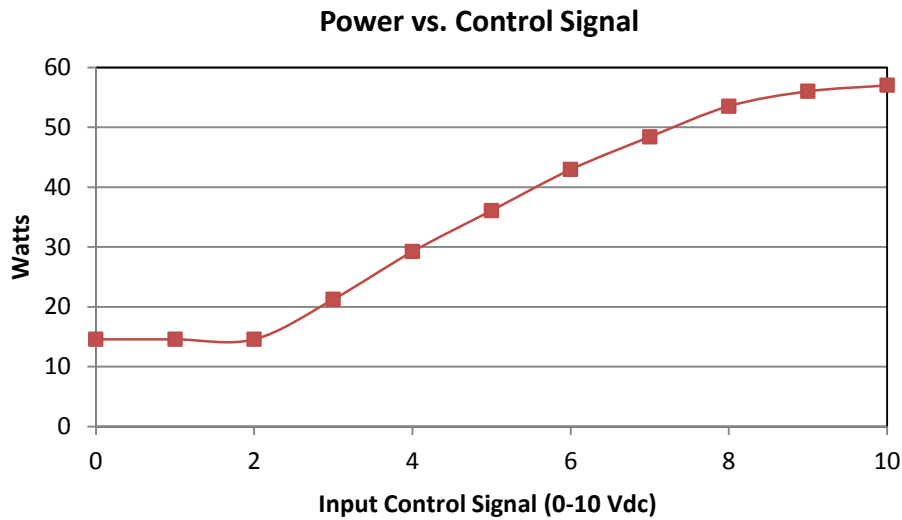
Figure 22: Company D Model 10: Power Input vs. Input Control Signal; 2-Lamp, 100%-5%

The light output versus control signal data (Figure 23) show a somewhat linear light output trend with input signals from 8 Vdc down to 2 Vdc. Deadbands in the light versus input signal occur below 2 Vdc and at 9 Vdc and above.

Light Output vs. Control Signal
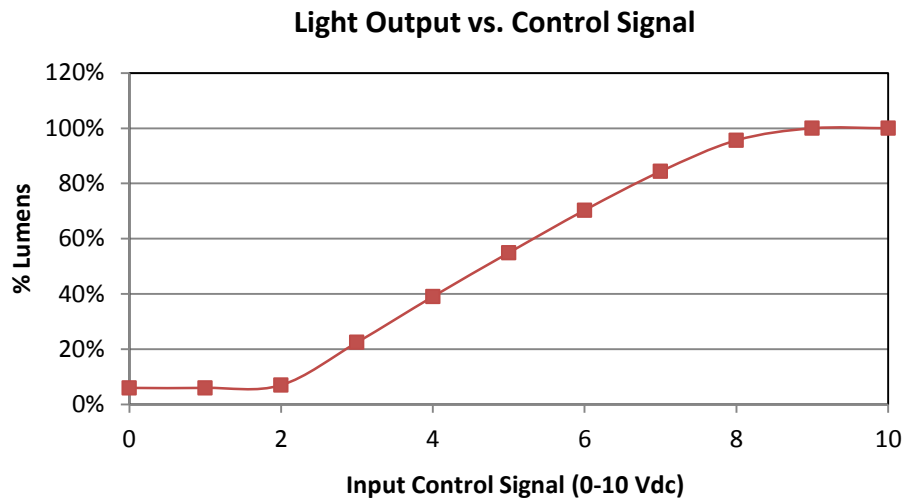
Figure 23: Company D Model 10: Light Output vs. Input Control Signal; 2-Lamp, 100%-5%

Model 11 is a 3-lamp, 120 V ballast, and model 12 is a 3-lamp, 277 V ballast. The manufacturer claims equal performance from both models (Figure 24). It shows a somewhat linear input power trend with input signals from 9 Vdc down to 0 Vdc. The upper deadband occurs at 9 Vdc and above.

Power vs. Control Signal
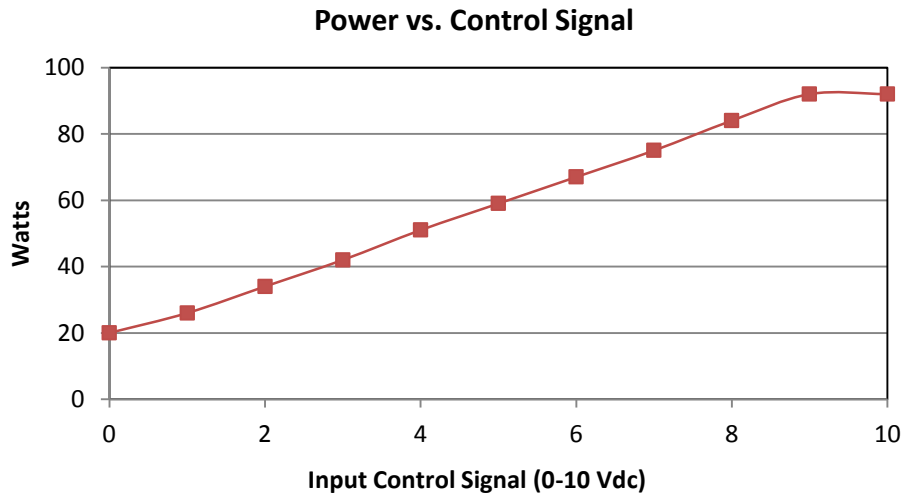
Figure 24: Company D Model 11 & 12: Power Input vs. Input Control Signal; 120 V & 277 V, 3-Lamp

The light output versus control signal data (Figure 25) show a somewhat linear light output trend with input signals from 9 Vdc down to 2 Vdc. Deadbands in the light versus input signal occur below 1 Vdc and at 9 Vdc and above.
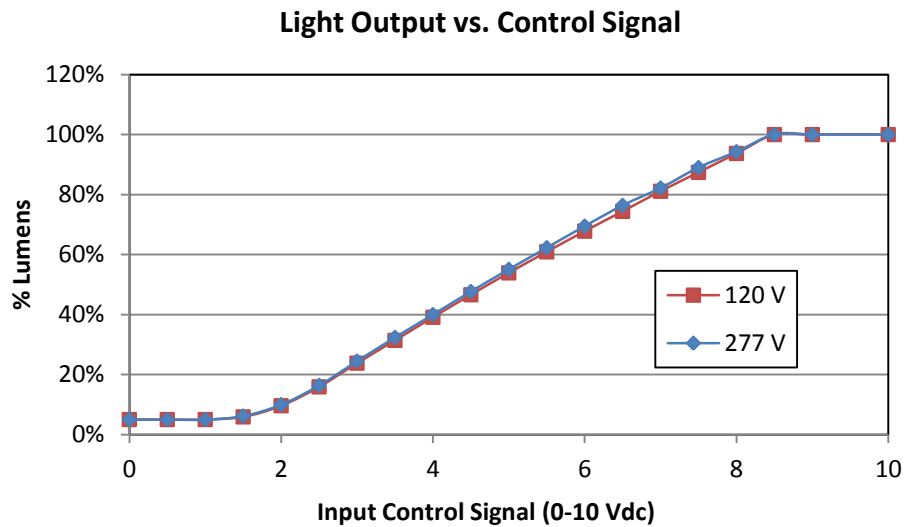
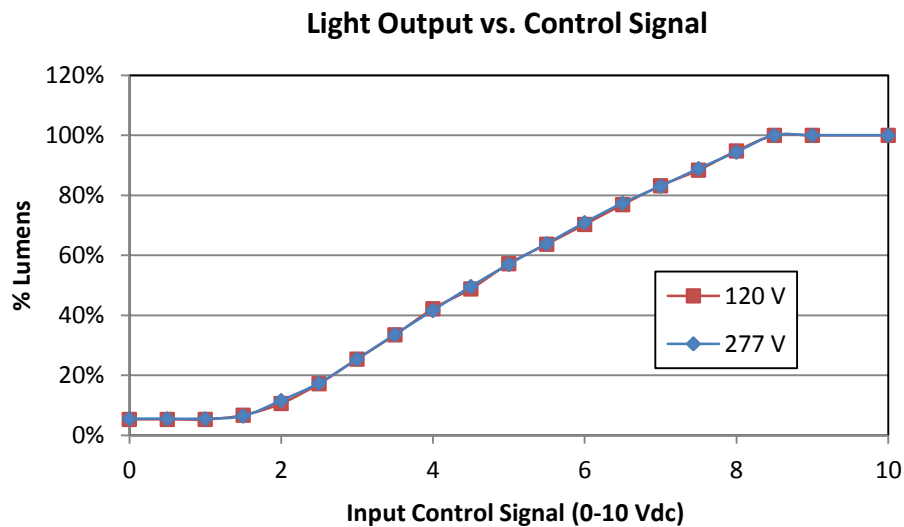**Light Output vs. Control Signal**
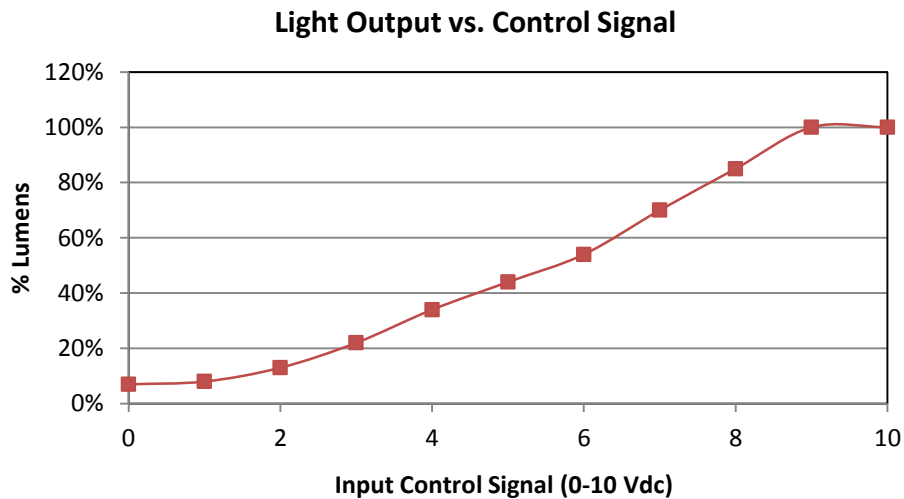
Figure 25: Company D Model 11 & 12: Light Output vs. Input Control Signal; 120 V & 277 V, 3-Lamp

4.5   Summary

The power and light output charts are summarized by plotting the ballast performance data for all the companies with comparable ballasts onto one chart. The power charts for the 2-lamp and 3-lamp ballasts are compiled and presented in Figure 26 and Figure 27 respectively. The light output summary data are shown for 2-lamp models in Figure 28 and for 3-lamp models in Figure 29.

Dimming Ballast Summary: 2-Lamp
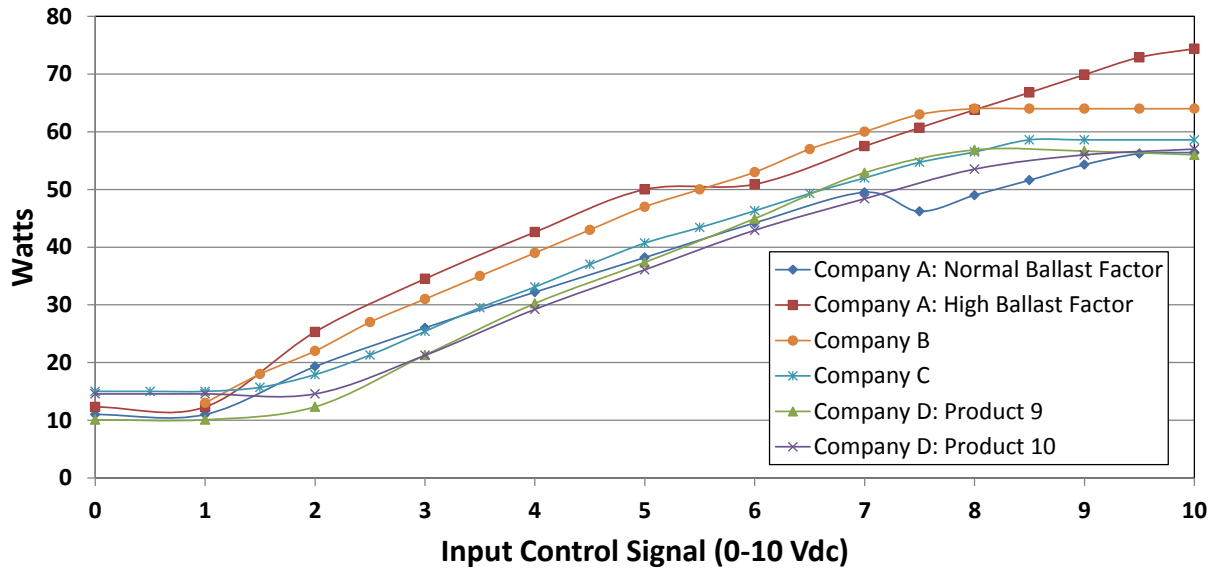
Figure 26: Summary for 2-Lamp, 277 V Dimming Ballasts

Dimming Ballast Summary: 3-Lamp
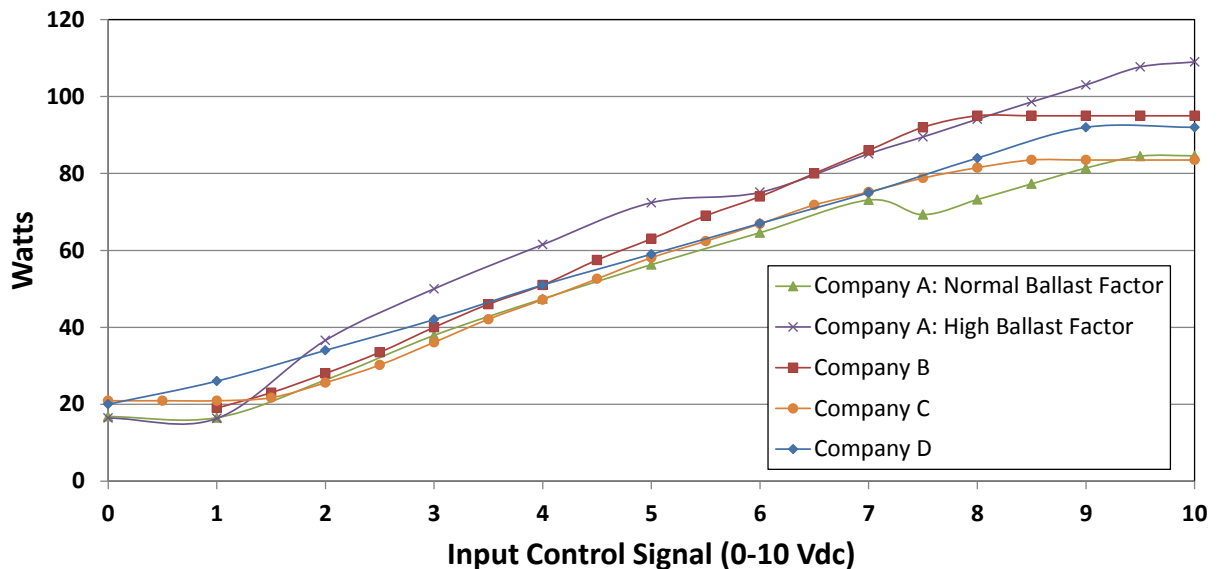
Figure 27: Summary for 3-Lamp, 277 V Dimming Ballasts

Light Output Summary: 2-Lamp
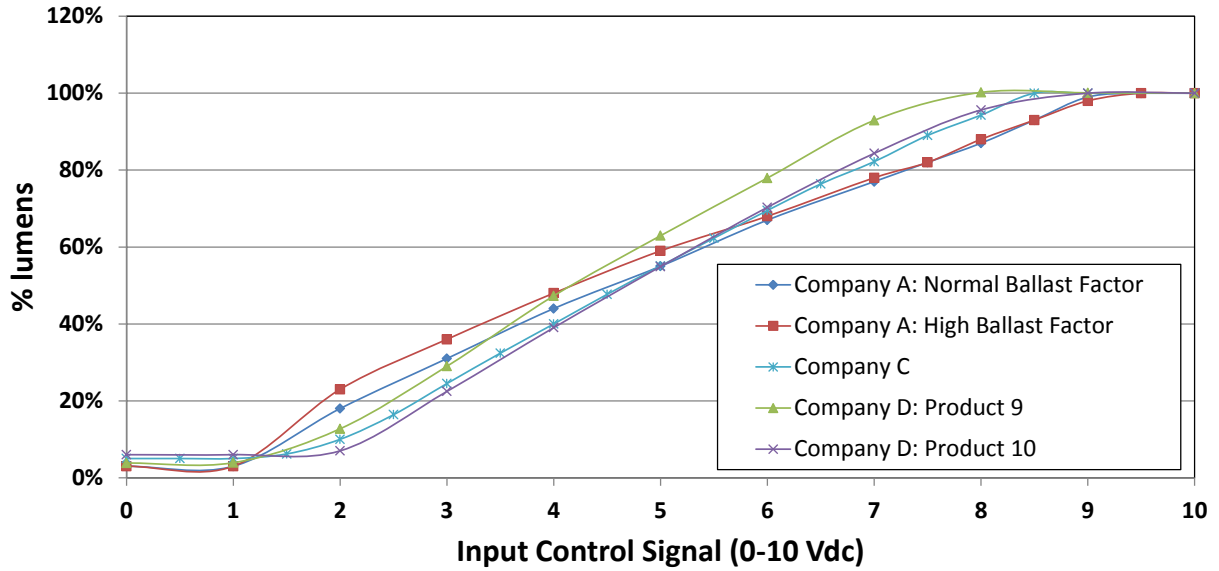
Figure 28: Light Output vs. Input Control Signal summary for 2-lamp models

Light Output Summary: 3-Lamp
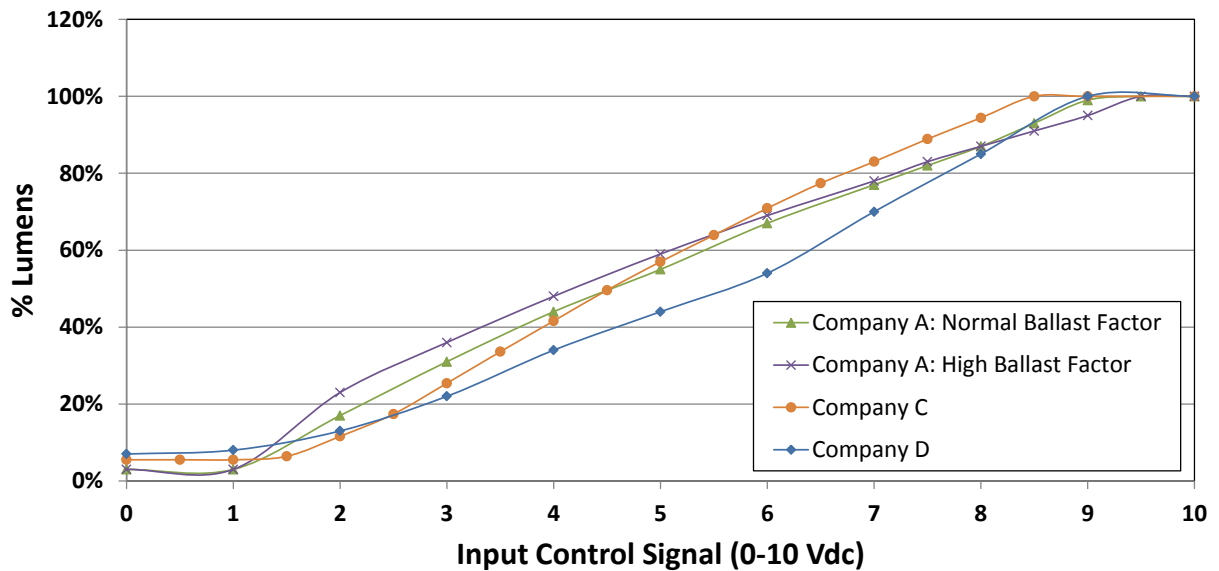
Figure 29: Light Output vs. Input Control Signal summary for 3-lamp models

5. Discussion

The anomaly in Brand "A" is attributed to the filament heating system. The lamp requires some amount of voltage to heat the filament. Some ballasts utilize two step lamp filament heating voltage steps called partial filament cut off. At full light output settings the input filament heating voltage can be set to the low setting. As the ballast dims to lower light levels, there is a point where the required voltage to heat the lamp filament is not met. At this point the ballast switches to the high filament heating voltage setting which is applied for the remainder of the curve. This point demonstrates an increase in input power for a dimmer setting. Other dimming ballasts have continuous filament heating voltage adjustment to meet precise filament heating requirements at the varying dimming ranges. These are characteristic of linear performance of input power and input control.

Brand "A" produces 4 ballasts out of the 12 listed from our market study. The list represents the majority of the market for ballasts that meet the criteria specifications. The performance anomaly seen in the products from Brand "A" span approximately one-third of the market.

Some lighting control systems account for ballast factor performance of specific brands of ballasts used with their system, although this could be problematic if ballasts are replaced with a different type in the future. Consumers should investigate the performance characteristics of a lighting system (lamps, ballasts, sensors, and controller) to understand how much energy savings they can expect for given conditions.

Company D has claimed equal ballast performance for both 120 V and 277 V systems. This assumption is not made by the other companies. Conducting independent tests will provide more conclusive data.

Light output versus input control signal is more consistent and linear across the brands than is power input versus input control signal. This is most likely due to manufacturers initially designing dimming ballasts to meet customer light level needs.

6. Conclusion

The new Title 24 Building Energy Efficiency Code standards will require dimming ballasts for efficient lighting control systems. This will lead to further interest in dimming ballast performance among the available brands. There is significant variability among the performance levels of dimming ballast products, and varying control signals do not always result in linear changes in power consumption. Although the trends of input signal to power consumption within the input control signal ranges of 20% to 70% are consistent with general expectations, there were some noteworthy findings:

- Almost all products exhibited control deadbands – instances where changes in the control signal voltage resulted in no corresponding changes in light output or power consumption. These tended to occur at the lowest settings (i.e. 0-2 Vdc) and at the highest settings (9-10 Vdc). One product (Brand B) exhibited a deadband in the range of 7.5 to 10 Vdc.

- Ballasts from one manufacturer (Brand A) exhibited a significant performance anomaly: the power consumption with an incoming signal of 7 Vdc was substantially higher than with a control signal of 8 Vdc. This is significant, as many users choose to use 70% of maximum output for energy conservation and demand response programs. The performance anomaly seen in Brand "A" products represents approximately one-third of the available market options (for products that met the criteria used in this study).

These findings indicate a need for careful review of ballast performance characteristics when developing specifications or choosing products for specific project applications. This is particularly necessary for electricians or control technicians tasked with commissioning lighting controls. A thorough understanding of fluorescent ballast performance characteristics and lighting control systems will be instrumental in achieving energy savings and end user satisfaction.

7. References

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[2] California Energy Commission, "2013 Residential Building Energy Efficiency Standards Measures Summary," California Energy Commission, 6 March 2013. [Online]. Available: http://www.energy.ca.gov/title24/2013standards/2013-03-12_Changes_for_the_2013_Update_to_Building_Energy_Efficiency_Standards.pdf.

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8. Appendix

8.1   Data Tables: Company A

Table 3: Company A Model 1: Data Points; 2-Lamp, Normal Ballast, 32 W

	Input Watts 120V	Input Watts 277V	BF	% Lumens	Control Voltage
	57.7	56.4	0.88	100%	10
	57.7	56.2	0.88	100%	9.5
	55.6	54.3	0.86	99%	9
	52.7	51.6	0.81	93%	8.5
	49.9	49	0.77	87%	8
F32T8	47.1	46.2	0.73	82%	7.5
	50.4	49.5	0.68	77%	7
	44.4	44.2	0.59	67%	6
	38.5	38.2	0.49	55%	5
	32.4	32.2	0.39	44%	4
	26.1	26	0.28	31%	3
	19.2	19.3	0.16	18%	2
	10.2	11	0.02	3%	1
	10.3	11	0.02	3%	0

Table 4: Company A Model 2: Data Points; Model 2, High Ballast, 32 W

	Input Watts 120V	Input Watts 277V	BF	% Lumens	Control Voltage
	76.4	74.4	1.17	100%	10
	75	72.9	1.15	100%	9.5
	71.5	69.9	1.11	98%	9
	68.3	66.8	1.06	93%	8.5
	65	63.8	1.01	88%	8
	61.7	60.7	0.96	82%	7.5
F32T8	58.5	57.5	0.91	78%	7
	51.6	50.9	0.80	68%	6
	50.4	50.0	0.69	59%	5
	42.8	42.6	0.56	48%	4
	34.8	34.5	0.42	36%	3
	25.6	25.3	0.26	23%	2
	14.3	12.3	0.03	3%	1
	14.2	12.3	0.03	3%	0

Table 5: Company A Model 3: Data Points; 3-Lamp, Normal Ballast, 32 W

	Input Watts 120V	Input Watts 277V	BF	% Lumens	Control Voltage
	86.9	84.6	0.89	100%	10
	86.8	84.5	0.89	100%	9.5
	83.7	81.4	0.86	99%	9
	79.4	77.3	0.81	93%	8.5
	75	73.2	0.77	87%	8
	70.8	69.3	0.72	82%	7.5
F32T8	74.6	73.1	0.68	77%	7
	65.9	64.6	0.59	67%	6
	57.1	56.3	0.49	55%	5
	48	47.4	0.39	44%	4
	38.3	37.9	0.28	31%	3
	26.9	26.3	0.15	17%	2
	15.8	16.5	0.03	3%	1
	15.9	16.8	0.03	3%	0

Table 6: Company A Model 4: Data Points; 3-Lamp, High Ballast, 32 W

	Input Watts 120V	Input Watts 277V	BF	% Lumens	Control Voltage
	112.8	109	1.17	100%	10
	111.3	107.7	1.15	100%	9.5
	105.9	103	1.10	95%	9
	101.3	98.6	1.06	91%	8.5
	96.3	94.1	1.02	87%	8
	91.5	89.5	0.96	83%	7.5
F32T8	86.7	85.1	0.91	78%	7
	76.6	75.1	0.80	69%	6
	73.3	72.4	0.69	59%	5
	61.8	61.5	0.56	48%	4
	50	50	0.43	36%	3
	36.3	36.6	0.27	23%	2
	20	16.3	0.08	3%	1
	15.2	16.4	0.03	3%	0

8.2 Data Tables: Company B

Table 7: Company B Model 5: Data Points; 2-Lamp

Control	Watts	Control	RLO %
10	64	10	100%
9.5	64	9.5	100%
9	64	9	100%
8.5	64	8.5	100%
8	64	8	100%
7.5	63	7.5	97%
7	60	7	90%
6.5	57	6.5	82%
6	53	6	74%
5.5	50	5.5	67%
5	47	5	60%
4.5	43	4.5	53%
4	39	4	46%
3.5	35	3.5	39%
3	31	3	32%
2.5	27	2.5	25%
2	22	2	19%
1.5	18	1.5	13%
1	13	1	8%
0.5		0.5	
0		0	

Table 8: Company B Model 6: Data Points; 3-Lamp

Control	Watts	Control	RLO %
10	95	10	100%
9.5	95	9.5	100%
9	95	9	100%
8.5	95	8.5	100%
8	95	8	100%
7.5	92	7.5	97%
7	86	7	90%
6.5	80	6.5	82%
6	74	6	74%
5.5	69	5.5	67%
5	63	5	60%
4.5	57.5	4.5	53%
4	51	4	46%
3.5	46	3.5	39%
3	40	3	32%
2.5	33.5	2.5	25%
2	28	2	19%
1.5	23	1.5	13%
1	19	1	8%
0.5		0.5	
0		0	

8.3   Data Tables: Company C

Table 9: Company C Model 7: Data Points; 2-Lamp, 32 W

CONTROL SETTING	277V				120V			
U_dc [V]	RLO [%]	P_in [W]	PF	THD [%]	RLO [%]	P_in [W]	PF	THD [%]
0.0	5.0	15.0	0.99	13.4	5.0	14.5	0.99	7.3
0.5	5.0	15.0	0.99	13.4	5.0	14.5	0.99	7.3
1.0	5.0	15.0	0.99	13.4	5.0	14.5	0.99	7.3
1.5	6.2	15.7	0.99	13.3	5.9	15.2	0.99	7.0
2.0	10.0	17.9	0.98	13.4	9.6	17.3	0.99	6.2
2.5	16.4	21.3	0.99	11.3	15.9	20.8	0.99	5.2
3.0	24.5	25.4	0.99	9.5	23.8	25.1	0.99	4.4
3.5	32.4	29.5	0.99	8.3	31.4	29.3	0.99	3.9
4.0	40.0	33.1	0.99	6.7	39.1	33.3	0.99	3.7
4.5	47.7	37.0	0.99	6.1	46.6	37.3	0.99	3.5
5.0	55.1	40.7	0.99	5.6	53.9	41.2	0.99	3.3
5.5	62.3	43.4	0.99	5.4	60.9	44.5	0.99	3.3
6.0	69.5	46.3	0.99	5.2	67.8	47.7	0.99	3.2
6.5	76.4	49.3	0.99	5.1	74.4	50.6	0.99	3.2
7.0	82.2	52.0	0.99	5.1	81.1	53.6	0.99	3.2
7.5	89.0	54.7	0.99	5.1	87.4	56.6	0.99	3.2
8.0	94.3	56.5	0.99	5.1	93.7	58.8	0.99	3.2
8.5	100.0	58.6	0.99	5.1	100.0	61.1	0.99	3.2
9.0	100.0	58.6	0.99	5.1	100.0	61.1	0.99	3.2
10.0	100.0	58.6	0.99	5.1	100.0	61.1	0.99	3.2

Table 10: Company C Model 8: Data Points; 3-Lamp, 32 W

CONTROL SETTING	277V				120V			
U_dc [V]	RLO [%]	P_in [W]	PF	THD [%]	RLO [%]	P_in [W]	PF	THD [%]
0.0	5.5	20.9	0.97	19.0	5.3	20.2	0.99	7.4
0.5	5.5	20.9	0.97	19.0	5.3	20.2	0.99	7.4
1.0	5.5	20.9	0.97	19.0	5.3	20.2	0.99	7.4
1.5	6.4	21.7	0.98	18.2	6.7	21.3	0.99	7.1
2.0	11.6	25.6	0.98	15.0	10.6	24.4	0.99	6.4
2.5	17.4	30.2	0.99	12.3	17.2	29.6	0.99	5.4
3.0	25.4	36.1	0.99	10.0	25.4	36.0	0.99	3.9
3.5	33.6	42.1	0.99	8.4	33.5	42.1	0.99	3.4
4.0	41.6	47.2	0.99	7.4	42.2	48.7	0.99	3.1
4.5	49.6	52.6	0.99	6.6	48.8	53.8	0.99	2.9
5.0	57.0	58.1	0.99	6.0	57.2	60.2	0.99	2.7
5.5	63.9	62.4	0.99	5.6	63.7	64.6	0.99	2.7
6.0	70.9	66.9	0.99	5.4	70.3	68.7	0.99	2.5
6.5	77.4	71.8	0.99	5.2	76.9	73.4	0.99	2.5
7.0	83.0	75.2	0.99	5.0	83.2	77.5	0.99	2.5
7.5	88.9	78.8	0.99	5.0	88.4	81.5	0.99	2.5
8.0	94.4	81.5	0.99	5.0	94.8	83.8	0.99	2.5
8.5	100.0	83.5	0.99	5.0	100.0	86.6	0.99	2.5
9.0	100.0	83.5	0.99	5.0	100.0	86.6	0.99	2.5
10.0	100.0	83.5	0.99	5.0	100.0	86.6	0.99	2.5

8.4   Data Tables: Company D

Table 11: Company D Model 9: Data Points; 2-Lamp, 100%-3%

Control	BF	Watts	Light Output
10	0.88	56.00	100%
9	0.88	56.65	100%
8	0.88	56.86	100%
7	0.82	52.89	93%
6	0.69	44.95	78%
5	0.55	37.37	63%
4	0.42	30.24	47%
3	0.26	21.28	29%
2	0.11	12.32	13%
1	0.03	10.08	4%
0	0.03	10.08	4%

Table 12: Company D Model 10: Data Points; 2-Lamp, 100%-5%

Control	BF	Watts	Light Output
10	0.87	57.00	100%
9	0.87	56.00	100%
8	0.83	53.52	96%
7	0.73	48.39	84%
6	0.61	42.93	70%
5	0.48	36.08	55%
4	0.34	29.21	39%
3	0.20	21.24	22%
2	0.06	14.56	7%
1	0.05	14.56	6%
0	0.05	14.56	6%

Table 13: Company D Model 11 & 12: Data Points; 3-Lamp

Control	BF	Watts	Light Output
10	0.88	92	100%
9	0.88	92	100%
8	0.75	84	85%
7	0.62	75	70%
6	0.5	67	54%
5	0.39	59	44%
4	0.3	51	34%
3	0.19	42	22%
2	0.11	34	13%
1	0.07	26	8%
0	0.06	20	7%