2.5 Conduct exploratory investigations and analysis of operational parameters required for each of the control technologies (occupancy sensors, photosensors, dimming electronic ballasts) in common commercial and industrial applications, such as private and open offices and warehouses.

Exploratory Analysis of Operational Parameters of Controls

A convenient way of analyzing control devices is to consider a device as a system of inputs and outputs. Inputs to control devices are usually sensors and commissioning set points, and the outputs are control signals that govern the operation of the controlled equipment. Once the inputs and outputs are identified, then the operation of the control device is described by how the inputs affect the outputs. The input/output relationships can either be logical relationships, continuous functional relationships, or a combination of the two. This type of analysis is effective for both small, local control systems such as an occupancy sensor in a room, and for large, distributed control systems where the outputs of devices such as occupancy and photosensors are used as inputs to higher-level building automation control systems. In fact, communication protocols for building automation systems, such as BACnet and LonWorks, are specified in terms of inputs and outputs. This report focuses on dimming ballasts, describing them in terms of inputs and outputs.

The information for this report was gathered from the publications cited as well as those listed in the bibliographies, and from manufacturers' web sites, conference seminars, product briefs and interviews with manufacturers.

Dimming Ballasts

Available inputs:

- 1-10V analog signal
- <0.5 volt standby signal
- Phase chop angle power line signal
- Digital control interfaces (DALI and SuperDim)

Outputs:

- Lamp power level
- Ballast status (e.g., lamp failure for DALI equipped ballasts)

Dimming Ballast Inputs

Control inputs to ballasts are divided into analog and digital categories. Within each of these categories, different signaling protocols and/or conventions are used. Digital control inputs to ballasts have only recently been introduced on the market and currently comprise a very small market share. There is, however, considerable interest in and backing by different ballast manufacturers for the DALI communication protocol for ballasts. (For a detailed listing of the strengths and weaknesses of the different ballast control interfaces see Task 2.9 below)

Currently, analog control interfaces for ballasts are the most widely available with 0-10V control interfaces being most common. The 0-10V interface was the first to be used when dimming electronic ballasts appeared on the market in the early 1990s. The control scheme itself dates back to the early 1970s where it originated in the theatrical lighting controls industry. In fact ANSI has recently approved a 0-10V standard for entertainment technology (Standard E1.3-2000). However, the implementation of 0-10V control in ballasts is different than that used in theatrical controls. ANSI Standard E 1.3-2000 even specifically states that the standard does not apply to fluorescent dimming ballasts. Ballast manufacturers themselves have not adopted a standard for commercial use at this time and it seems likely at this time that none will ever come about. As a result, consistent behavior across different ballasts types or manufacturers is not assured.

The main difference between the implementation of 0-10V control for ballasts and that used in the entertainment industry is that the ballast is capable of providing its own signaling voltage while other 0-10V devices require the signaling voltage to be provided by a separate controller. The benefit of having a device that provides its own signaling voltage is that it allows the use of very simple control devices that do not require their own power sources. For example, a 0-10V ballast can be dimmed by a simple variable resistor connected across the control wires. Compatibility problems arise when a ballast is connected to a controller that also supplies a signaling voltage. To work properly the controller must be able to conduct current from the higher voltage control wire to the lower voltage wire (sink current). If a controller cannot conduct current in this reverse direction, from the viewpoint of the controller, the ballast will keep the signal high and no dimming will take place.

A deficiency of 0-10V control for both ballasts and products covered by the Entertainment Industry standard is that the relationship between dim level and control voltage is not defined. As a consequence, consistent dimming behavior among different ballast types and ballasts made by different manufacturers is not assured. For example, a 5-volt signal for one ballast might result in a 30% dim level, while the same 5-volt signal might result in a 50% dim level for another manufacturers ballast. This is problematic for at least two reasons. First, it prevents the mixing of different ballast types within one control area, and second, it complicates the commissioning of dimming systems because each system must be individually calibrated for dimming response. Some manufacturers also provide for analog command regions within the 0 to 10V signal range. For example, a control voltage less than 0.3 volts might signal the ballast to shut-down. While these extensions might provide desirable features, they can also lead to compatibility problems with controllers not designed with these features in mind.

Another problem with the 0-10V conventions used by ballast manufacturers is that the signal levels are low and thus suspect to interference. Little, if any guidance is given by ballast manufacturers on proper cabling techniques to avoid interference, but anecdotal evidence suggests that control wires must be kept away from power lines and lamp leads, and that the total cable length is a concern.

As an alternative to 0-10V control, two-wire, or ac phase chop dimming is available. This analog approach uses the power lines for signaling. In this control scheme, the rise of the ac signal after each zero-crossing is delayed an amount of time (zero to 8.3 ms or one-half of the wave form period) which is related to the dim level. Delaying the rise of the ac voltage after each zero-crossing results in a lower rms ac voltage signal whose shape looks as if part of the waveform has been removed, or chopped. This chopping is inexpensively performed by solid-state switching devices such as triacs or silicon controlled rectifiers (SCRs). This technique is used for controlling certain electrical loads such as heater coils and incandescent lamps. Operating a non-dimming electronic ballast on a phase-chopped voltage could be damaging to the device, but electronic ballasts designed to accept such signals use the phase-chopped signal to set the output power to the lamps.

The major benefit of using power line phase-chop signals for dimming is that no additional wiring is needed to control dimming. For retrofit applications, dimming controllers can replace existing switches and the existing power lines carry both the power and the signal. A secondary benefit is that the signals are less sensitive to interference than low voltage analog signals.

An alternate way of using the existing power lines to carry control signals is by using a power line carrier signal (PLC) at a frequency much higher that than the 60 Hz power frequency. While somewhat successful for caring digitally encoded signals, such a scheme has not been used for analog control.

For digital control PLC communications have been around for many years, although they have not been very successful in commercial and industrial environments. From the start such systems have been plagued with interference problems and are now considered to be unreliable, except for residential use. Ironically, many of the interference problems are the result of electronic power equipment, such as electronic ballasts, on the same, or nearby circuits. The X-10 protocol for digital control using PLC signals is supported by some lighting equipment manufacturers although no ballast manufacturers are known to have incorporated this directly into their ballast designs.

Another digital communication protocol not supported by ballast manufacturers, but used for lighting equipment is the DMX-512 protocol. DMX-512 is used extensively in theatrical lighting control systems. It is a high-speed, wide bandwidth (250 kbytes/s) method of communication allowing up to 512 points of control per control loop. DMX-512 has not been incorporated directly into ballast designs, most likely because of the relatively high cost of adding such a high-speed communication interface. Also, the existing commands do not lend themselves well to architectural and energy saving applications.

The two digital interface control protocols that are directly incorporated into ballasts are the SuperDim protocol by Energy Savings, Inc. and the Digital Addressable Lighting Interface (DALI), originally conceived by Tridonic, a European lighting equipment manufacturer. Without going into all the details of the protocols, there are some important features that make these protocols useful for commercial lighting control.

Both protocols use two, isolated, low voltage control wires to carry control signals. Twisted pair wiring such as what is used for computer networking is commonly used for cabling. Both use a form of serial communication similar to the common and widely used RS232 method. Data rates are low, 2400 baud for SuperDim and 1200 baud for DALI. The use of relatively low signal rates indicates the need for a robust, low cost network over a higher speed network. Both protocols emphasize the need for both low cost and simple implementation.

The main barrier to overcome when setting up a ballast control network is finding an easy way of commissioning the system. To commission such a system the interconnected ballasts must be logically grouped together to realize different lighting scenes and energy saving strategies. With analog control, the grouping of ballasts is “hard-wired” when the ballasts and control gear are installed. This hard-wired approach could also be done with digital controls, but it would not take advantage of one of the main benefits of digital controls which is the increased flexibility that they offer. Realizing this increased flexibility means that the burden of commissioning has largely been shifted from the installer to a later user of the system. Having a system that can be easily reconfigured seems to be an important selling point of digital control systems over existing analog control systems.

SuperDim and DALI protocols make use of each ballast in a network a having unique address. With the SuperDim protocol a permanent, unique 28-bit address is assigned to every ballast at the time of manufacturer. Part of the commissioning process is then having the addresses of all the connected ballasts input to the controller. Though not mentioned in the communication protocol, ballasts by Energy Savings, Inc., make use of an optical sensing commissioning tool that is used to retrieve the addresses of ballasts by receiving a high frequency modulated light signal from the fluorescent lamps being operated by the particular ballasts. When so instructed, ballasts will output their addresses via high frequency light output modulation. The commissioning tool receives this information when aimed at the ballast of interest and relays the address information to the main controller. In this manner installed ballasts within luminaires can identified and grouped into logical zones for control without dismantling fixtures.

The DALI protocol handles addressing in a different manner. When so instructed, all DALI ballasts on a network will assign each oneself a randomly generated 24-bit address. The controller then determines each ballast’s address through an iterative trial-and-error process of trying different addresses until it gets a response. Once the addresses are all known, individual ballast locations can be identified by having the controller send signals to a particular ballast instructing the ballast to flash the lamps on and off, for example. If by chance more than one ballast has the same address, provisions are made for just those ballasts with identical addresses to repeat the randomization process.

Dimming Ballast Outputs

Lamp power level

Reducing the power delivered to a fluorescent lamp reduces the light output and effectively dims the lamp. Due to the operational characteristics of fluorescent lamps, power reduction must be done with at least two major provisions to keep the lamp from extinguishing and to preserve long lamp life.

- Maintain a sufficiently high voltage across the lamp to sustain the arc.
- Keep the electrodes properly heated so that they can supply sufficient free electrons to the discharge without being severely damaged.

For these reasons, a specially designed dimming ballast is required to effectively dim fluorescent lamps to levels less than about 70% of full light output.

The requirements of maintaining lamp voltage and electrode heating prohibit magnetic ballasts from being used successfully as dimming ballasts. While products are on the market that dim magnetic ballasts (e.g., panel-level dimmers), the dimming range is limited to about 50% of full light output. In addition, long operation times at a low dim level are likely to reduce lamp life.

High-frequency electronic ballasts have been successfully developed to dim fluorescent lamps to light output levels as low as 1% of full light output through the use of active electronic components that can dynamically change ballast-operating characteristics as the lamp is dimmed. Lamp voltage can be maintained even at low currents and supplementary electrode heating can be increased to maintain proper electrode heating as the lamp is dimmed.

Even though electronic ballasts are capable of dimming lamps to low power levels while preserving life, the supplemental electrode heating requirements, as well as the power requirements of the additional circuit components, reduce the overall system efficacy of dimming systems compared to non-dimming systems. This is clear from an analysis of the different electronic ballast types currently on the market.

Table 1 lists manufacturer-reported and National Lighting Product Information Program (NLPIP) test data on ballast factor and ballast efficiency factor for instant start, rapid start, and dimming ballasts. For each group of similar ballast type, the average ballast factor and average ballast efficiency factor is calculated. In the case of dimming ballasts, the ballast efficiency factor is for the full light output condition. For the same lamp type, and the same number of lamps operated per ballast, ballast efficiency factors can be directly compared to show relative system efficacy. All the ballasts in this analysis are two-lamp ballasts operating T8 lamps. To aid in comparing relative system efficacy, the group averages are shown as a percentage of the highest BEF group, in this case the instant start ballast group. Relative efficacies are also shown for the dimming ballast group at 40% and minimum light output levels calculated directly from NLPIP reported light output and system power measurements.

Table 1 shows that, on average, instant start ballast systems are about 5% more efficacious than electronic rapid start systems. This efficacy difference, combined with lower costs and similar lamp life performance, can explain why instant start electronic ballasts constitute about 80% of electronic ballast sales based on U.S. census data.

When instant start systems are compared to dimming ballasts, the discrepancy in efficacy increases to about 9%. Consequently, from an energy point of view, the average power reduction from dimming would have to be nearly 10% just to break even on energy consumption if dimming ballasts were used in place of instant start electronic ballasts. In other words, the user would get 10% less light from a dimming system than from an instant start system for the same energy usage.

Most dimming ballasts show a linear relationship between light output and dim level. (See Figure 1 from NLPIP Dimming Ballast Specifier report.) It is important to note that the curve showing this relationship does not intersect the origin, but rather it is offset to the right. This offset is due to a combination of lower lamp efficacies when operated at low power, and energy that is consumed by the ballast, which represents an increasing percentage of the total power consumed by the system as the lamp is dimmed. Therefore, though linear with power, light output is not proportional to power, but shows diminishing returns as the light output is reduced. The data in Table 1 reveal this by showing the relative efficacies for dimming systems at 40% and at minimum light output levels. The relative efficacies for these conditions are 66% and 37%, respectively. The reduced efficacy at 40% light output gives only a 43% energy savings when the light are dimmed 60%. When compared to non-dimming instant start systems, the energy savings are only 40% for a 60% reduction in light output.

Because of the diminishing energy savings with dimming, dimming below about 20% of full light output is ineffective when dimming for energy savings. Below this level, the only way to get further substantial energy savings is to switch off the ballast.

Other dimming ballast outputs

In addition to lamp power output, digital addressable ballasts using the DALI protocol are capable of a limited form of two-way communication. While at present there doesn’t appear to be any clear energy-saving argument for two-way ballast communication, there are instances where feedback from the ballast could improve lighting quality. For example, failed lamps could be automatically reported to facility personnel.

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Table 1. Relative Efficacies of 2-lamp, T8 Electronic Ballasts by Type

Gray indicates NLPIP test results, otherwise manufacturer data

Instant Start

BF	BEF	BF	BEF	BF	BEF
1.23	1.57	0.87	1.49	1.17	1.53
0.87	1.50	0.78	1.52	0.91	1.54
0.89	1.55	0.77	1.48	0.78	1.53
0.87	1.55	0.79	1.52	0.79	1.56
0.86	1.53	0.88	1.52	0.88	1.50
0.87	1.47	0.90	1.49	0.87	1.54
0.89	1.55	0.89	1.50	0.88	1.49
0.87	1.50	0.88	1.52	0.77	1.51
0.87	1.54	0.89	1.56	0.77	1.55
0.90	1.53	0.88	1.52	0.88	1.51
0.90	1.54	0.89	1.53	1.18	1.55
1.18	1.55	0.88	1.49	1.16	1.57
1.08	1.41	0.88	1.53	0.88	1.49
0.80	1.51	1.18	1.49	0.91	1.54

Averages	BF	BEF	Relative Efficacy
	0.91	**1.52**	**1.00**

Electronic Rapid Start

BF	BEF
0.88	1.40
0.92	1.46
0.92	1.42
0.94	1.53
0.86	1.50
0.89	1.49
0.88	1.45
0.88	1.40
0.78	1.44
1.21	1.39

Averages	BF	BEF	Relative Efficacy
	0.91	**1.45**	**0.95**

Dimming Ballasts

BF	BEF	NLPIP Data Relative Efficacy 100%	40%min	
0.88	1.36	99	76	26
1.00	1.43	99	75	25
0.86	1.41	98	73	73
0.86	1.43	96	70	70
0.86	1.43			
0.74	1.29	85	58	17
0.85	1.33	93	42	40
0.91	1.34			
0.91	1.34	96	78	24
0.88	1.40	99	77	58
0.88	1.36	92	66	31
1.00	1.43	100	76	24

Averages	BF	BEF	Relative Efficacy	Relative efficacy at dim levels 100%	40%min. Level

0.89	**1.38**	**0.91**		**0.91**	**0.65**	**0.37**

Figure 1. Gray area shows range of relative light output (RLO) plotted against power demand for dimming ballasts tested for NLPIP Specifier Report: Dimming Electronic Ballasts (1999).