FINAL REPORT

REDUCING BARRIERS TO THE USE OF HIGH EFFICIENCY LIGHTING SYSTEMS

Submitted to:

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Prepared by:

Lighting Research Center

Rensselaer Polytechnic Institute

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Preface

Following is the first-year final report for the project, *Reducing barriers to the use of high efficiency lighting systems*. From the outset of this project (December, 2000) everyone agreed that the focus this project would be to identify barriers to the penetration of lighting controls into commercial-industrial (C/I) applications that employ fluorescent lamp technologies, and to recommend means for overcoming these barriers. This agreement was based upon the fact that C/I applications are the largest market segment and are dominated by fluorescent technologies. Moreover, “static” fluorescent technologies, such as T8 electronic ballast fluorescent systems, were well established in C/I installations and did not deserve special attention under this contract. Also, research conducted at the LRC shows that photosensors presently on the market had very low penetration and were of limited practical value as a cost-effective strategy for energy savings in C/I applications. The high cost of photosensor commissioning and poor energy savings are the main barriers to wide spread implementation of photosensors currently on the market. Under a separate contract, the LRC is developing a “self-commissioning” photosensor that should overcome these barriers. The “self-commissioning” photosensor project is offered as cost-sharing for the present contract. Thus, it was agreed that resources available under this contract with the USDOE would not be applied directly to photosensors. The results of our current studies on photosensor will, however, be included in our third-year final report.

Through the course of this study it was reaffirmed that payback from energy savings, per se, would not be enough to transform the market for controls in C/I applications. Purchase costs and installation/commissioning costs were significant barriers to penetration of all controls into C/I applications. Early in the project, however, peak load reduction became an important topic for discussion because the real cost of electric power is highly dependent upon the time-of-day when the power is required. Typically, the highest price for power is during hot summer days, reaching in New York City, for example, $1/W for several hours during the summer of 2000. Lighting controls for fluorescent systems were quickly seen as potentially important technologies for load management, because electric load for lighting can be modulated more quickly and with less disruption to occupants than other electric technologies. Consequently, a great deal of effort was expended under this contract to establish load-shed strategies and technologies for fluorescent systems. As a result of this concentration the LRC has received funding from two state agencies to support research on load-shed fluorescent systems. Moreover, this work is being performed in cooperation with major lamp/ballast manufacturers. As with the “self commissioning” photosensor project, these two load-shed projects are offered as cost-sharing for this project, and the results of our studies will be included in our third-year final report.

In the coming year, the project will be bifurcated into two areas: automatic shut-off controls and load-shed strategies and technologies. Much of the work to be done with automatic shut-off controls is related to the development of new programs to be undertaken by the market transformations groups. The LRC will help support these programs by providing a technical foundation for market transformation. In the area of load-shed strategies and technologies, the LRC will work with manufacturers, utilities (both regulated and unregulated), and large customers to develop technologies and markets for load shed management strategies.

The team for this project are: Andrew Bierman, Jennifer Brons, Mariana Figueiro, Claudia Hunter, Russ Leslie, and Mark Rea from the LRC, and Steven Purdy, who has been participating in the project as an independent consultant.

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Purpose of the project

The purpose of this project is to identify and seek to reduce the technology and market barriers limiting the wide acceptance and use of energy saving daylighting, electric lighting, and control technologies, including photosensors, occupancy sensors, dimming ballasts, and lighting control systems. The project is limited to fluorescent systems for C/I applications using lighting controls. The project will be conducted in three years, and there were three main tasks to be performed in the 1st year:

Task 1. Project Planning Meeting

Kick off meeting was held on December 13th, 2000. The meeting was held at the Lighting Research Center in Troy, NY. Tasks 2 and 3 were discussed in detail, since these two tasks were assigned for the first year of the project. All participants agreed on the scope of work to be performed during the first year of the project.

Task 2. Technology Assessment (photosensor, occupancy sensor, dimming ballast, control systems)

- Market Assessment
- Technology Assessment

Identify barriers limiting use and application of components and systems

- Develop draft Performance Criteria
- Develop peer review group

Task 3. Identify Manufacturing Partners

- Obtain commitment for participation
- Conduct a technical and market assessment review of the information obtained in task 2
- Develop, plan and host a roundtable to review activities conducted during the first year of the project.

Task 1 was detailed in a prior report. Task 2 was completed in October 2001. Below are reports on each of the sub tasks included in Tasks 2 and 3.

Task 2.1 – Conduct searches and reviews of latest technical and patent literature related to photosensor, occupancy sensor, and dimming fluorescent lamp ballast technology and communications systems protocols.

Review of Recent U.S. Patents Related to Lighting Controls and Fluorescent Lamp Ballast Technology

A review of the patents in a particular technology area is one method of assessing its status in terms of technological achievement. While patents may not provide answers on the significance of certain technological achievement, a counting and categorization of them provides a good indication of the amount of economic investment and activity in a given technology area. Patents cost money, including both application fees and the implied costs of defending one's patent rights when challenged by others. Therefore, we would expect to find that the areas of technology that are viewed in the business world as offering the greatest economic growth or activity would have the greatest amount of patent activity associated with them.

Of course patents are certainly not the only measure of economic activity in a technology area. Many technology businesses survive on trade secrets, or just knowing a better way of doing business. Patent activity does not indicate how successful a business is, or will be either, but without any intellectual property in a technology area, it is doubtful that any economic growth will take place.

With this in mind, a U.S. patent search was conducted in the technology area of lighting controls and fluorescent lamp ballasts. The purpose of the search was to was two-fold: to seek out newly developed lighting technology that looks promising for increasing the efficiency of lighting systems, and to get a better understanding of technological state of the lighting controls and ballast industry.

Method

The Delphion.com website, operated by Delphion, Inc., was used to conduct the search. Delphion is a spin-off company from IBM making use of the extensive former IBM patent database, as well as providing other intellectual property management and services. At the time when this information was collected, the full Delphion database appeared to be freely available for searching. The LRC used these free services.

The search covered patents granted within the last five years (1996-2001) for lighting control technology, and the last three years (1998-2001) for fluorescent lamp ballast technology. The ballast technology search was limited to the past three years to the reduce the relatively large volume of patents found in this area.

Searches were conducted by assignee, titles, and abstract fields using company names and/or a list of key control words. The list of company names and preliminary key words, organized alphabetically are given in Appendix 2.1 A. Additional product key words were generated as a result of a preliminary search of the technical literature using the IEEE Explore, Inspec, and Engineering Index Compendex databases.

Search Result Statistics

About 350 patents were flagged as meeting the search criteria and appearing to be relevant to lighting control technology and/or fluorescent lamp ballast technology. Abstracts of these patents were printed and reviewed to make sure they still met the search criteria, and to categorize them into more specific technology areas. Of the 350 printed patent abstracts, 271 were deemed germane to the topic. Most of the 80 eliminated from the first pass filtering were concerned with HID ballasts, emergency lighting and similarly sounding technology such as lighted indicator switches.

By far, most of the patents found are concerned with ballast technology; 172 of the 271 patents and this despite limiting the search for ballast companies and ballast key words to only the past three years. These 172 patents were categorized into the following groups:

- 133 dealt with lamp operation, including, but not limited to efficiency, safety (with respect to the newer, small diameter T-5 fluorescent lamps), power quality, starting, lamp life, and novel circuits and materials.
- 35 dealt with ballast control, including, but not limited to dimming, addressing, and on/off power schemes involving control elements within the ballast.
- 4 dealt with mechanical fixtures for ballasts and electrical connectors. This category was not eliminated because of the possibility that better connectors and fastening systems could help reduce installation costs; a well know barrier to introducing new more efficient technology.

The remaining 111 patents were concerned with lighting controls. This group was categorized into the following groups and subgroups.

- 61 dealt with lighting control components
    - o 22 on dimming and/or switching including panel-level control among others
    - o 26 on occupancy sensors
    - o 4 on photosensors
    - o 5 on combined sensor technology (e.g., combining a photosensor with and occupancy sensor)
    - o 3 on window treatments (all having same assignee)
    - o 1 on time clocks
- 30 dealt with energy management systems including, but not limited to home automation products and schemes, control networks and methods of communication.
- 8 patents were categorized as design patents. These patents concerned the embodiment of a specific product. For example, some of these patents were on the physical shape of a switch or dimming knob used in a wall dimmer.

All of the 271 germane patents are listed in Appendix 2.1 B. They are cross referenced by U.S. patent number, assignee name, and the above technology categories.

Preliminary Analyses

The fact that most of the found patents concern ballast technology indicates that this technology area has received far more economic attention then other areas involving lighting controls. The well-known ballast manufacturing companies (e.g., Motorola, Philips, GE, Magnetek and Howard) are all represented with patents, some more so than others. Interestingly, many patents in this area are also held by some very small companies, and even what appears to be private individuals. Most notably, Mr. Ole Nilssen of Barrington, IL, is represented with nine patents in the Ballast Operation category and one patent in the Ballast Control category. The question of whether such patents are important in any way is beyond the scope of this report, but it does signify that a lot research effort and/or legal claims are being pursued in the area of ballast technology, both by large companies and small.

A relatively small number of the ballast patents, 35, appeared from their abstracts to deal directly with control issues such as dimming, addressing and the integration of control logic into the ballast. Most of the patents in this category deal with specific circuits for dimming fluorescent lamps. The few that are concerned with addressing and the integration of control logic into the ballast tend to be represented in these results by smaller companies such as Energy Savings, Inc. and JRS Technology, Inc. Examples of this technology include ballasts with microprocessors that receive control signals and perform control functions to switch-off or reduce lamp power, and a “modular” ballast design that allows it to receive many different types of control signals from sensors and controllers.

Looking at the 111 patents concerned directly with lighting controls, it is again obvious where most of the economic attention has been within this area; energy management systems and panel-level controls, followed closely by occupancy sensor components. Only a total of 13 patents were found on photosensors, combined sensor technology, window treatments and time clocks combined. The lack of patents in these lesser-used control areas signifies that there is not much investment in these areas, economic or research. Occupancy sensing, manual dimming, and panel-level switching seem to be the types of controls most actively pursued by the lighting industry.

The occupancy sensor patents are concerned with circuit and sensing improvements and added features such as lower power consumption, two-wire installation, and use as security system component. The photosensor patents include a scheme for semiautomatic calibration, a dual-photosensor feedback system, a skylight photosensor system and a circuit for using photoconductive cells as linear detectors. The patents that describe combining different sensors most often combine a photosensor with an occupancy sensor. One adds a dimmer and a thermostat to the combination. One patent describes a method to control lights from a remote desktop device.

The category of patents on dimming and switching can be further divided into three groups; one dealing with incandescent type dimming (e.g., phase chopping or triac dimming circuits), one concerning panel, or multi-zone controls and one concerning dimming of fluorescent lamps. Lutron Electronics Company has many patents in all these areas. Some of the panel-level and multi-zone control patents are closely related to the building energy management system patents and make reference to their use in building automation systems.

Of the 30 patents dealing with energy management systems, eight have the word “home” in the titles and are not directly relevant to the commercial and industrial marketplace. Assignees of these patents include names such as Microsoft, IntelliNet, Inc., and Samsung Electronics Co., Ltd. Nevertheless, as far as the base technology is concerned, the technology and concepts used in home systems could likely be used in commercial and industrial settings as well. It is interesting that, because the home is a different market, it involves different companies than those traditionally associated with building control. The influx of new players in the building automation industry portends continued innovation in this area.

Breaking down the building automation patents into subcategories is difficult because there is not always a clear distinction between the different aspects of building automation. For example, software permeates all levels, but some patents deal more specifically with the software that others. Keeping this in mind, a somewhat subjective breakdown yields the following results:

- 10 appeared to deal with user interface and software issues
- 9 dealt with system-level designs
- 8 to concerned the physical communication layer
- 2 dealt with incorporating various sensors into the network
- 1 dealt with communication protocols

Johnson Controls Technology Company has a series of 6 patents all dealing with building automation control software. Terms such as “distributed-object” and “object oriented” and “standard-object” are used in the titles signifying that the recently developed, high-level software programming architectures are being incorporated into building automation systems.

Of the eight patents concerning the physical communication layer, three employ power line carrier schemes and one employs a dedicated fiber optic carrier. A patent on “distributed intelligence,” assigned to Echelon Corporation, is also included in this group.

Hubble Corporation and Leviton Manufacturing Co., Inc., are the assignees for the two patents concerned with sensors. Both patents describe a multifunction sensor on a network having at least occupancy, ambient light level, and temperature sensing functions.

The appearance of only one patent dealing with communication protocols seems at first contrary to expectations. This result might reflect the inadequacy of this search, or the difficulty of placing these types of patents into the above categories. Patents that deal with communication methods and protocols in general are beyond the scope of this search, even though they might be applicable to building automation. On the other hand, the lack of patents found in this area having to do with lighting controls might be a reflection of the trend within the controls industry to gravitate towards “open systems” that use existing, open communication protocols.

Task 2.2 – Identify current controls manufacturers (occupancy sensors, photosensors, dimming electronic ballasts, and appropriate building control systems) and obtain up-to-date data on relevant new and existing technologies.

Please see Appendix 2.2 A.

Task 2.3 – Develop a list of these manufacturers and their control products (ballasts, photosensors, occupancy sensors, energy management systems) and which protocols they offer.

Please see appendix 2.3 A.

Task 2.4 – Obtain samples and data sheets for relevant products and technologies where necessary.

Two binders containing the data sheets for relevant products and technologies were submitted to Ron Lewis, Program Manager at USDOE, email: ronald.lewis@hq.doe.gov, on May 22, 2001. Please refer to these binders for information.

Task 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 occupancy sensors, photosensors, and 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.

Occupancy sensors

- Available sensor inputs:
    - Passive infrared (PIR)
    - Ultrasonic
    - Acoustic
- Other inputs:
    - Sensitivity adjustments (for PIR and ultrasonic)
    - Time delay
- Outputs:
    - On/off power relay
    - Bi-level switching on/off power
    - Low voltage logic signal (to be used a an input for another controller)

Input sensing technologies

Three sensing technologies are used in occupancy sensors for commercial and industrial lighting applications: PIR, ultrasonic, and acoustic. Products are available that use either PIR or ultrasonic, or a combination of ultrasonic or acoustic with PIR sensing. The latter are referred to as "dual technology" products.

Passive Infrared

PIR sensors respond to movement of infrared sources, such as human bodies in motion. A patterned IR transmitting lens is placed in front of a pyroelectric detector that is sensitive to the infrared blackbody radiation emitted by objects at a temperature near and around human body temperature. The patterned lens, typically of Fresnel design, focuses radiation from adjacent wedge-shaped areas of the room onto the detector. As an IR radiating object moves in and out of each segment of coverage, the signal strength received by the detector changes, signaling the detection of movement. Newer designs use a dual-element pyroelectric detector with the elements connected in series with opposite polarity. Changes in the room temperature then do not affect detection, because for static objects, both elements receive the same signal and cancel one another due to the opposite polarities of their electrical connections. The coverage area and sensitivity of a PIR sensor is greatly affected by the type of patterned lens used. Different lens designs are suited for different applications. An overall wide field of view combined with many narrow field of view segments is used for room occupancy sensors, while fewer, larger segments with an overall narrower field of view are used for corridors to maximize to length of the coverage area.

Advantages

Passive detection does not emit any potentially harmful or interfering signals. It offers the possibility of consuming very little energy to operate (potential for battery operation).

Limitations

Historically, PIR sensors have had trouble detecting small hand movements. The size of movement for reliable detection depends on the number and size of each wedge-shaped field of view segment that is focused onto the detector. The smaller the segments, the smaller the differential signal strength as an object moves. This places a limitation on how small the segments can get for a detector of a particular sensitivity. PIR sensors must have an unblocked line of sight to detect motion. Room partitions and furniture can prevent PIR sensors from detecting motion. PIR sensors are most sensitive to movement perpendicular to the direction of the sensor, as this type of movement cuts across the wedge-shaped segments. Sensitivity is lowest for objects moving directly towards and away from the sensor.

Ultrasonic sensors

Ultrasonic occupancy sensors are active devices that must emit ultrasonic sound energy at a frequency typically in the range from 25 to 40 kHz, at sound pressure levels in excess of 90 dB (0.63 Pa). Motion is detected by sensing the Doppler shift in the frequency of reflected sound waves when reflected off moving objects.

Advantages

Ultrasonic sensors cover the whole volume of the space. A direct line of sight is not required for motion detection, and motion can be detected around partitions such as inside office cubicles and lavatory stalls. Ultrasonic sensors are more sensitive to small movements than PIR sensors.

Limitations

Emission of relatively high levels of ultrasonic sound energy raises health concerns for long-term exposure, even though most sensor companies claim that their products emit less energy than the safe exposure limits set by organizations such as OSHA and the World Health Organization (WHO). Ultrasonic devices require up to 0.5 watts to generate the ultrasonic signal, so battery operation is not practical. They are also sensitive to air movement as well as body movement; therefore, HVAC system operation can cause false triggering.

Acoustic sensors

Acoustic sensors are passive devices that respond to sound pressure levels in a space; i.e., a microphone. In commercial and industrial products, these sensors are not used for primary detecting, but rather are used in combination with PIR sensors to reduce the occurrence of false off-triggers. That is, a PIR occupancy detector equipped with an acoustic sensor will only switch off the lights after a period of time during which both the PIR sensor and the acoustic sensor do not indicate occupancy.

Advantages

Simple passive device.

Limitations

Since ambient noise levels in buildings vary greatly, and acoustic sounds can travel quite far, acoustic sensors cannot differentiate sounds generated inside a space from sounds generated elsewhere. Also, occupancy does not necessarily generate sound, which would lead to annoying false off-triggers in a quiet space. These facts limit the application of this technology to a secondary role in occupancy detection.

Other inputs of occupancy sensors

To help reduce the occurrence of false triggers, occupancy sensors usually have sensitivity adjustments to fine-tune operation for specific room conditions. Recent designs are incorporating more sophisticated logic for automatically adjusting sensitivity. The incorporation of microprocessors in the devices makes these new features possible at competitive prices. Sensitivity adjustments can be triggered by at least three different inputs: ambient signal strength, time of day, and on/off state of the output.

Ambient signal strength

Having sensors automatically compensate for ambient signal strength helps the device distinguish between background “noise” and the more erratic signals generated by occupant movement. Instead of having one sensitivity setting that is a compromise between adequate sensitivity for detection and background “noise” rejection, certain sensors can dynamically adjust the signal level that causes a trigger. For example, the steady signal caused by HVAC air movement would cause the device to set a higher trigger threshold to avoid a false trigger. In the absence of a steady signal, when the HVAC system cycles off, the trigger threshold would lower, thereby increasing the likelihood of detecting occupancy.

Time of day

Sensors with microprocessors are also incorporating real-time clocks that provide a time-of-day and calendar-day input to the device. This information can be used to alter the sensitivity or trigger level of the sensor. Real-time clocks and sophisticated logic are now being combined in a form of artificial intelligence through which the sensor “learns” the daily and weekly routines of motion in the space and uses this information to dynamically adjust sensitivity and/or trigger levels.

On/off state of the output

A simpler kind of logic added to occupancy sensors permits different trigger levels to be assigned under different conditions. For example, a false trigger that turns off the lights when the room is occupied is a worse mistake than keeping the light on a few minutes longer when the room is unoccupied. Therefore, when the lights are on, a lower trigger level might be used to insure that the smallest of movements will keep the light on. On the other hand, when the lights are off, the trigger level might be set higher so that only a large movement, like someone entering the room, will trigger the lights to turn on.

Variable time delays for turning off the lights are another method used to avoid false off signals. Under one scenario, if the occupancy sensor erroneously switches the lights off while the room is occupied, the occupant will immediately make a large movement to switch the lights back on. The sensor could be programmed so that if a large signal is detected immediately after switching off the lights, the following time delay for switching off the lights for a second time might be extended. Similarly, the sensitivity could be increased, or the trigger level lowered to avoid future false off conditions.

The extent to which these different types of logic are used and how successfully they are implemented undoubtedly varies for different manufacturers. The above information was distilled from the claims manufacturers make in promoting their products and was not further verified. Nevertheless, the claims demonstrate that occupancy sensor technology for lighting products continues to be refined and developed.

Occupancy Sensor Outputs

The output from an occupancy sensor is a two-state binary signal: occupied or unoccupied. Such a signal can be directly connected to a power relay to switch lights on and off. Occupancy sensors for local control most often incorporate a power-switching relay right into the device, while others provide a logic-level signal that is connected to some other lighting controller.

While the signals from occupancy sensors are two-state, the output does not necessarily have to completely switch the light on and off. In many applications where a certain low level of illumination is always required, occupancy sensors are used for bi-level switching of the lighting. For example, occupancy sensors are used in warehouses to switch on the lights over individual aisles to provide high visibility for tasks such as reading labels, while the unoccupied part of the warehouse can remain at lower illumination levels.

Photosensors

- Available sensor inputs:
    - Illuminance (wide field of view)
    - Luminance (narrow field of view)
- Other inputs:
    - Sensitivity (gain)
    - Light level set point
    - Hysteresis (dead band)
- Outputs:
    - On/off power relay
    - Bi-level switching on/off power
    - Continuous dimming level (e.g. 0-10V)

Background

The input to a photosensor is optical radiation. Loosely speaking, the input is light, but because some photosensors respond to infrared (IR) and ultraviolet (UV) radiation as well, it is necessary to make a distinction between optical radiation that is visible light and other kinds of optical radiation. The response of a photosensor to optical radiation is fully described by the *spatial response* and the *spectral response*.

The spatial response describes the sensitivity of the photosensor to incident radiation from different directions—in other words, what the photosensor "sees" at different locations. Spatial response is analogous to a luminaire intensity distribution, but describes sensitivity instead of output.

The spectral response describes the sensitivity of the photosensor to optical radiation of different wavelengths. This is important because only a small part of the optical radiation spectrum is visible. Daylight and fluorescent lighting differ substantially in spectral composition. Daylight has a comparatively uniform distribution of energy over the near-UV, visible, and near-IR regions of the spectrum. Fluorescent lamps, on the other hand, have most of their output concentrated in the region of the spectrum where visual sensitivity is high. This is one reason fluorescent lighting is so efficient. Even though the exact spectrum of daylight changes depending on weather conditions, times of the day and season, as well as being affected by surrounding buildings and foliage, these differences are small compared to the relative differences in UV and IR content between daylight and fluorescent light sources. The greater UV and IR content of daylight, combined with the broader than ideal spectral response of most photosensors, makes most photosensors much more sensitive to daylight than to light from fluorescent lamps. A greater sensitivity means that a photosensor will respond as if more daylight were present than actually exists. This can lead to problems where precise switching or dimming levels need to be realized.

Illuminance sensors (wide field of view)

The signal produced from illuminance type sensors is useful for detecting ambient light levels. A wide spatial response corresponds closely to what an illuminance meter would measure.

Advantages

The advantage of a wide spatial response is that the optical signal sensed by the photosensor is representative of the illumination on the whole workplane, or over the entire room, when the sensor is located on ceiling. The optical signal is also less affected by normal activity in the room than for a narrow response sensor.

Limitations

The difficulty with a wide spatial response is that the ceiling illuminance does not usually correspond to the workplane illuminance as the balance between daylight and electric light changes. In fact, the ratio of ceiling to workplane illuminance typically changes by a factor of five or more in offices with vertical windows as the proportions of electric light and daylight change. However this non-correspondence in illuminance levels can be largely overcome by the photosensor control algorithm and the above advantages can be realized.

Luminance sensors (narrow field of view)

Not as common as illuminance type sensors, luminance sensors detect light from a particular direction and over a small field of view. They are used to detect brightness from a distant location; for example, to detect desktop luminance from a mounting position in the ceiling.

Advantages

The narrower the photosensor's spatial response, the more closely it responds to the luminance (brightness) of the surface at which it is aimed. The luminance of a surface, in turn, is directly proportional to the illuminance falling on the surface provided that the reflectance factor of the surface is constant. Therefore, provided that the reflectance properties of the surface do not change, a narrow spatial response can effectively track illuminance changes; the narrower the response, the better the tracking for a particular location.

Limitations

The narrower the spatial response, the smaller the sensor's field of view, so what the sensor "sees" may not be representative of the whole surface or workplane. Therefore, a narrow response makes the sensor very sensitive to changes in the reflectance properties of what it is viewing. In practice, the reflectance of the workplane is not constant, but changes depending on the activities going on in the room. Examples include a dark desktop that is sometimes covered with white papers, the colors of peoples' clothing, such as a white shirt versus a dark suit, and even rearrangement of the room's furniture.

Another limitation of a narrow spatial response is increased sensitivity to mirror-like, specular reflections off shiny surfaces. Illuminance on a surface is directly proportional to luminance only for diffusely reflecting surfaces. Most surfaces in a room are diffuse, but some, like a glass table top, can reflect overhead light directly back into the photosensor's field of view causing erratic performance. Specular reflections have proportionally less effect on photosensors with a wider spatial response.

Other Photosensor Inputs

The following inputs are set during the commissioning of photosensors. Depending on the type of output (on/off or continuous dimming), as well as the type of control algorithm employed in the particular device, one or more of these inputs will be available to the user. On some photosensor products, the sensitivity and certain set points are combined into one input that controls both together according to some programmed relationship.

Sensitivity (gain)

The spatial sensitivity and the spectral sensitivity of the photosensor characterize the optical gain. Electronic gain amplifies the weak signals from the photocell to practical signal levels. These two gain mechanisms (optical and electronic) determine the sensitivity of the photosensor. Sensitivity adjustments are required for open-loop sensors where the sensitivity adjustment determines the relationship between electric light levels and the sensed signal. For photosensors that do not have a sensitivity adjustment, or those that combine sensitivity with other set-point adjustments, the sensitivity alone can always be adjusted optically by the positioning of the photosensor. While positioning the photosensor differently for different sensitivities is an option, it not very practical and it certainly is not a systematic way of commissioning photosensors.

Set-points

The signal level that must be attained before an action occurs is known as a set-point. For photosensors, set-points determine the signal level at which lights will be switched, or at what light level dimming will start and/or end. The type and number of set-points that are employed in a photosensor depends on the type of control algorithm used. Simple, open-loop photosensors that switch lights on and off only need to have one set- point that determines the level at which the lights will switch. Often, two set-points are used, however, to give the switch some hysteresis, or a deadband, whereby the light switches on at a higher signal level than that which turns them off. This is to prevent unstable frequent switching when signal levels are near the set-point.

More complicated closed-loop control algorithms may employ several set-points, which might be measurements that determine sensor and task illuminance ratios used in the algorithm to determine the electric light level.

Photosensor Outputs

Photosensors fall into two main categories depending on the output. The most familiar and the most prevalent use of photosensor control is on/off control output which is used to turn lights on, or off, based on the light level detected. Far less prevalent is the continuous level output photosensor, which is used with dimming systems to dim the electric lighting level based on some dimming function or control algorithm.

The light-sensing element within a photosensor might be a photodiode, a phototransistor, or a photo-resistive cell. It is important to make a distinction between this, the photocell, and a complete photosensor device that includes additional circuitry to produce the desired output signal(s).

Photosensors for on/off control

Photosensors for on/off control work most effectively in applications where a large difference in light level exists between the on condition and the off condition. Photosensors for outdoor street lighting is such an example. The set-point at which the output is switched does not have to be precise due to the large difference in illumination levels between night and day. Photo-resistive sensing elements are commonly used in this application because of low cost and relatively simple circuit design. Photo-resistive sensors do not have a linear response with light, part-to-part consistency is poor, and they have a large temperature dependency. Taken together, these characteristics make precise action at specified set-points difficult. A further disadvantage of photo-resistive devices is that many common types use cadmium, a heavy metal that is considered harmful to the environment.

When switching at precise light levels is needed, silicon photodiode detectors are commonly used. Used in conjunction with an amplifier circuit, these devices offer very predictable and linear output that is stable with time and temperature. This allows switching at precise set-point levels. These types of detectors are useful for indoor applications where the overall range of acceptable light levels is orders of magnitude less than that encountered outdoors.

The output from an on/off sensor is a two-state binary signal. Such a signal can be connected directly to a power relay to switch lights on and off, or used as a low level logic-level signal that is connected to some other lighting controller.

Photosensors for dimming

Photosensor control for dimming is divided into two main types: open loop and closed loop:

Open loop

The photosensor does not respond to, or “see” the electric light that it controls. An example of an open-loop system is a photosensor mounted on the outside of a building that controls the electric light level inside the building. In such a case the photosensor is exposed only to daylight. The electric light level is determined from the daylight signal alone. In the case of on/off control, such systems can be designed to simply turn electric lights off when outside daylight reaches a predetermined level. In the case of a dimming system, a signal proportional to the outside daylight instructs the system to dim the electric light by an amount proportional to the amount of available daylight sensed by the photosensor. No feedback control is used for an open loop system.

The drawback of open-loop feedback control is that the system cannot compensate or correct for any changes in the light distribution that affects the constant of proportionality between interior light levels and outside daylight levels. For example, the system will not respond to the use of window blinds, so if the occupant draws the blinds to block direct sunlight, the system will not increase the electric light to compensate for the decreased daylight levels inside the room.

Closed loop

The photosensor senses and responds to the electric light that it controls. An example of a closed-loop system is a photosensor mounted on the ceiling of the room where the electric lighting is being controlled. In this case the photosensor is exposed to both the daylight and the electric light in the room. The sensing of the electric light forms a feedback loop.

Closed-loop systems use negative feedback to respond to changing conditions. Negative feedback is a means of error correcting or compensating whereby an increase in an input signal level causes a decrease in the output signal. Conversely, a decrease in input signal causes an increase in output signal. This is the desired action of photosensor control; an increase in the amount of light in the room causes a decrease in the electric light intensity, and a decrease of daylight causes an increase of electric light. The overall feedback loop of a photosensor system must be negative for proper operation. The control algorithm characterizes the negative feedback of a photosensor.

The amount of feedback can vary for different systems and different locations of the system components. In systems where the photosensor is mounted near a window, the feedback is proportionally less than in systems where the photosensor is mounted deep within the room. This is because near the window the proportion of daylight is greater than electric light and the photosensor “sees” proportionally less of the electric light that it is controlling. The opposite is true for a photosensor mounted deep within a room. The amount of feedback is also governed by room geometry and surface reflectances. A room with light-colored finishes will have a greater feedback gain than a room with dark-colored finishes. The gain caused by room geometry and surface reflectances combines with the optical and electrical gain of the photosensor to determine the actual signal level received by the photosensor.

Effect of photosensor output on light level

For dimming systems, the dimming ballast controls the electric light level based on input from the photosensor. The amount of dimming as a function of input signal is characterized by the dimming response function. For many dimming ballasts, the dimming response function is linear, meaning that it reduces the electric light level in proportion to the input signal. However, the active input dimming range is usually less than the specified range of input control voltage. For example, for a ballast with an input signal specification of zero to 10 V, dimming may actually take place over a more limited range from about 1.5 V (minimum light output) to 8.5 V (maximum light output).

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.

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

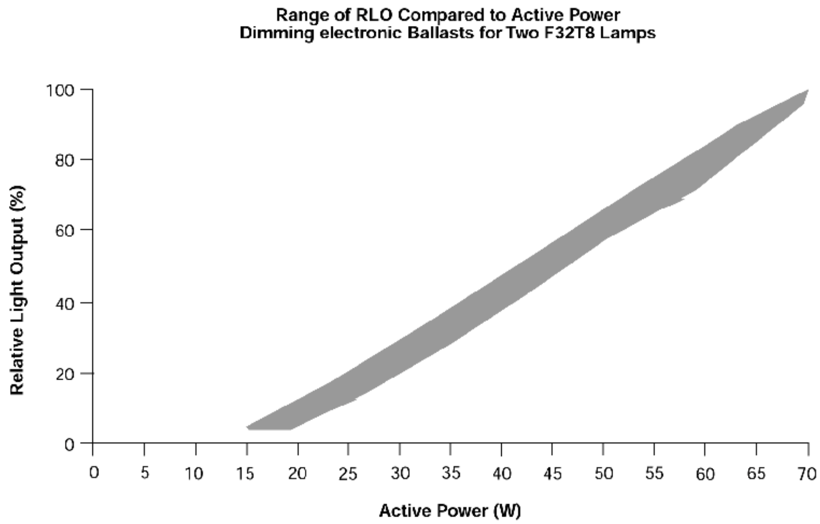

Figure 1. Gray area shows range of relative light output (RLO) plotted against power demand for dimming ballasts tested for NLPIP Specifier Report: Dimming Electronic Ballasts (1999).

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Task 2.6 – Protocol utilization share in commercial lighting applications

Lighting controls can be divided into local, central and two-way controls. Local controls allow users to control light levels in their working area. Central controls turn the lights on or off in large areas, such as whole buildings, whole floors, or large sections of an open plan area. The status of the lighting is not known. For a two-way control system, the ballast sends and receives information to/from a centralized computer and information about the status of the lighting can be determined.

There is no information available on the percentage of local, central, or two-way control installations in commercial/industrial buildings, but the last is certainly in the extreme minority. In addition, many buildings can have more than one type of control installation.

It is also very difficult to separate lighting control hardware and software when classifying lighting controls systems. A lighting control system protocol always implies a combination of hardware and software. Some types of hardware or software may be common to two different protocols, or the same hardware may be linked to two different types of software. Below is an estimation of the percentage of utilization of different protocols based on market observation and manufacturers' literature. The "trend" reflects the possible increase, decrease, or stability of the market penetration of a technology. These trends need to be put into perspective, however. According to lighting controls manufacturers, the market penetration of all lighting controls is approximately 2%.

Protocol	% Estimate	Trend	Comments
Ethernet	80%	Increase	A majority of control companies offer some means of interfacing with computer LANs to share information or allow for remote utilization of the system. As technology evolves, companies will use the Ethernet protocol closer to the device level replacing
RS-232	90%	Flat	Used by most companies as a method to connect peripheral devices, the majority of control systems provide RS232 connection at some point in their system. Due to distance limitations, protocol is not used for panel-to-panel connectivity.
USB	5%	increase	Due to changes in the computer industry, USB may replace RS-232 in the future
BACnet	65%	Increase	Appears to be gaining momentum as the protocol of choice for communication between subsystems.
LonMark –LonWork	35%	Flat to increase	Difficult to gage trend. Although most companies have invested in the development of systems, few lighting related companies actually introduced products. Widespread acceptance has been limited due to silicon costs and commissioning requirements.

Twisted Pair RS-422 RS-485	99%	Flat to decline	These protocols are defined primarily by their hardware characteristics. 2-wire communication methods are the dominant means to carry custom protocols. Although marked as declining it will be perhaps a few decades before the market truly changes
0-10V	85%	Flat to increase	The leading open protocol for dimming fluorescent lamp ballast. Most all architectural lighting control providers offer a connection to control 0-10Volt
DMX-512	99%	Flat	Control manufacturers participating in the theatrical lighting control segment implement DMX-512
Phase control	30%	Increase	Gaining momentum as the method of choice for lighting control retrofit applications and new installations were simple fluorescent lamp dimming control is required
X-10	5% -	Flat	Once seen as the technology with the most potential (early 80's). The X-10 powerline carrier technology protocol had difficulty maintaining momentum due to reliability issues with noise interference. X-10 is still used in residential and limited commercial applications.
ESI- SuperDIM			Digital fluorescent lamp ballast protocol recently introduced in the market. To soon to predict the acceptance level.
DALI			Digital fluorescent lamp ballast protocol recently introduced in the market. To soon to predict the acceptance level in the US. Protocol has been adopted as a IEC standard for Europe and has the support of top ballast manufacturers.

Protocol	Comments
ALC MODBUS Honeywell Johnson Controls N2 ETC Leviton LUTRON Lightolier Controls Watt Stopper / Horton	The large installed base of control equipment in both the HVAC and Lighting segments with companies to continue offering devices or bridges to existing protocols. Of the custom protocols listed Johnson Controls-N2 and Seimens-Modbus have the largest market share within the HVAC Segment and Lutron has the largest market share within the Lighting segment.

Task 2.7 – Review the types of whole building communication protocols used in the US including, but not limited to BACnet and LON Works.

There are a plethora of communication protocols used within the building controls market. Every control system manufacturer had proprietary protocols prior to the late 1980's. As open protocols emerged, most companies started to support them.

It is important to note that a majority of the protocols identified here did not meet the project criteria [commercial/industrial (C/I), fluorescent lighting systems] and therefore were not included in the evaluation. A significant number of protocols are focused on the residential control and home electronics market. Only protocols specific to commercial lighting controls are discussed.

Proprietary protocol information was not available for review; however, due to the market share controlled by the many manufacturers we included them in the following list.

Protocols identified during review process:

Open Protocols: Residential and Commercial

1394ta	5Ghz IAG	AHAM	BACnet
Bluetooth	CableLabs	CEBus	DSL Forum
DALI	EIB	ETI Alliance	Ethernet
Konnex	HiperLAN2	HAVi	HomeCNA
HomePlug	Home Plug & Play	HomePNA	HomeRF
Jini	Jetsend	LonMark -LonWork	OSGi
OFDM Forum	PLC	R7.1-R7.5	RS-232
RS-485	SC25/WG1	Salutation	SCP
SIA	SNMP	TCP/IP	Twisted Pair
UPnP	WAP Forum	WECA	WLANA
WGNA			

Lighting Related: Residential and Commercial

0-10V	ACN	DMX-512	ESI- SuperDIM
DALI	X-10		

Communication protocols meeting project requirements:

Building Control Communication Protocols (higher level):

OPEN

BACnet	LonWorks	SNMP	Ethernet

PROPRIETARY

ALC	Johnson Controls N2	Honeywell	MODBUS

Lighting Communication Protocols (higher level):

OPEN

Advanced Control Network (ACN)	DMX512	0-10V	X10	DALI	ESI superDIM

PROPRIETARY

GE	Douglas Controls	Horton/Watt Stopper	Ledalite
Leviton	Lightolier Controls	LUTRON	PCI
Sensorswitch			

It is important to point out that a majority of the C/I communication protocols used today for whole building communications evolved with a HVAC applications. Heating and cooling systems involve occupant control (feedback) combined with central building control. Lighting controls for the most part however, are usually only locally controlled loads using wall switches and control relays. Dimming control of fluorescent fixtures is usually confined to executive offices, conference rooms, and classrooms.

Task 2.8 – Investigate to what extent the whole building communication protocols are currently integrated with lighting system products.

LON works and BACnet have the most support from the lighting control manufacturers. Devices range from protocol translators through control devices fitted to support the protocol directly. Proprietary systems from Johnson Controls, Honeywell and Modicon have the second largest following.

Ethernet should receive mention as the dominating computer network protocol. Several controls manufacturers have devices that connect directly to Ethernet.

Summary of lighting control manufacturers and the communication protocol supported:

Item	Company Name	Supporting Protocol
1	ABB Control Inc.	Custom, BACnet, Modicon and LON
2	Advance Transformer	0-10VDC, 2-wire
3	Advanced Control Technologies Inc	LonWorks Independent Developer
4	Agilent Technologies	LAN/WAN Ethernet
5	Alerton Technologies, Inc.	BACnet, Modbus, Ethernet
6	Andover Controls Corporation	BACnet, Ethernet, LON
7	Architectural Lighting Management	DMX-512
8	Automated Logic Corporation	Supports all major communication protocols including BACnet, LON works, MODbus and SNMP.
9	Cooper Lighting	ESI digital protocol
10	Crestron	LAN/WAN/Internet connection
11	Cutler Hammer (Eaton)	X-10, CEBus, RS232, INCOM
12	Delta Controls Inc	BACnet and ORCAview
13	Douglas Lighting Controls Inc	LonWorks
14	Easylite	
15	Echelon Corporation	LON works
16	Electronic Theatre Controls Inc	DMX 512, ETCnet, ETClink, MIDI, BACNet, LON Works
17	Elk Products Inc	RS232, RS485, SIMPLE
18	Energy Savings Inc.	Digital - SuperDIM
19	GE Industrial Systems	Ethernet, MODbus, RS485/232, LON works

20	GE Lighting	See MagneTek
21	Genlyte - Lightolier Controls	RS232, RS485, BACNet, DMX512
22	H I Solutions Inc	LAN Ethernet, RS485
23	Honeywell	RS232, ARCnet, Ethernet, BACNet, Modbus, Allen Bradley Data Highway, Modbus plus, and a wide variety of other common protocols are available.
24	Horton Controls / Watt Stopper	LON works
25	Hubbell and Hubbell Lighting	0-10VDC, 2-wire
26	Hunt Controls Systems Inc	0-10VDC, 2-wire, ESU super dim
27	Johnson Controls Inc	BACnet, LON works, Ethernet and most other major protocols.
28	JRS Technology Inc	LON works, 0-10VDC
29	LEAX Lighting controls	LON works, DMX512, RS232, Analogue Input, Volt free, 2wire, DALI, 0-10VDC, DSI
30	Lehigh Electric Products	LON works, DALI, DSI, 1-10VDC
31	Leviton (LON products group)	0-10VDC, DMX512, LON works, BACnet
32	Leviton Lighting Control Division	LON works, BACnet, 0-10 VDC, LAN/WAN Ethernet
33	Lithonia Lighting (controls)	BACnet, DMX512, 0-10VDC, 10-30VDC
34	Lutron Electronics Co Inc	0-10VDC, 2-wire line voltage control, 3-wire line voltage control, DMX 512
35	MagneTek Lighting Products Group	0-10VDC, DMX 512, DALI
36	MYTEC Corporation	2-wire, 24VDC
37	NexLight	2-wire, BACnet
38	Novitas Inc	0-10VDC
39	Osram Sylvania/ Ballast Division	0-10VDC, DALI
40	Panja Inc	DMX512, Ethernet, BACNet
41	Pass & Seymour/ Legrand	2-wire
42	PCI Lighting Control Systems Inc	RS232, RS 485, DMX 512
43	PLC Multipoint Inc	Direct Serial RS232, FIBER OPTIC COMMUNICATION, LOCAL MULTI-DROP COMMUNICATION BUS

44	SensorSwitch Inc	1-10VDC
45	Siemens Building Technologies Ltd	BACnet, MODbus, LON works, DMX 512
46	Smart America	Ethernet
47	Square D Company	RS232, RS 485, MODbus, Ethernet 10Base T Connectivity with TCP/IP Protocols
48	The Watt Stopper / Pass & Seymour	0-10VDC, LON works
49	Tork	
50	Touch-Plate Lighting Controls	BACnet
51	Triatek Inc	TRIATEK Link, BACnet, MODbus, Ethernet TCP/IP, RS 485, DALI
52	Tridonic Inc. (North America)	Digital - DSI, DALI
53	Vantage	RS232
54	Xitron Technologies Inc	RS232

Task 2.9 – Investigate strengths and limitations of each protocol as they apply to lighting system performance

Overview:

Protocol architecture for computer communication was developed in the early 70's and defined in the 7-layer Open Systems Interconnection (OSI) – Basic reference model (ISO 7498). OSI is an international standard that defines the structures for developers to achieve multi-vendor computer communications protocol standards. The benefit to following the layered structure approach is that minimal understanding of the other layers is required to develop a compatible / working interface.

One point to keep in mind is that there are substantial incremental costs associated with implementing all 7 layers into products. Therefore the complete OSI model is typically followed through interfaces plugging directly into computers.

Pertaining to the building and lighting control markets only the protocols categorized as backbone communications architecture contain every OSI. Ethernet is the most dominate protocol meeting these criteria. BACnet uses a 4-layer version of the OSI standard. LON Work's protocol also resembles the OSI standard.

Most control systems do not use the OSI standard because of the high cost to do so (hardware overhead and development time). Moreover, the speed, amount, type and portability of data communicated do not require the entire structure.

Because several communications methods are utilized within the building environment, compatibility between subsystems is an overriding issue. To overcome protocol in compatibility issues, routers, translators, bridges and other defined modules are usually required. There are obvious distinct differences between the protocols used for building controls and for lighting controls. This fact is independent of whether the protocols are open or proprietary. Building control systems typically control HVAC devices that do not require fast response times and do not require many control points. Lighting control systems require immediate response times, the ability to detect if occupants are still active in a space and significantly more control points. Naturally, lighting control systems need to be sensitive to these differences.

For a lighting control system to operate successfully the system must:

- Minimize command strings aggregating control points
- Warn occupants of lighting system changes
- Sense delay override commands
- Interact with other sensors and controls within the office environment

These requirements often exclude existing building automation system protocols from being used to control the lighting because they have slow response speeds, cannot control many points, and if they did, they would be prohibitive expensive.

Until recently lighting control systems were predominately on/off control. Lighting systems that provided dimming control were limited to local room or area control, and not tied into a central lighting control system or building automation system. Recent introductions of digital fluorescent ballast with communication protocols have created a new way for control manufacturers to approach the design of lighting control components.

The following review of existing protocols describes how well they are suited for use as lighting control.

Building Control Protocols:

Lamp-ballast control techniques (protocols)

0-10 volt	
Strengths	**Weaknesses**
1. Many suppliers already have products that use it. It has been commercially available since the early 1970's for theatrical lighting controls ANSI has recently approved 0-10V std. for Entertainment Technology – published standard E1.3-2001. 2. Entered commercial electronic fluorescent dimming ballast products in 1993. 3. Conceptually simple - light output varies with control voltage. Three analog command regions (-0.5V to 0.3 volts = "zero state: 0.3V to 9.8V = active range: 9.8V to 30V = full state) 4. Simple, inexpensive analog control devices for simple control functions. A variable resistor can provide dimming control, but for controlling multiple ballasts, a slightly more complicated circuit in the control device is needed. 5. Incremental cost to implement ballast input control circuit is low. (Not to be confused with cost associated with implementing overall dimming capabilities.) 6. Protocol defines control device function intended for controllers and dimmers	1. Ballast manufacturers have not adopted standard for commercial. As a result consistent behavior across different ballast types or manufacturers is not assured. For example, 5 volts for one ballast manufacturer might result in 30% dim level, while the same 5-volt signal might result in a 50% dim level for another manufacturer's ballast. 2. Small bandwidth (0-10Volt) creates difficulty obtaining enough space for control functions in addition to dimming resolution. 3. Control cable is polarity sensitive making it more difficult to install and troubleshoot. 4. Low dc voltage is susceptible to electrical interference from power lines and lamp leads. (e.g., running control lines in same conduit as ac power can cause lamps to flicker). 5. Total cable length becomes issues due to line loses. 6. Requires low voltage control wiring. This is more of a problem for retrofit installations. 7. The linking of a particular ballast (addressing), or group of ballasts, to a control function must be pre-planned and hardwired electrically. Ballast control is dependent on the control wire circuit. 8. One-way communication. Ballasts cannot communicate information back to the controller. 9. When multiple controls or sensors are used a master – satellite configuration is required to provide setting control hierarchy and avoid conflicts. 10. Does not define function of load device, so device could source or sink current.

X-10 (power line communications)	
Strengths	Weaknesses
1. Uses existing power wiring as control communication media. 2. Very low cost communication technique. 3. Good for residential and small building applications (256 addresses) 4. Supported by several control device manufacturers. 5. Proven technology	1. Due to inherent limitations and concern for robustness ballast manufacturers have not endorsed powerline communication approach. 2. Susceptible to power line noise disturbances. 3. Limited to 256 addresses 4. One-way communication protocol. 5. Conflicts between other systems highly possible.

Two-wire (ac phase control dimming)	
Strengths	**Weaknesses**
1. No additional wiring required for dimming control (reduces retrofit costs). Uses existing line switch leg and neutral wiring as control communication. 2. Uses conventional incandescent type wall dimmers (although some implementations require special dimmer circuits). 1. 3. High-level signals are less sensitive to interference from adjacent power wires and lamp wiring in fixture, especially compared to 0-10 volt systems at low voltages.	1. No specification or standard to insure consistent behavior across different ballast types or manufacturers. 2. Control/ballast manufacturers have not developed standard for commercial use. 3. Susceptible to power line power quality disturbances. Phase-cut technology creates power factor imbalance and harmonic distortion on the neutral. 4. Its use in large installations could potentially cause power quality problems. 5. Interfacing to controllers requires ac line voltage to low voltage signal interface circuitry. 6. The linking of a particular ballast, or group of ballasts, to a control function must be pre-planned and hardwired from the controller. 7. Ballast control is power circuit dependent. 8. One-way communication. Ballasts cannot communicate back to controller.

DMX-512 communications	
Strengths	**Weaknesses**
1. Industry standard for theatrical lighting control systems. Limited use in general commercial lighting applications. 2. Supported by all theatrical control manufacturers 3. High-speed wide bandwidth for control of as many as 512 points per loop. 4. Transmission speed 250k bites/sec. 5. Simple command structure 3 data types (Reset, Null Start code and valid dimmer levels 0-255). Commands are sent in an asynchronous continuous serial format.	1. Not supported for fluorescent dimming control by ballast manufacturers. 2. Control circuit is expensive to incorporate into ballast design. 3. Continuous one-way transmission 4. New standard is being reviewed to possibly replace DMX512 called the Advanced Control Network (ACN). 5. Command structure limited and does not support basic commercial lighting control requirements. 6. Standard does not define minimum performance levels of connected equipment.

DALI Communications	
Strengths	**Weaknesses**
1. Recognized standard in Europe IEC-929 and supported by all major ballast manufacturers. North American control and ballast manufacturers are supporting concept however have not agreed to adopt as a standard. 2. Two-way communication - ballasts can report operational parameters and lamp status information back to the controller. 3. Individual ballast control through individual addressing, as well as the ability to configure groups for common operation. 4. Addresses are dynamically allocated - no agreements between manufacturers are needed to ensure unique addresses, able to mix manufacturers products within one job. 5. Grouping ballasts with particular control functions and controls can be changed	1. Commissioning of digital lighting systems is new to industry. Therefore a process is not in place to service and commission systems. 2. Potential for initial control cost to be more expensive for some applications until economies of scale are reached. 3. Commissioning burden shifted from designer/installer to facility manager/end-user. This could be considered a strength if new controls specialists are brought into the scene. 4. Setting up addresses requires a person to physically identify individual ballasts to the controller. 5. Newly introduced protocol in North America - lack of availability of products (both ballasts and controls) makes investment risky at first. 6. Lack of diverse control products that provide high level functions and pre-

<table>
<tr>
<td>without any rewiring.
6. Uniform action in response to commands across different manufacturers' products.
7. No analog interface circuitry when microprocessor controllers are used (reduces device cost and increases reliability of control systems).
8. Incremental cost to implement ballast input control circuit is low.
9. Cost effective way to provide individual luminaire control to office occupant.</td>
<td>programmed control operations such as dimming for daylight or load shedding. This might be only a temporary, initial shortcoming.
7. Uses communication technique called ‘Manchester code’ making the use of standard UARTS difficult.
8. Protocol defines ballast definition but not control criteria. Opening the door for controls to be incompatible within a specific system.
9. Limitation of 64 addresses per loop increases requirement for additional hardware when implementing in larger spaces.
10. Control manufacturers are uncertain about performance of the product.</td>
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<tr>
<td colspan="2">Comments on DALI Functional Profiles -
• Although 32 bit address has been developed, there is no way to control devices with this number, limiting total output control to 64 addresses per loop.
• No single command to reset load device to default values.
• No command priority structure leaving the scheme to the control input device.
• No single command available to clear a specific device address.
• No commands for passing variables between DALI loops.
• No commands to define function of the control devices.</td>
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<table>
<tr>
<th colspan="2">ESI Super Dim communications</th>
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<tr>
<td>Strengths</td>
<td>Weaknesses</td>
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<tr>
<td>1. North American control and ballast manufacturers are supporting concept, however, have not agreed to adopting it as a standard.
2. Individual ballast control through individual addressing, as well as the ability to configure groups for common operation.
3. Groups of ballasts with particular control functions and controls can be changed without rewiring.</td>
<td>1. Commissioning of digital lighting systems is new to industry. Therefore, a process is not in place to service and commission systems.
2. Potential for initial control cost to be more expensive for some applications until economies of scale are reached.
3. Commissioning burden shifted from designer/installer to facility manager/end-user. This could be considered a strength if new controls specialists are brought into the</td>
</tr>
</table>

4. No analog interface circuitry is required when microprocessor controllers are used. This reduces device cost and increases reliability of control systems. 5. Incremental cost to implement ballast input control circuit is low. 6. Uniform action in response to commands across different manufacturers' products. 7. Cost effective way to provide individual luminaire control to office occupants.	scene. 4. Setting up addresses requires a person to physically identify individual ballasts to the controller. 5. Newly introduced protocol in North America - lack of availability of products (both ballasts and controls) makes investment risky at first. 6. Lack of diverse control products that provide high level functions and pre-programmed control operations such as dimming for daylight or load shedding. This might be only a temporary, initial shortcoming. 7. Presently, only one-way communication to ballast. 8. Addresses are factory assigned requiring agreements between manufacturers to avoid duplicate addresses. 9. Protocol defines ballast definition but not control criteria. Opening the door for controls to be incompatible within a specific system.
Comments on ESI Functional Profiles - • No single command to reset load device to default values. • No command priority structure leaving the scheme to the control input device. • No single command available to clear a specific device address. • No commands to define function of the control devices. • No commands for two way communications. • No commands supporting device status. • No device min or max commands.	

LON Work communications	
Strengths	Weaknesses
1. Recognized as a global standard for building automation control devices. 2. Supported by many control device manufacturers. 3. Introduced in the early 80's and is no longer a first generation protocol. 4. Supports lighting and HVAC control attributes. 5. Financially backed by large electronic companies. 6. High Speed communications (up to 1.5 Mbits/sec.).	1. Expensive for applications requiring large number of points of control. 2. A fee is charged per address making the technology cost prohibited for each ballast. 3. As a result of the component costs, the protocol has not been adopted by major ballast suppliers. 4. Increased installation complexity. 5. Setting up addresses requires a person to physically identify individual ballasts to the controller.

Comments on LonMark Functional Profiles -

Light Sensor: 1010, version 1.1 - Sensor output is defined in units of lux with valid ranges from 1 to 65,535 lux. First, this is potentially confusing since the sensor will most likely be responding to ceiling illuminance rather than work plane illuminance. Second, most ceiling light sensors for daylighting applications do not have cosine spatial responses, so calling the variable lux is misleading. Third, ceiling illuminances typically are much lower than work plane illuminances for common office lighting (such as ceiling troffers with parabolic reflectors), often by a factor of five or more. Therefore, a resolution of one lux may not be sufficient for smooth dimming control. Since the high end of the scale needs to include values as high as 10,000 lux, a data type with more dynamic range than an unsigned, two-byte word is needed. Using the optional Reflection Factor and Field Calibration SCPTs could overcome this limitation. The terminology is inconsistent with lighting terminology and potentially confusing since more than just the reflectance of the of the surfaces is involved. A more suitable term for Reflection Factor is ceiling/work plane illuminance ratio.

Occupancy Sensor: 1060, version 1.0 - The Location Label SCPT is mandatory for the occupancy sensor and not for the light sensor. The Debounce Time SCPT does not need a value longer than a few hundred milliseconds

Lamp Actuator: 3040, version 1.0 - 0 to 200 correspond to 0 to 100% light output. 255 is undefined and rejected.; values from 201 to 254 are undefined. The Energy Counter SNVT is in units of kWh but is not calibrated. It is unclear whether the optional SCPT runHrAlarm is for re-lamping purposes.

Constant Light Controller: 3050-10, version 1.0 - The inputs for manual override and control seem well designed. A constant set-point control algorithm (also known as reset control, or integral control) is all that this device is capable of doing. This type of control algorithm has been shown to be inappropriate for daylighting control. Control algorithms more appropriate for daylighting are open-loop proportional and closed-loop proportional (also known as sliding set-point control). To be able to perform these other control algorithms additional SCPTs are needed to allow proper commission.

Occupancy Controller: 3071, version 1.0 - Well designed inputs, especially having the capability to provide input to a constant light controller, thereby combining manual switching, occupancy sensing and photocell control into one control scheme.

Partition Wall Controller: 3252, version 1.0 - This function seems to have great potential for being able to redefine which fixtures are controlled from which switches and controls.

BACnet communications	
Strengths	**Weaknesses**
1. Recognized as a global standard for building automation control devices. 2. Supported by many control device manufacturers. 3. Open Protocol. 4. Preferred whole building (higher level) protocol. 5. HVAC control attributes defined. 6. High Speed communications (up to 1.5 Mbits/sec.) 7. 4 layer collapsed architecture.	1. Expensive for applications requiring large number of points of control. 2. Designed as a HVAC protocol. 3. Lighting protocol attributes are currently under review for adoption into standard. 4. Installation complexity. 5. Expensive to implement into control devices. Setting up addresses requires a person to physically identify individual ballasts to the controller.
Comments on BACnet Functional Profiles - • Priority assignments are supported in architecture. • Trend logging and other monitoring functions supported.	

Proprietary / custom protocols:

Prior to the 1990's all lighting control systems and most building automation systems utilized custom or proprietary communication protocols.

Even today there are several well-recognized manufacturers using custom communication protocols. Companies like JCI (N2-Metisys), Honeywell, Lutron, GE, PCI all use proprietary systems.

Johnson Controls provided a copy of their N2 protocol for our review. The N2 protocol is a simple protocol for exchanging information between devices on the N2 network. No specific commands are provided pertaining to lighting control or control strategies.

There are 7 object types that make up the command record: 1) analog inputs, 2) binary inputs, 3) analog outputs, 4) binary outputs, 5) float internal values, 6) integer values and 7) byte internal values.

In addition JCI provided a copy of their METASYS system architecture. Their system overview is similar to other building automation system architecture reviewed.

As a result of not having access to other proprietary protocols we were not able to provide specific details regarding their performance.

Task 2.10 – Interview contractors and installers to determine installation and commissioning issues, such as times and costs, and to identify other possible technology, market and application barriers to use of the control technologies under investigation (occupancy sensors, photosensors, dimming electronic ballasts).

The LRC decided to conduct a direct-mail survey to contractors and control installers to try to identify market barriers affecting the acceptance of lighting controls. The results of the survey are described below.

Direct-Mail Contractor Survey

Executive Summary

This report represents the results of a direct-mail survey conducted from May 15 to June 15, 2001, by the Lighting Research Center. The purpose of the survey was to determine contractors' and controls installers' attitudes about market barriers affecting the acceptance of lighting controls.

This survey confirmed overall what the industry already knows about lighting controls. Two significant results were quite clear:

- The potential market for occupancy sensors, photosensors, and dimming electronic ballasts is much greater than the present market. Installers were willing across the board to say that they could install far more controls than they do, if there were no barriers to market penetration.
- The universally cited barrier to market penetration was lack of customer demand, as expected. Although not directly asked, installers responded that they had difficulty proving that customers would see the payback from lighting controls.

Other market barriers seem relatively unimportant to this group:

- Lighting controls do not seem to cost installers much difficulty, either for time to install, or from returning to the job to adjust the controls. Everyone who completed the surveys commissions as well as installs the controls, so it can be assumed that all the installers are familiar with problems that arise in commissioning.
- Neither difficulty in finding skilled labor, nor a lack of compatible products seem to affect the number of controls this group installs. The majority of installers rate these barriers as "low" in importance across all types of controls, with only a few rating them "medium."
- Information about profitability was unclear; most installers have not broken out the cost of individual controls, as they use fixed contract pricing. However, for all four types of lighting controls, low profitability was cited as a major barrier no more than 20% of the time.

The results of this survey seem to show that customers must first be convinced that lighting controls will benefit their bottom line. If that happens, little else remains in the way of their widespread use.

Results for each type of lighting control are discussed in detail below.

Survey Demographics

The survey was mailed to 350 addresses obtained through the web sites of organizations whose members are likely to install lighting controls, including the following:

- National Association of Energy Service Companies
- National Association of Lighting Management Companies
- National Electrical Contractors Association
- New York Energy Efficiency Council
- Association of Energy Efficiency Engineers

Addresses were evenly distributed across the United States. As an incentive, installers received three Lighting Research Center publications of their choice if they returned the surveys. The response was 20 completed surveys, a return rate of approximately 5.7%. This return rate is in line with average return rates in direct-mail survey work. Note that not all installers who responded work with all types of lighting controls. Thus, the number of responses for each type of control can be less than the total number of surveys returned.

The surveys were more heavily returned from the eastern half of the U.S. Only one set of surveys came in from California, although 23 requests were sent. The rest of the surveys clustered in the Midwest and the upper South. No surveys came from the Northwest or Southwest. The distribution by state is given in Table 1.

Table 1: Each returned survey’s state provenance

CA	KY	NC	TN
GA	MD	NH	TX
IA	MI	NY	VA
KS	MN	OH	WI
KS	MN	TN	WI

Finally, the addresses were evenly distributed in three categories. The first category was independent companies taken from the memberships described above, and the second and third categories were branch offices or affiliated installers from two major controls manufacturers, Siemens Building Technologies, Inc. and Johnson Controls, Inc. The returned surveys included approximately one-third independent companies and one-third each from Siemens and Johnson installers.

Dimming Electronic Ballasts

(12 responses)

The surveyed group installed relatively few dimming electronic ballasts in the last year, but the potential for increasing this type of control was high. Although 50% of the group installed fewer than 100 dimming ballasts, more than 40% thought that they could potentially install 1000 to 50,000 additional ballasts.

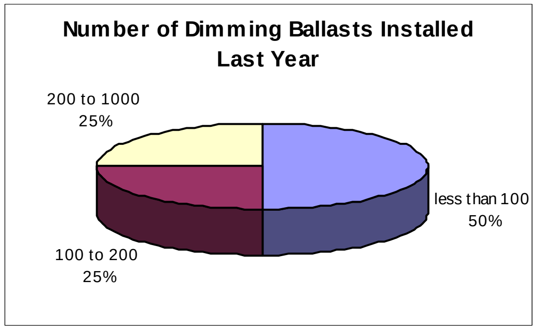

Figure 1: Percentage of installers who cite range of dimming ballasts installed last year.

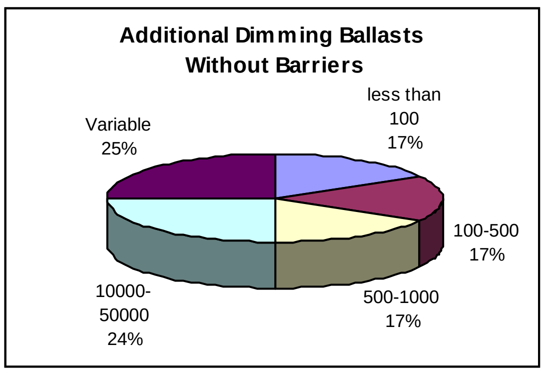

Figure 2: Percentage of installers who cite the range of additional dimming ballasts they could install if no barriers existed.

The major barrier holding back that number, they said, was lack of customer demand—73% of installers cited this barrier. One installer told us that it is "always difficult to obtain a good payback." He also said, "Dimming controls have always been a compatibility problem."

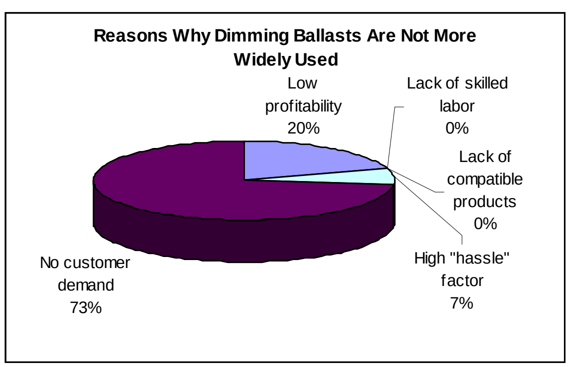

Figure 3: Percentage of installers who cite the importance of a reason for not using dimming ballasts as "high."

Dimming ballasts were time-efficient to install, with 33% of installers able to complete installation in 30 minutes or less. An additional 25% could install a ballast in 30 to 60 minutes. The majority of installers charge for dimming ballasts by fixed contract price, with a number using hourly rate as the next most common method. Thus, the average charge they cited varied by contract as well. The most common brand of ballast they use was Advance (4 installers), while Lutron, Howard, and Motorola brands were also mentioned (1 installer each). About half say they sometimes use a different dimming ballast than the one specified by the engineer, architect, or designer.

Occupancy Sensors

(17 responses)

The surveyed group installed a relatively large number of occupancy sensors in the last year. Three installers (18%) put in 1000 or more, while four more (23%) installed between 200 and 1000 occupancy sensors. However, an equal number installed 100 or fewer occupancy sensors. Seven installers said that they use Watt-Stopper occupancy sensors, while SensorSwitch and WattMiser were each mentioned once. Again, about half of the installers say they sometimes use a different occupancy sensor than the one specified.

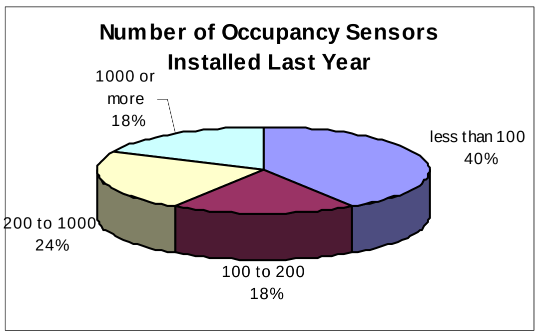

Figure 4: Percentage of installers who cite the range of occupancy sensors installed last year.

If no barriers existed, over 50% of installers feel they could put in anywhere from 500 to 50,000 additional occupancy sensors.

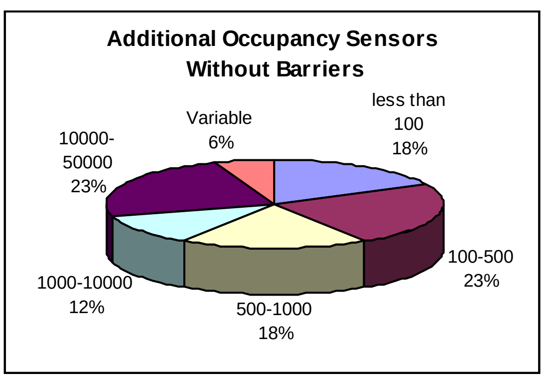

Figure 5: Percentage of installers who cite the range of additional occupancy sensors they could install if no barriers existed.

Lack of customer demand is the greatest barrier, but a high “hassle” factor with the sensors also interferes with growing the market for this type of lighting control. Comments about occupancy sensors from the installers included this: “It is difficult to measure exact savings and also more time-consuming to design, which are two reasons we do not propose them as often.” And another said, “[Our] biggest objections are based on poor past customer experience; it’s always difficult to predict accurate savings.”

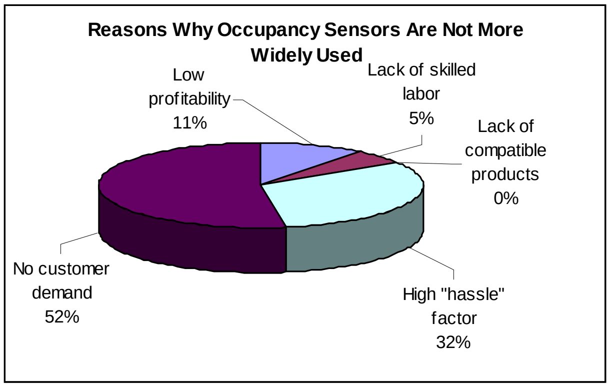

Figure 6: Percentage of installers who cite the importance of a reason for not using occupancy sensors as “high.”

It took most installers one to two or more hours to install an occupancy sensor. All respondents said that they themselves commissioned the sensors in addition to installing them. Customers did not often call them back to adjust the sensors once they were installed; 58% of installers say customers only call them back 1 to 10% of the time.

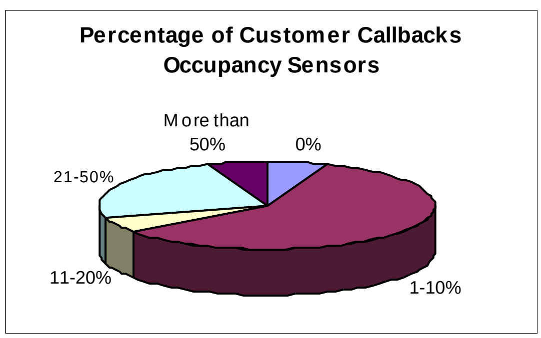

Figure 7: Percentage of installers who report frequency of customer callbacks for occupancy sensor installations.

The installers mostly charged by fixed contract for occupancy sensors, so many could not say what they charged for an individual control. However, one installer did charge a fixed price for a single control ($20 to $60) and another charged a unit price per room ($150 to $200).

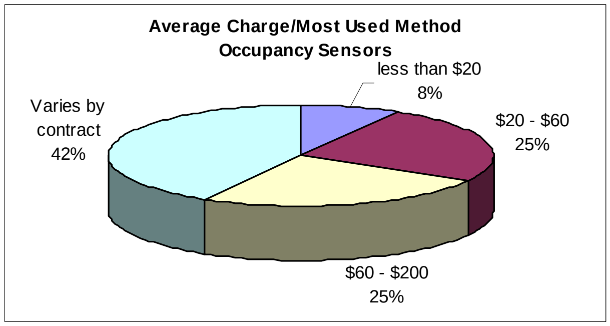

Figure 8: Percentage of installers who report range of average prices for their most frequently used method of charging for occupancy sensors.

Photosensors

(9 responses)

Very few installers work with photosensors; only nine returned or filled out this survey. Of those, two said that they did not install any photosensors last year. The most photosensors anyone installed was about 200.

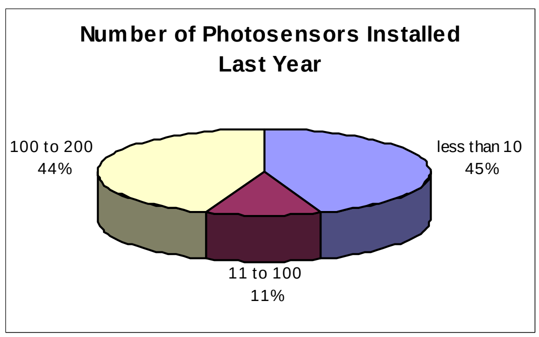

Figure 9: Percentage of installers who cite range of photosensors installed last year.

Unlike occupancy sensors, the installers do not see much additional market potential for photosensors. If no barriers existed, four installers (45%) felt they could put in fewer than 100 additional photosensors. Three installers, however, did think that they could put in between 100 and 1000 additional sensors.

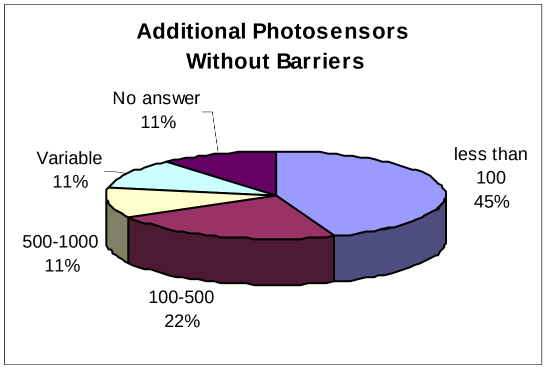

Figure 10: Percentage of installers who cite the range of additional photosensors they could install if no barriers existed.

The two reasons universally cited for resistance to photosensors were lack of customer demand and high hassle factor. However, installers were able install both ceiling- and wall-mounted sensors in less than an hour, and a majority (67%) were only called back to adjust photosensors 1 to 10% of the time. One of those who commented on this type of control said, “It is difficult to measure the exact savings, which is one reason we do not propose many of them.” But another commented, “Many simple applications are overlooked where photocontrols are a good fit; it’s easy to obtain a good payback. We can install sensors as a standalone project with no other change in technology.” Because these facts appear contradictory, it is difficult to ascertain the real reasons why photosensors are not more widely used; the sample is too small to draw any conclusions. Perhaps there are simply few installers who have experience with this type of control.

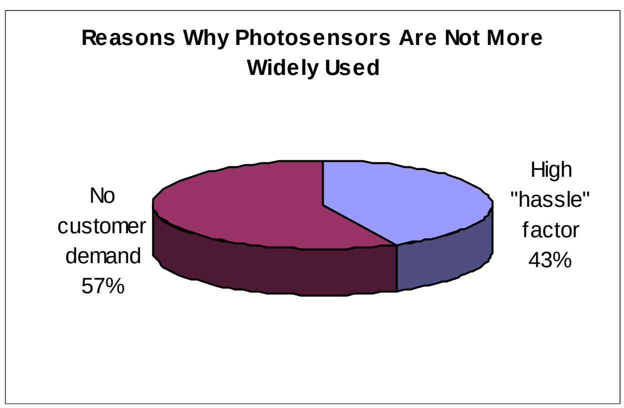

Figure 11: Percentage of installers who cite the importance of a reason for not using photosensors as “high.”

Building Automation Systems

(15 responses)

Most of the surveyed group install building automation systems. However, they are not using them to control the lighting. Controlling HVAC systems is by far the most common use of automation. More than 73% of installers say that automation systems control HVAC systems 76 to 100% of the time. In contrast, 53% of installers said that lighting is seldom controlled by building automation systems (only 0-25% of installations). Figure 12 shows how often installers cite each percentage range of installations for each type of building system.

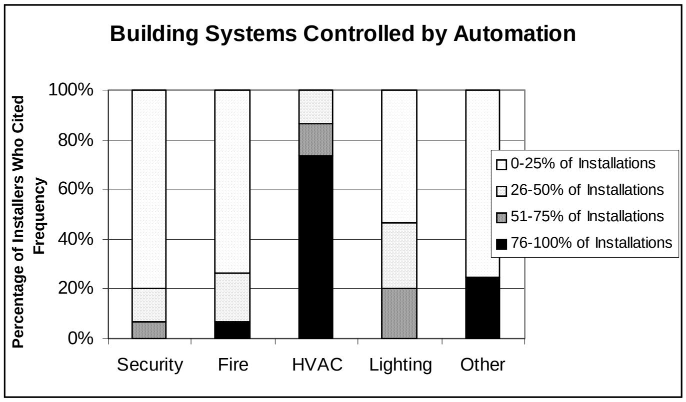

Figure 12: Percentage of installers who cite the frequency with which each building system is controlled by automation systems.

In most cases, the systems they install use twisted pair wire as the method of communication. Sixty percent of installers said they use this method in 76 to 100% of their systems. Very few installations use existing communication infrastructure as opposed to adding dedicated infrastructure for the automation system. Installers primarily use a proprietary protocol or LAN network with Ethernet as the communication protocol in these systems; 53% of installers use this method 76 to 100% of the time. BACnet or LonWorks, two other popular protocols were seldom used; in both cases about two-thirds of the installers said they used these protocols in 0 to 25% of installations.

The installer is most frequently responsible for commissioning the automation system, 46% of the surveyed group said this was true for 76 to 100% of their installations. Responsibility for maintaining the system falls to the installer about 51 to 75% of the time, and to the building's owner 26 to 50% of the time; about half of the installers gave these responses, as shown in Figures 13 and 14. Two installers said that the manufacturer, which in this case was the same as the installer, was responsible for maintaining the system in all their installations.

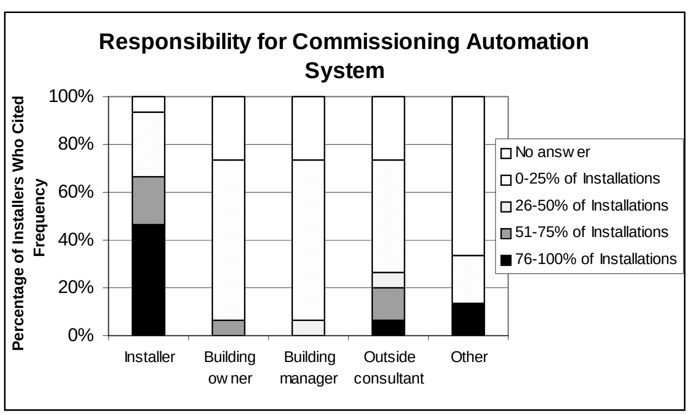

Figure 13: Percentage of installers who cite the frequency with which each category of responsibility commissions building automation systems.

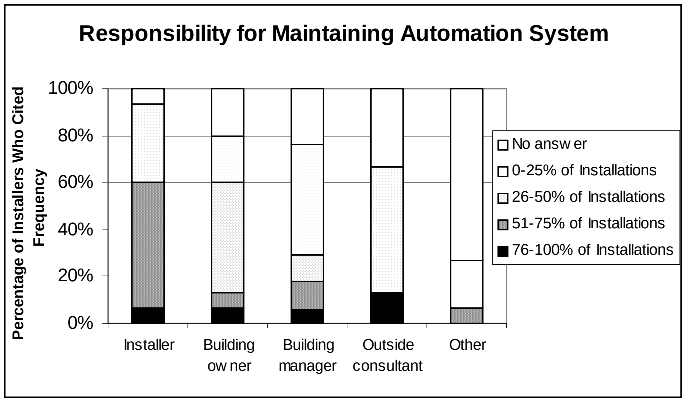

Figure 14: Percentage of installers who cite the frequency with which each category of responsibility maintains building automation systems.

Up to half of their customers ask for and make use of the data that they can obtain from their building automation systems, according to 53% of the surveyed group. This fact implies that building owners and managers might decide to increase the automation of lighting controls as they get used to seeing the benefits supported by the hard data.

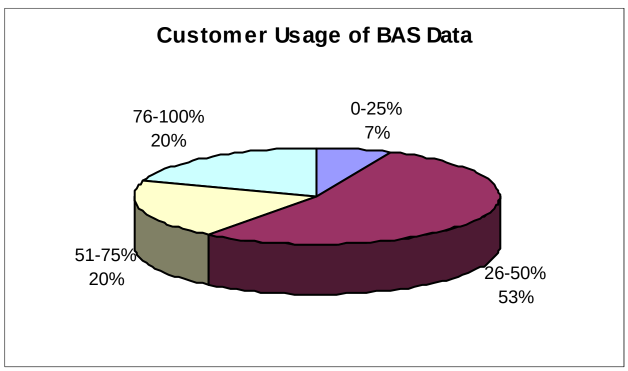

Figure 15: Percentage of installers who report range of customers who ask for and use the data they can obtain from building automation systems.

Again, lack of customer demand is the predominant reason why building automation systems are not more widely used, followed by high initial cost for the customer and low profitability for the installer. These reasons may go far to explain why such systems are seldom used to control lighting; the potential savings from controlling lighting are not enough to justify the investment. One installer commented, “System potential is underutilized.”

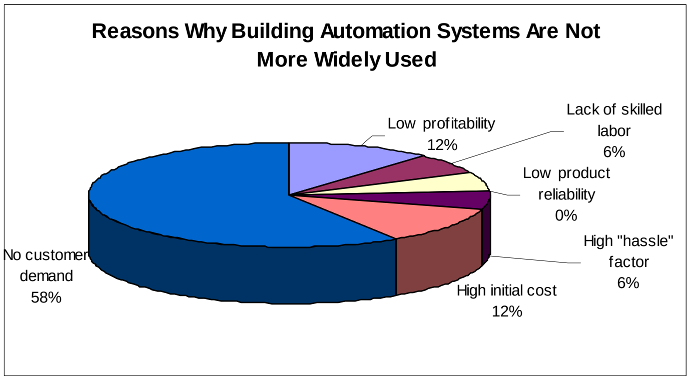

Figure 16: Percentage of installers who cite the importance of a reason for not using building automation systems as “high.”

However, 59% of the surveyed group perceive that customer demand for building automation systems is increasing, whether slowly or rapidly. Another third say that demand is holding steady. The results of this survey indicate that the future is promising for this type of system, but to maximize benefits for lighting loads, customers must be educated in the benefits of controlling their lighting with the systems.

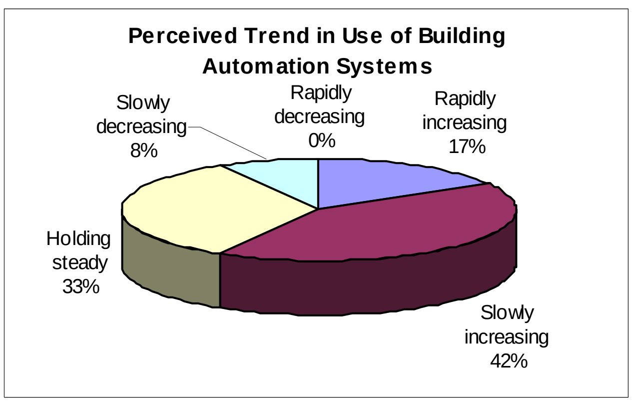

Figure 17: Percentage of installers who perceive trends in the use of building automation systems.

Task 2.11 – Interview key control manufacturers (occupancy sensors, photosensors, dimming electronic ballasts, and appropriate building control systems) to get their inputs regarding the information and analysis conducted.

The LRC staff interviewed Steve Carson (Lightolier Controls), Pekka Hakarinen (Lutron), Brian Platner (Sensor Switch), Dave Peterson and Dorene Maniccia (Watt Stopper), Kevin Keefe (GE Industrial Systems), Troy Maeder (Automated Logic), and Brent Medearis (Siemans Lighting Control). Many of what was learned during the interviews was summarized in the white paper developed in task 2.15. Below is a summary of the notes taken during the interviews.

Lightolier Controls

Key Interviewee: Steve Carson

Carson noted that lighting is the most complex building system to control (compared to other building systems). Variable light levels are needed because “on” will not please everyone. Lighting controls involve many nodes, very subjective comfort levels, and often very different configurations, e.g., direct/indirect.

He is concerned about the lack of controls protocols and the lack of building automation systems that include lighting in the planning; these systems focus on HVAC; lighting is seen simply as a “load.”

As for penetrating market barriers to lighting controls, he thinks energy savings companies (ESCOs) are the major influence for existing systems. They operate on guaranteed energy savings. Replacing existing lamps with T-8s provides guaranteed savings, so ESCOs will always do this. But they find it difficult to sell unknown savings based on statistical usage.

Simple, standalone control devices need “perks” that must be tied into a centralized system, such as monitoring or load shed, but then the system cost is too great for ESCOs to sell easily.

For example, consider the installation of a $10-15 individual addressable ballast; a gap exists between specifying it and making it work. No commissioning is included in the cost. These units need to be easily commissioned, and set up for “back end zoning.”

The controls industry also needs a way to certify commissioning (not a problem for Lutron). Additionally, the commercial sector needs “systems integrators”--a new profession that does all the commissioning work. Such a professional could from the security or audio-visual industry, as controls systems started with home theater. Carson believes that legislation should be undertaken to fill these needs.

Lutron

Key Interviewee: Pekka Hakarinen

Hakarinen says that lighting as an industry is not successful with architects (or building owners, or business operators); poor communication leads to poor penetration with these groups. She believes more education is needed. Communication about the value of lighting controls stops at the facility manager; because of this, the industry needs to work to get its messages to the right level.

The “first cost” mentality is a significant market barrier, in her view.

Technology is not an issue. Daylighting systems have been available since the 1980s.

An additional market barrier is that certified electricians must be used for line voltage installations. Although Lutron has no problems in this area, having its own field service technicians for commissioning, other companies with different business models may have difficulty finding qualified people to commission their products.

She believes that DALI is not the answer; how does one individually address and control each fixture? Also, DALI is incomplete because it doesn’t address commissioning.

Commissioning is a difficulty that the industry has not yet overcome. The lighting industry needs to create the installer/commissioning professional and educate the owner that [lighting] is a good investment. This education is vital, because service charges for set-up and commissioning may be equal to or greater than the cost of the hardware.

Concerning building integration, she notes that technically, systems can meet the design intent, but they are not free.

Hakarinen says, “Specifiers understand the value of lighting, but we need to give them better tools to get the point across. If you see a value, then you won’t mind paying for it.”

Payback is a problem (two years is too long). Lighting needs to have another value proposition. Opinion leaders play a big role in market development. For example, Governor Davis of California talking about lighting controls as a solution for the present energy crisis would be effective. This effort must be accompanied by financial incentives. She thinks the industry should stay away from products rebates. Products need to sell themselves. Product or technology rebates do not sustain a market. Some other incentive is needed.

Sensor Switch

Key Interviewee: Brian Platner

Platner points out that there is no lighting controls section or category in the AIA checklist for buildings. He believes that not enough attention is paid early on to lighting. Getting lighting into guidelines like the AIA will help it get a spot.

In penetrating markets, he says that up-front cost is critical; however, we need to get beyond first costs.

He does not agree that more legislation is the answer, because the existing laws are not enforced. People who are responsible for inspections do not know about lighting and lighting-related energy standards–they are only concerned with fire safety and related issues. Who is the policeman for energy code compliance? For example, a large engineering firm has no compliance form for energy codes for small jobs, but 30-35% of its business is small jobs. A full 65-75% of the country’s population already lives where energy codes exist. He thinks ASHREA 90.1 is pretty good and explicit–it simply needs to be enforced. Building departments need, at a minimum, a form to be filled out by the builder that checks for lighting controls and energy compliance.

In his opinion, lighting controls should be local controls. Central control for lighting is ludicrous. Building automation systems (BASs) need information for monitoring, but they don’t need to control the lighting. However, centralized control for load shedding would be good.

He is unsure about the benefits of DALI.

He would like to see hard data on actual case studies that show energy savings is needed, and believes that education is necessary to articulate the value of controls.

Horton Controls (The WattStopper)

Key Interviewees: Dave Peterson, Dorene Maniccia and Harold Jepsen

Harold noted three barriers to the penetration of lighting controls:

1. Initial cost
2. Hassles involved in commissioning; in general, installers avoid hassles that are not required. In their world, lighting controls are a low priority compared to fire safety, HVAC security, etc.
3. Basic lack of knowledge: the unknown is risky, and people avoid risk.

Peterson commented that lighting controls are not mission-critical. They suffer from a lack of proof for payback, unlike T-8 replacement, which is guaranteed savings.

As for building automation systems and centralized control issues, Peterson says that

the best results for lighting controls come when control is done at the local level. Central monitoring offers perks, such as data for security, but this is not so meaningful for energy savings. Most energy savings come from stand-alone controls. Monitoring the whole building is important for spotting trouble and waste. All the members of this group said that the lighting controls should be local, with the data sent back to the central system.

Harold remarked that when direct digital controls (DDC) were introduced, a new profession came into being to commission the controls for HVAC–a “temperature control contractor,” who works as a sub-contractor to the HVAC contractor. However, there is no analogous “lighting controls contractor.” Warranty contracts are used in HVAC.

This group feels that DALI is a beneficial movement in controls protocols, since all manufacturers will build ballasts that work the same. Individual addressing is good, but major questions remain about commissioning–it is much more difficult than with non-addressable systems. However, nothing is being done beyond the ballast. The industry has no guidance on how to do system things. No one makes digital logic devices to use with DALI. DALI is focusing on “individual satisfaction” with the Ledalite company and not energy savings.

The group also says that legislation is one way to get controls used--at least money is budgeted for controls. Rebates are good. They reduce payback. The industry should look at the past incentives for electronic ballasts, as these can work for speeding up penetration. However, manufacturers do not like on-again, off-again incentives.

On load shedding technology, they note that when lighting is already as low as 1 W/sq.ft., load shed offers little benefit.

Their advice to the Department of Energy is to “get moving on ASHREA 90.1.”

GE Lighting Control Systems

Key Interviewee: Kevin Keefe

Market:

What would you list as the top 3 primary market barriers restricting the increase demand and utilization of lighting control and fluorescent dimming systems?

- Cost of retrofit
- Understanding of potential energy cost savings
- Lack of codes/code enforcement

If the LRC and or the DOE could assist in increasing demand for lighting control and fluorescent dimming systems what action would you recommend?

- DOE – financial incentives

From a cost perspective which part of the system is the largest contributor (initial design, product, installation, commissioning, warranty service)?

- In new construction, product & commissioning
- In existing construction, installation

What is the number one issue the end user has for not purchasing lighting control and fluorescent dimming systems?

- In new construction, lack of lighting control strategy
- In existing construction, cost of installation

System:

What are the primary product barriers restricting the increase demand and utilization of lighting control and fluorescent dimming systems?

- Wireless systems to facilitate cost-effective system retrofits

How easily do systems support daylight and load shed control of lighting loads?

- This is a common application today (at least for GE)

Regarding your companies lighting control system what communication bus is supported? Does the protocol support on-off control and dimming?

- We currently have 2 protocols…. 1 is GE proprietary, running on RS232 & twisted pair. The other is LonWorks running on twisted pair. Both currently support ON/OFF only.

Installation and Service:

What percentage is retrofit vs. new construction?

- 85% new construction

What is the largest installation barrier?

- In a retrofit situation, it's pulling the wire

Who performs the project commissioning?

- GE or GE Factory Authorized Service Teams

Who provides the service for your systems?

- Same as above

Automated Logic

Key Interviewee: Troy Maeder

Market:

What would you list as the top 3 primary market barriers restricting the increase demand and utilization of lighting control and fluorescent dimming systems?

- Automated Logic's dealers would be better able to answer this question. We manufacturer our BAS and our dealers sell, install, and service the systems.

If the LRC and or the DOE could assist in increasing demand for lighting control and fluorescent dimming systems what action would you recommend?

- Same answer as above.

From a cost perspective which part of the system is the largest contributor (initial design, product, installation, commissioning, warranty service)?

- Same answer as above.

What is the number one issue the end user has for not purchasing lighting control and fluorescent dimming systems?

- Same answer as above.

System:

What are the primary product barriers restricting the increase demand and utilization of lighting control and fluorescent dimming systems?

- Same answer as above.

How easily do systems support daylight and load shed control of lighting loads?

- It is not inherent in ALC's system but it is easy to do.

Regarding your companies lighting control system what communication bus is supported? Does the protocol support on-off control and dimming?

- BACnet is our native protocol. On-off control and dimming can be accomplished very easily using BACnet.

Installation and Service:

What percentage is retrofit vs. new construction?

- Same answer as #1.

What is the largest installation barrier?

- Same answer as #1.

Who performs the project commissioning?

- Same answer as #1.

Who provides the service for your systems?

- Same answer as #1.

Siemens Building Automation (Lighting Control)

Key Interviewee: Brent Medearis

Market:

What would you list as the top 3 primary market barriers restricting the increase demand and utilization of lighting control and fluorescent dimming systems?

- Cost
- Lack of nation wide energy codes
- Lack of applications expertise by the consulting electrical engineer

If the LRC and or the DOE could assist in increasing demand for lighting control and fluorescent dimming systems what action would you recommend?

- Get ASHRAE 90.1-1999 incorporated into the UBC in all 50 states.

From a cost perspective which part of the system is the largest contributor (initial design, product, installation, commissioning, warranty service)?

- Small jobs – commissioning
- Large jobs – product

Cost including installation:

System:

What are the primary product barriers restricting the increase demand and utilization of lighting control and fluorescent dimming systems?

- No common universal communication protocol (ModBus, BACnet, Lonworks, etc…) among manufacturers.

How easily do systems support daylight and load shed control of lighting loads?

- Load shedding is easily accomplished. Non-dimmed daylighting is easily accomplished

Regarding your companies lighting control system what communication bus is supported? Does the protocol support on-off control and dimming?

- Lighting Control – PCI, ModBus, SBT – Modbus, LonWorks, Johnson Controls N2, BACnet. Lon and BACnet do allow for dimming, but we do not implement it.

Installation and Service:

What percentage is retrofit vs. new construction?

- Lighting Control - 20/80

What is the largest installation barrier?

- Space in the electrical closet

Who performs the project commissioning?

- Our field service representatives

Who provides the service for your systems?

- Our field service representatives

Task 2.12 – Meet with lamp manufacturers to get their inputs on lamp operating parameters that are key to maintaining performance when used with control technologies.

LRC staff interviewed Ed Yandek (GE Lighting), John Wilson and Tom Leyh (Philips Lighting), and David Bay, Bob Horner, David Reid, and Walter Lapatovich (OSRAM SYLVANIA). The outcome of the interviews was incorporated in the white paper developed in task 2.15. Below is a brief summary of the interviews.

GE Lighting

Key Interviewee: Ed Yandek

Mr. Yandek stated that the technology of lighting controls is not a problem. “[We] can do anything technically,” he remarked. However, problems arise with understanding the markets’ requirements for these technologies. For example, there is a problem with dimming, in that there is no standardization or definition of basic requirements. “No one has defined what the system functionality has to be,” said Yandek. GE can bring new products to market in less than five years, but “we need to know the requirements.”

He stated that what manufacturers need, from his point of view, is a functional specification for a “box” that interfaces to lighting, and this needs to be standardized. How can this happen? In his opinion, some organization needs to take charge and hold meetings to drive this to closure. The first meetings should not include lighting designers or lighting scientists. He believes that the first attempt should be to figure out communications, then bring in lighting people. The “high level guys” for building automation want to grab onto lighting and use it without having to know all about it. They need this “box.”

Current controls involve “front-end” design solutions that need extensive custom design work. The DALI protocol might be useful between ballast and ballast control modules (BCMs). BCMs have the intelligence to perform the control algorithms, and could potentially be the “box” Yandek referred to.

Yandek knows of no current work by ANSI on taking the lead for controls standardization. The acting panel of IEC that will look at standards needs industry agreement on minimum standards. The IEC panel is the only group doing work, but it suffers from a slow pace, and is not involving major building automation controls manufacturers.

Yandek also stated that lighting controls go way beyond daylighting.

GE works mainly with Universal (the old Magnetek).

Philips Lighting

Key interviewees: John Wilson and Tom Leyh

Major barriers for use of lighting controls:

1. Lighting controls are not totally safe for all lamp/ballast systems; no known problems, but plenty of uncertainty
2. Reliability of dimming systems are lower than reliability of on/off systems
3. Lighting is too specific to applications, not everyone needs all types of controls

4. Lack of skilled labor force; lack of educated users

Ways to overcome these barriers

1. Understanding in the marketplace the total cost of ownership; life of the system cost is not taken into consideration
2. Increase interchangeability of lamps and ballasts

Opportunities for lighting controls

1. Expect high growth in the next years
2. More controls options will be available
3. Reliability of lamp/ballast combinations will increase

They believe that central controls will be open protocol in a near future, but they are still unfamiliar about the future of DALI.

OSRAM SYLVANIA

Key Interviewees: David Bay, Bob Horner, David Reid, Walter Lapatovich

The group agreed that manufacturers perspective on lighting controls, and especially on dimming systems may be different than customers.

From their standpoint, the main barriers for widespread use of lighting controls are:

1. Installation
2. Perceived high cost ; full benefits are still not known
3. Manufacturers do not fully understand the operating characteristics of lamp/ballast when operating in a dim condition
4. Proprietary understanding of system performance; manufacturers are doing their internal research, but are not communicating their findings to the industry

In order to overcome some of the barriers they believe that industry should agree communicate a common message. With this in mind, they believe that DALI will be the “good housekeeping seal” that will assure good compatibility between different manufacturers.

They also believe that real time pricing will be a growing area, and that manufactures should work closely with utilities to develop load management strategies.

Overall, this group believed that lighting controls market will be growing in the next years, especially in the area of load management. They also believed that the technical barriers encountered today will be resolved in a near future.

Task 2.13 – Catalog any solutions that have been recommended for improving lighting and whole building control protocols.

Practical Solutions for Improving the Penetration of Lighting Controls for Fluorescent Systems in Commercial/Industrial Applications

The perceived difficulties and hidden economic barriers that may be hindering acceptance and demand for lighting controls are part of a broader picture. Any intervention to develop market demand should be considered in the widest social and economic context.

Naturally, the minimum acceptable requirements for lighting controls are that they:

- Provide sufficient light for the users of a space—after all, we can achieve perfect control by simply turning out all the lights in a building, but that is not a productive solution.
- Avoid waste—that is, turn off lights when no one is there to benefit from them (except for security, display, etc.).
- Reduce lighting levels, without compromising occupants' satisfaction and productivity.

In addition, we believe that no lighting controls solution is effective or acceptable unless it contributes to, or does not compromise, the following goals:

- Productivity
  Planning, installation, commissioning, maintenance, and use of controls should not decrease business productivity.
- Energy savings
  Lighting controls should save significant amounts of energy and money in relation to the expense involved in using them (acceptable payback period), *and/or…*
- Reduced power demand
  Society as a whole should benefit from the lowered demand for expensive power and for more natural resources.

In general, technological problems pose relatively low market barriers for lighting controls. A failure to show reasonable payback periods and other economic benefits, however, (e.g., low energy costs), limits the acceptance of controls in the marketplace. Without greater market demand for lighting controls, manufacturers have little incentive to eliminate the remaining, albeit small, technological problems.

Our recommendations for decreasing the barriers revolve around these economic arguments, laid out in detail in Section 2.15. The recommendations are also specifically centered on "on-off" technologies and load-shedding dimming as energy solutions, rather than on architectural dimming. These technologies are likely to provide the most economic benefit to society as a whole, not only by providing energy savings, but also by reducing peak demand and, concomitantly, the need to add more power-generating capacity (peak load reduction).

The technological barriers that do surround the lighting controls and applications discussed here are also those most likely to yield to attack under concerted market demand. For example, lamp/ballast compatibility is a problem that requires developing a full understanding of lamp/ballast system characteristics, but not one that is insuperable if sufficient market demand exists to make solving it worthwhile.

Within this context, we see opportunities for improving acceptance of each of the following lighting control solutions:

Lamp/ballast compatibility – While not a control technology, compatibility is the *sine qua non* of dimming control solutions. Performance criteria for lamp/ballast systems would help ensure against premature failure of lamps when they are operated in the dimming mode.

- *Benefits*: Assured compatibility of lamps and ballasts would help improve acceptance of dimming control solutions. Facilities owners and managers often deem the control system itself unsuccessful when lamp life is shortened.
- *Barriers*: No criteria exist at present, and thus far, no organization has pressed for them. Additionally, compatibility criteria must examine performance within luminaires, not just still-air testing.
- *Investments required*: Technology research and development, campaign for the adoption of performance standards for lamps and ballasts.

Local control (manual controls for 'on' functions) – Nothing replaces local control, because no sensor or zoning plan can account for novel situations (a lone worker finishing a project late at night, unplanned meetings, etc.).

- *Benefits:* Provide the most occupant satisfaction, because once lights are turned on to occupants' desired level, no further action must be taken.
- *Barriers:* Provide the least guaranteed energy savings, as lights are more often on when they are not needed.
- *Investments required:* No additional investment, unless optional access improvements are provided to promote turning lights off.

Occupancy sensors – Occupancy sensor technology is robust, and works well for defined spaces. Obviously, it is not suitable for open-plan areas that require a level of continuity in the lighting, or where different categories of occupants come and go.

- *Benefits:* The major benefit of occupancy sensors is their ability to get some of the lights in a building completely off when people aren't in the space, without reducing occupant satisfaction. Because dimming is not involved, implementing occupancy sensor systems is simpler than implementing photoelectric dimming systems.
- *Barriers:* Hassles in commissioning remain; the technology must also overcome specifiers' inertia when considering controls solutions. Additionally, specifiers are loathe to accept claims of statistical rather than guaranteed savings.
- *Investments required:* Effective marketing campaigns.

Photoelectric dimming – New developments in simplified-commissioning photosensor technology (a new device developed and patented by the LRC) means that photoelectric dimming can be made to work cost effectively.

- *Benefits:* Photosensors are an obvious, though hard-to-implement solution, now rendered more or less hassle-free by the simplified-commissioning feature.

- *Barriers:* Simplified commissioning is not yet fully developed or commercially available. Without this feature, photosensors continue to involve commissioning and fine-tuning problems.
- *Investments required:* Technology development and demonstrations, commercialization, and effective marketing campaigns

Time clocks/central control – Relay-panel products and the like are capable of reducing lighting loads, but only if the zoning is truly logical for the space. Such technology makes sense if a careful analysis of the zoning is carried out, yet the scope of the analysis required, and the need for exceptions to any zoning plan, militates against productivity.

- *Benefits:* The ability to get large groups of lights in a building guaranteed off, yet with fewer control nodes than occupancy sensor or photosensor systems.
- *Barriers:* Difficulties in zoning logically, hassles in planning and commissioning, lack of flexibility when space usage changes.
- *Investments required:* R&D effort to improve ease of use, effective marketing campaigns.

Load-shed ballasts – Electronic ballasts can be modified at minimal cost to reduce power by 20% or more to fluorescent lamps during peak demand. When developed, these load-shed ballasts would allow a utility or building manager to lower the power to the lighting system "on demand" at a rate that minimally affects building occupants. Presently, it is envisioned that a non-dimming programmed start ballast can be redesigned to meet these objectives.

- *Benefits:* Load-shed ballasts would not be as expensive as electronic dimming ballasts, and their installation would require minimum wiring. It is envisioned that utilities can control the load shed by signaling the customers from a remote location. Preliminary studies have shown that dimming up to 20% over a period of five seconds is acceptable to customers.
- *Barriers:* Load-shed ballasts have not yet been developed and tested for commercial markets.
- *Investments required:* Technology research and development, demonstrations, commercialization, and effective marketing campaigns

Logical zoning and communications – Emerging controls protocols allow grouping lights together into a logical control scheme that minimizes the number of control nodes and sensors.

- *Benefits:* Logical zoning enables users to dim or shut large groups of lights off in specific locations, while being able to change zoning as their needs change. The ideal protocol would allow facilities managers to cope easily with high "churn rates," as a building's commercial tenants come and go.
- *Barriers:* The development of open, industry-accepted standards that allow lighting components to communicate with each other has been a lengthy process, but new standards such as DALI and BacNet might prove successful.
- *Investments required:* Technology development and commercial acceptance of standards, as well as effective marketing campaigns directed at producing societal change.

Task 2.14 – Develop draft performance criteria for the control technologies (occupancy sensor, photosensor, dimming ballasts) for selected commercial and industrial applications.

Draft Performance Specification – Load-shed Ballasts

Operational definition of load-shed

What:	Reducing power demand
Why:	To avoid brownouts and blackouts, to avoid peak demand expenses (society or utility expenses)
How:	Dimming fluorescent lighting or switching off lamps operated on multi-lamp ballasts
When:	Only when required. Low frequency and duration of occurrence (less than 30 days per year, less than 6 hours duration)
Where:	All C/I applications except light-dependent critical tasks (e.g., hospital operating rooms)

Load-shed signal

Source:	Utility or user based in utility signal
Information carried in signal:	Loadshed on, or off
Duration of signal:	Continual (repeated) throughout loadshed condition
Default state of ballast:	Full light output
Time needed to receive signal from utility initiation:	5 minutes
Elapsed time with no signal to revert to full light output:	15 minutes
Staggered return to full power:	(Some provision must be made so that all ballasts do not return to full power operation at the same time, causing a sudden demand condition. For example, a random time interval could be set before returning to full power.)

Ballast performance non-load-shed condition

(The idea here is to make sure that a load-shed ballast is in every other way equivalent to the high quality ballasts now being specified and required in many areas. A load-shed ballast must meet or exceed most existing performance specifications so that it can be installed everywhere.)

Power factor:	> 0.9
THD:	< 20% (ANSI definition)
Ballast efficiency factor:	Multiple requirements dependent on lamp type and number of lamps operated by ballast (table needed)

Power factor: >	**0.8** (we want to make sure that the demanded current is reduced along with the power in the event that load-shed is needed because of a transmission capacity situation. A little leeway is given so that current ballast designs can meet the spec even if, as expected, power factor changes slightly upon dimming or switching lamps.)
THD:	While load-shedding, the root mean square (rms) of the current harmonics 2-33 shall not be greater than that during non-load-shed operation. (THD as a percentage of fundamental current can increase as fundamental current drops without causing any more harm. What is important is that the absolute value of the distortion current not increase.)

How much power should be reduced during load-shed must be determined by consensus, and the following factors must be considered:

- How much demand reduction is needed to make load-shed worthwhile
- How much reduction in light output will building occupants tolerate, or if none is tolerated, how much can light output be reduced without awareness of dimming

Determining these factors will determine whether switching lamps of multiple lamp ballasts or dimming is the best strategy. The above specifications apply regardless of the actual power reductions agreed upon and regardless of the method used to obtain them. If occupant requirements prohibit the switching of lamps, then maximum dimming rates (< 2% per second, say), and minimum light output dim levels (80%, say) must be specified.

Draft Performance Specification – Occupancy Sensors

Performance Requirements

Coverage Area:	Minimum of 400 ft^2
Field of view:	Ceiling - Horizontal: 360; Vertical: up to 180
	Wall – Horizontal: up to 180; Vertical: up to 90
Extraneous Signal Sensitivity:	Shall not be sensitive to: Radio signals Electromagnetic interference Electrostatic discharge Sudden changes in temperature and humanity Noise or vibrations Natural or forced air movement Movement of inanimate objects Occupancy or motion beyond the boundaries of the office

Failure Mode:	Manual on/off remains operable
Maintained Detection:	Regardless of occupancy orientation to the sensor, location in the room, or speed of performing a motion, products shall detect: 1) small body motion (e.g., writing, typing, reading); 2) medium arm motion (e.g., reaching for telephone); 3) large body motion (e.g., walking)
Products Shall:	Have silent operation Unobtrusive status indicator
Operating Temperature Range:	0 to 35 C
Operating Humidity Range:	45 to 85%
Time Delay:	Adjustable Demarcations clearly labeled Calibrated and accurate within $\pm$ 10% of the set value Minimum: 15 seconds Maximum: 30 minutes No user access to adjustment
Installation & Commissioning:	$<$ 30 minutes
Power Requirements:	> 1 watt

Draft Performance Specification - Photosensors

Performance Requirements

Photosensor must:

1. Independently adjust illuminance when dimming begins (E_1)

   1a. $1 \leq E_1 \leq 10{,}000$ lux

2. Independently adjust illuminance when dimming stops (E_2)

   2a. $1 \leq E_2 \leq 10{,}000$ lux

3. Any adjustment must not affect E_1 or E_2 by more than 5%
4. $E_2 \geq E_1$
5. Photosensor must be able to interface with a ballast such that $\phi_2 \leq \phi_1$
6. Gain must not deviate by more than 10% for $(E_2\text{-}E_1)/0.8\ \phi_1$ throughout the dimming range

Provisions must be made during operation and commissioning for occlusion of the photosensor from direct illumination from natural and electrical light sources (shielding provisions is necessary).

Subject to the previous provision, the light-sensitive element of the photosensor must have an unobstructed acceptance angle of at least 2 Ω (≥ 50% maximum response).

Electric lighting levels must not dim at a rate faster than 1% per second so that the dimming rate is acceptable to occupants.

The device must have a spectral response that is photopic with a maximum f_1’ error of 30%. (f_1’ is defined in CIE Publication No. 69, “Method for characterizing illuminance and luminance meters,” CIE, 1987).

Incremental adjustments of illuminance of the set points E_1 and E_2 < 5% of E_1 and E_2 respectively.

Installation and Commissioning:	less than 25 minutes
Failure Mode:	Lights on/full brightness
Products Shall:	Have silent operation
Operating Temperature Range:	0 to 35 C
Operating Humidity Range:	45 to 85%
Power Requirements:	> 1 watt

Task 2.15 – Summarize current state of the art for each component evaluated above. Elucidate the technical and market barriers for each with an overall synopsis of potential opportunities. Develop a peer review group consisting of industry leaders and authorities.

The LRC summarized the technologies, barriers and potential opportunities in the following white paper. The LRC also sent a letter to Ron Lewis, Program Manager and at USDOE suggesting names of possible participants in the peer review group. The members of the peer review group are: David Bay (OSRAM SYLVANIA), Jim Benya (Benya Lighting Design), Jim Gallagher (NYS Public Service Commission), Arthur Kressner (ConEdison), Ron Lewis (USDOE), Peter Morante (Northeast Utilities), Dave Peterson (The Wattstopper), Michael Stein (Consultant, Universal Ballast), Edward Yandek (GE Lighting).

Introduction

The goals of this project are to identify barriers to the penetration of lighting controls into commercial/industrial (C/I) applications that employ fluorescent lamp technologies, and to recommend means for overcoming those barriers. Preliminary recommendations have been developed after discussions with various stakeholders and examinations of published research and patents. Subsequent efforts over the next two years will refine, improve and validate the preliminary recommendations presented here.

There are four categories of barriers that have been identified that include several barriers within each category: lamp–ballast compatibility, component compatibility, installation/commissioning assurance, and marketing. Penetration of lighting controls for fluorescent systems into C/I applications will not be simple or rapid. Indeed, to reach significant penetration into the market a cultural change will have to occur in the lighting industry. This cultural change can be characterized as developing effective communications among all stakeholders in electric energy efficiency and load management, particularly those charged with the responsibility of establishing rational social policies for power generation and transmission.

I. Lamp - ballast compatibility

Static, on-off fluorescent lighting systems are the most common technology used in C/I applications. This technology evolved over the middle of the 20th century to become the commodity lighting system because it was more energy efficient and required less maintenance than incandescent technologies. Compatibility among different lamp and ballast manufacturers was another attractive feature of fluorescent systems prior to the 1980s. Virtually any fluorescent lamp could be operated with virtually any magnetic ballast to achieve the same operating performance and life prior to this time.

As a consequence of the energy crisis of the 1970s, significant improvements in the efficacy of fluorescent systems were achieved in the last two decades of the 20th century. The physical properties of fluorescent lamps and ballasts were continually optimized during this era to improve not only efficacy, but also to give them smaller size, better maintenance (lumen depreciation and life), lower mercury content, and higher visual quality (better color rendering and reduced flicker). This evolving sophistication has led to higher and higher expectations of fluorescent system performance in terms of energy efficiency, maintenance, visual satisfaction and, of course, low cost. One down side of this sophistication, however, has been the proliferation of products that provide poor system reliability. Lamps operated on ballasts that do not have optimized starting and operating electrical properties for those lamps will fail prematurely, leading to dissatisfaction among specifiers, owners, and facility managers. This was a common situation in the 1980s and early 1990s as the electronic ballast manufacturers learned how to operate lamps produced by the “big three” global manufacturers: GE, Philips and OSRAM. Today, there are still stories of poor performance, but those days are essentially over for static, on-off fluorescent systems, largely because the global manufacturers have taken control of the specifications for ballasts that operate their lamps. This fairly modest but important step reflects the fact that modern fluorescent lamps and ballasts are two parts of the same system.

The confidence levels among specifiers, owners, and facility managers for dimming electronic ballasts are not nearly as high as they are for static, on-off fluorescent systems. Anecdotal reports from the field suggest that lamps are failing prematurely when operated on dimming electronic ballasts. Manufacturers have discussed new requirements for lamp seasoning among the, but consensus standards cannot be obtained because the operating characteristics of fluorescent dimming systems are not defined. Presently, a specifier or building facility manager must simply trust the company representative to obtain a reliable fluorescent dimming system. It is important to note that the global manufacturers of lamps and ballasts do not fully understand the basic physics involved in operating fluorescent lamps under dimmed conditions. Coupled with an emphasis on low mercury lamps, there is much more to be understood about fluorescent dimming systems than is currently known.

Poor reliability of fluorescent dimming systems, real or imagined, is a significant barrier to the penetration of dimming controls into C/I applications, and one that is not being presently addressed by any of the controls manufacturers. This is a problem for control manufacturers because the controls may properly communicate with the ballast, but the ballast may not reliably start and operate the lamp, leading to premature failure or inconsistent operation. An owner or facility manager really won’t understand *why* the system failed, but he/she will swear never do that again!

The global manufacturers are beginning to understand reliable operation of lamps on dimming ballasts, but progress is slow because of low market demand for dimming ballasts. Thus, there is a “Catch 22”; poor demand retards development and retarded development leads to poor demand. Nevertheless, there is some reason for optimism because all three global manufacturers are now taking responsibility for both the lamp and the ballast. And whereas there may not be a complete understanding of the underlying physics in operating lamps under dimmed conditions, it seems likely that the major manufacturers will eventually produce dimming ballasts that work well, if not perfectly, with any commodity fluorescent lamp. If market demand for dimming increased substantially, it seems very likely that reliable fluorescent dimming systems would be produced more quickly. But, again, without that demand, there is little reason to expect commodity fluorescent dimming systems to work reliably in the near future.

II. Component compatibility

One barrier that is being effectively addressed by the control manufacturers is the issue of interoperability of control components. On a local level, interoperability means attaining communication to control the ballast. More globally, interoperability concerns communication between individual control devices and, at a higher level, with whole building automation systems (BAS). Lighting controls manufacturers are working successfully to develop products that conform to open communication and command protocols (rather than proprietary systems) for all of the control technologies peripheral to the ballast. Several protocols are being discussed and it seems likely that standards will continue to be developed and refined in the next two years that will facilitate utilization of control components in larger systems.

Most lighting control manufacturers offer one or more product types that conform to the popular communications protocols and can be integrated into BASs. LONworks and BACnet have the most support from the lighting controls manufacturers. Devices range from protocol translators to control devices fitted to support the protocol directly. Proprietary protocols from Johnson Controls, Honeywell and Modicon are also supported by the lighting controls manufacturers, but to a lesser extent. At the physical communication level of many of these protocols is the Ethernet protocol. The widespread use and success of Ethernet for computer local area networks (LANs) has undoubtedly aided in establishing Ethernet for building process controls and has helped to lower the cost of hardware components. Other, higher-level communication network protocols from the computer industry are being used and reconfigured for BASs. For example, Microsoft's OPC (Object Linking and Embedding for Process Control) protocol is based on Microsoft's earlier and successful OLE network protocol and it leverages the previously established and widely accepted Windows client/server technology. A review of product literature and advertisements in trade magazines reveals lighting control products offering Internet connectivity, web browser interfaces, and remote monitoring technologies. Therefore, it is evident that controls manufacturers are quick to incorporate the latest crossover technology from the computer industry into their product offerings.

There have also been some recent advances at the more local level of control between individual control devices and fluorescent lamp ballasts, although progress here seems slower than for the higher-level network controls. Direct digital control (DDC) was introduced to the controls industry about 25 years ago and has greatly improved the performance and functionality of building systems. Digital controls operate security, HVAC, fire alarm, and many other specialty systems in modern buildings, yet only in the last year or so has any direct digital control ballast been available on the US market. The lack of a robust and reliable control method with fluorescent lamp ballasts can partly explain why lighting systems are not routinely connected to building energy management systems, except at the electrical panel for simple, on/off control of large areas. Currently, however, there is much activity in the lighting industry regarding digital control interface protocols for fluorescent lamp ballasts. The ESI Superdim DDC protocol and ballast is presently the only system available in the US market that offers one-way communication with ballasts for both on/off and dimming control. The market share of ESI ballasts, however, is very small. DALI is a current protocol used in Europe that has recently been accepted as an ANSI standard. Although no products that incorporate DALI yet exist on the US market, the major fluorescent lamp and ballast manufacturers have shown support for incorporating the standard protocol in future products, and the leading ballast manufacturer in Europe, Tridonic, has plans to begin marketing a DALI-equipped ballast in the US.

DDCs for ballasts will offer many advantages over the existing hardware available for lighting control by providing reliable, consistent control and simplified installation. More importantly, a uniform implementation of a protocol based on a widely accepted standard can increase market penetration of control technologies by raising people's confidence in using products that bear a seal of conformity. A widely accepted dimming control protocol such as DALI could serve these purposes.

One significant problem, however, is that these controls manufacturers are not effectively discussing the issues of controls outside their own community. There is no discussion with the ballast manufacturers on reliable operation of fluorescent lamps and ballasts. There is little if any discussion with installers, and, as will be emphasized later, there is no discussion with utilities and government agencies charged with the responsibility of providing reliable electric power to the public. *Without these discussions, there will be little demand for control systems no matter how robust the controls protocols.* Effective interaction with all stakeholders, particularly with the utility industry and related government agencies, is essential to creating market demand and thus overcoming the major barrier to the penetration of fluorescent lighting controls into C/I applications.

III. Installation/commissioning assurance

The ability to install and commission controls ranges from very good to nonexistent. The reliable installation of on-off controls into C/I applications is simple and can be accomplished easily by trained technicians. Time controls, occupancy sensors, and manual switching are reliable and easy to install. There is not, however, significant market demand for on-off lighting controls beyond simple switches in C/I applications. This barrier will be discussed in the next section.

Dimming systems, however, are both expensive to acquire and difficult to install. Commissioning photosensors is prohibitively time-consuming and, consequently, photosensors are almost never installed. Recent development by the Lighting Research Center of a simplified-commissioning photosensor to take advantage of daylight may, however, overcome this barrier.

Even if this photosensor technology becomes commercially available, there are still nagging small barriers to installing and commissioning lighting controls, particularly dimming systems. These barriers include wiring uncertainty, identification and zoning issues for groups of ballasts, the need for manual overrides, and the training of installation personnel.

As mentioned previously, DDC ballasts are essentially non-existent in the United States. Therefore, the only options today for dimming control are either a 0-10V analog control interface or a line voltage phase-chop signal interface, neither of which conform to any open standards. 0-10V control is by far the most common for dimming ballasts. At first glance, the 0-10V control appears to follow the newly introduced standard for 0-10V control in the entertainment industry (ANSI E1.3-2000). Closer inspection reveals, however, that the 0-10V control used with fluorescent lamp ballasts in C/I applications differs significantly from the entertainment industry standard. In fact, the ANSI E1.3 standard draws attention to this point.

Even if dimming fluorescent lamp ballasts did conform to this particular standard, problems would remain. One problem is that the standard does not detail the functional relationship between the control signal level and the light output level of the ballast. Therefore, a consistent dimming level across different ballast types is not assured. For example, a 5V signal from one ballast manufacturer may result in a 30% dim level, while that same 5V signal may result in a 50% dim level for another manufacturer’s ballast. Controls must be field-calibrated to work consistently in many cases, and mixing ballasts from different manufacturers under the same controller will likely result in different light levels.

Perhaps a bigger problem with the 0-10V-control scheme as implemented in ballasts today is the lack of application guidelines that result in poor field performance. These problems arise from the fact that 0-10V signals are susceptible to electrical interference, yet little or no information is given to installers concerning proper cabling practices. Examples of wiring installation practices that lead to performance problems include lamp flickering, lamp brightness striations, and lamp extinguishing at low dim levels. These problems are the result of running the control wires in close proximity to power lines and/or lamp leads, excessive control wire lengths, and reversing polarity of one or more control wires when operated on parallel circuits. The wide skepticism among lighting specifiers about fluorescent dimming systems could be reduced by educating installers about the special wiring requirements for dimming ballasts, providing clear and readily available literature on system installation, and improving product design to eliminate these field problems.

In addition to hardware and wiring problems, there are logistical problems when installing and commissioning large installations with dimming ballasts. For conventional analog input ballasts, the task of zoning must be done when the ballasts are installed. In other words, the zoning is "hard-wired" for the life of the lighting system. This makes the zoning difficult to change should the space be renovated or used for a different purpose. For the newer DDC ballasts appearing on the market, zoning is done after installation as part of the commissioning process. This makes re-zoning much easier as the space functions change, but zoning is still a laborious task because each ballast location must be manually identified to the controller. While different communication protocols offer different methods of assigning addresses, all methods involve time-consuming human interactions that increase cost as well as the potential for problems.

Finally, attention must be paid to insure that all systems are equipped with manual overrides for unpredictable events. Occupants want to have control over their lighting during unusual work schedules or events. However, engineers and facility managers seem hesitant to provide manual overrides, because it is assumed that people will use them too often and energy savings will be lost. In general, and as discussed below, automatic controls should be used to turn lights off when no one occupies the space. Manual controls should be used to turn lights on when the space is occupied. These principles consistently meet the demands for occupant satisfaction and energy savings. Automatic dimming during occupancy is still an area of uncertainty, because no principles have been established for occupant acceptance of the amount of dimming and the rate of dimming. This uncertainty further undermines the confidence of engineers and facility managers in dimming systems, but could be addressed with a program of human factors research.

IV. Marketing

First cost remains a barrier for lighting controls. Often the person or department that pays for the installation of lighting equipment does not receive the benefit from the reduced electrical bills. Also, in existing buildings, managers do not want the "hassle factor" of implementing a change. First cost and hassle factor have been overcome for other energy-efficient lighting technologies with demand-side management (DSM) incentive programs, market transformation program procurement, shared-savings marketing by energy service companies (ESCOs), and new code requirements. Combinations of these approaches increase market demand for energy-efficient lighting products, leading to lower product cost and market transformation. Products such as T8 lamps, electronic ballasts, and LED exit signs are examples of successful lighting market transformations. Lighting controls, however, have yet to benefit substantially from these market forces because of the difficulty in predicting the energy savings resulting from control use.

DSM program developers and evaluators, code developers, and ESCOs do not have adequate information to predict expected savings by control measures. They need to know, for example, when and for how long the control switches off or dims the lights. There are case study examples, but robust, statistically significant control use factors need to be developed that will afford the program developers confidence that a specific control installation will deliver a specific energy savings. With this confidence, controls will more likely find their way into lighting incentive programs, code provisions, and ESCO strategies.

The lighting industry is a fragmented collection of component manufacturers. No sector of the lighting community, private, public, or non-profit, is the recognized champion for lighting. Each agency works very hard to communicate the value of its own product or service. However, that communication is most often to other lighting component agents. Consequently, the lighting industry members do not and cannot communicate the value of lighting to specific markets such as auto manufacturers, health care professionals, sports and recreation, community development, etc. Remarkably, the industry remains largely uneducated about the perceived value of lighting to these sectors, focusing on market share in traditional markets rather than growing new markets. This is a significant cultural barrier to the penetration of fluorescent lighting controls into the C/I market.

In particular, lighting controls manufacturers fail to communicate the value of lighting of their products. The lighting controls manufacturers are insulated not only from the public, but also from other sectors of the lighting industry (e.g., lamp and ballast manufacturers) and from specifiers. Lutron is one notable exception. They have established themselves not as a component or even system manufacturer, but, rather, they have successfully reached the specification community by providing assurances that their lighting controls will work and will deliver value to their customers. The majority of the lighting controls manufacturers remain focused on components, which drives down price. With little profit, there is little innovation or marketing. Consequently, there has been little penetration of lighting controls into the C/I market.

The overwhelming sentiment among the installers of controls technologies, other than those produced by Lutron, is that they can make controls work, but there is no market demand. They believe that some agency needs to repeatedly and effectively communicate the value of lighting controls to building owners and facility managers. This sentiment is essentially correct, but misses perhaps the largest opportunity for fluorescent lighting controls, both static and dimming.

To understand this potential, one must first ask the basic question: “What is the value of lighting controls?” Lutron has identified a need for lighting controls in multi-use spaces, particularly conference rooms, and fulfilled it in the marketplace. There is indeed a real need for controls in these spaces. Often the conference room is a space designed to create a positive impression with customers and clients and perhaps, dynamic lighting during a meeting, meal or formal presentation. Most often AV needs in a conference or meeting room require multiple lighting levels. Lutron has focused on this market and has established a reputation for reliable solutions, albeit at a cost well in excess of the components involved.

There seems to be little or no need, however, for multiple lighting scenarios in the largest C/I spaces, private and open-plan work areas. Tasks performed by office workers do not demand sophisticated lighting controls, with one clear exception: control of sunlight and, to a lesser extent, daylight. A recent study of private offices showed that workers rarely used dimmers on a regular basis, although the majority of workers did prefer to set electric light levels in daylight spaces below those found in interior offices (approx. 500 lx). Thus, even though building occupants may perceive individual lighting control to be of some value, that perception is not a major driver for widespread implementation of control technologies.

The main driver for lighting controls is most often assumed to be energy savings. However, there is always the concern that controls may compromise the productivity of the workers in controlled spaces. Common wisdom for saving energy, therefore, requires turning lights off when the space is unoccupied. Certainly, on-off strategies such as time clocks, occupancy sensors, and even manual switching are effective and commonly employed strategies for saving energy. Indeed, there is no technical barrier to implementing these tried-and-true techniques except establishing awareness on the part of owners considering a lighting retrofit or renovation. Again, the installers of lighting controls identified this failure to communicate the value of (static) lighting controls to the important sectors of the building industry as the major barrier to their penetration into the C/I market.

To ensure against disappointment in this communication of the value of lighting controls, however, there are some important principles to be considered for simple on-off strategies that have emerged from research into lighting controls. First, the goal of static controls is to turn lights off when no one is in the space. This strategy cannot annoy the occupant or compromise the worker's productivity in the space because the space is unoccupied. Because no technology is completely foolproof, however, it is essential that there be a local, manual override to any automatic strategy to turn the light "off." For example, if a worker is working late one evening and the automatic time clock initiates an "off" command, the worker must be able to manually override the automatic command in the work space and in areas needed for exiting the work space. Again, these simple principles and the technologies for achieving energy savings are well established; there are no technical or human barriers to turning the lights off in unoccupied spaces to achieve energy savings. There is simply "a failure to communicate" that *static, on-off lighting control technologies that turn lights off in unoccupied spaces are reliable and cost effective.*

It is much more difficult; however, to garner energy savings in occupied spaces. People do not like lights to go on or off unpredictably. Although some pilot data are available, little is known about the acceptance of automatic dimming in occupied spaces. There are limits to the amount of dimming and the rate of dimming that occupants will accept, but again, no guiding principles have been established. A program of human factors research could provide valuable information.

Daylight dimming is the most obvious strategy for dimming in occupied spaces. Ideally, the natural light offsets electric light to save energy and the dimming goes largely unnoticed by the occupant. However, daylight dimming represents several significant barriers to energy savings. Most notably, it is difficult or impossible to commission commercially available photocells. Recent research and development at the Lighting Research Center offers some promise for a simplified-commissioning technology. Nevertheless, the energy saved by photocells is limited largely to windowed spaces, and these spaces represent only about 20% of the commercial building stock. The amount of energy saved by dimming electric lighting in daylit spaces is also small. One study suggests that the incremental energy savings from dimming over simple switching in daylit spaces may be only 10%. Further, the level of dimming is not usually proportional to the amount of power reduction in the lighting system. Rapid-start fluorescent lighting systems are usually employed with dimming systems because filament heat must be provided to the lamp during operation. Thus, the ballast continues to use some fixed amount of power at every level of dimming. Finally, the price of electricity is a barrier to energy savings. Electric energy is inexpensive relative to the incremental cost of dimming ballasts. Presently, dimming ballasts cost 100% more than static ballasts. All of these economic factors lead to a very long return on investment (ROI) for daylight dimming, usually more than a decade. Other strategies such as lumen depreciation and manual dimming for energy savings are also cost-prohibitive, again, not just in terms of first costs but also in terms of commissioning costs. Finally, the effects of dimming on lamp life are not, as yet, well understood by the lamp-ballast manufacturers. Anecdotal reports of premature lamp failures and other problems such as flicker and brightness striations permeate the industry and create a perception of high risk for fluorescent dimming systems.

These issues paint a very bleak picture for fluorescent dimming systems. There is little perceived value of dimming by the occupants, and there is no cost incentive for widespread investment. The simple conclusion is that the barriers are too high to be overcome to have a significant effect on energy efficiency. However, there is an important angle that has not been addressed by the lighting industry, reflecting again their insular behavior. Some states and regions in the United States are struggling to meet the growing demand for electric power at traditionally low prices. Utilities must build power capacity for peak demand, not for average demand. In California for example, peak demand coupled with inadequate supply and price caps for exceedingly high energy costs have led to sporadic blackouts and high wholesale energy costs. Dimming fluorescent systems used in conjunction with utility communication systems offer a potentially valuable means of keeping businesses operating during periods of peak demand while maintaining relatively low energy prices and, most significantly, while avoiding construction of new power plants and transmission corridors.

Central to understanding the potential value of dimming systems is an examination of the real costs of electric energy. The cost of electric energy usage for lighting can be measured in several ways, and each measurement differentially affects the value, or potential value, of lighting controls. To understand the value of lighting controls, it is necessary to delineate the costs and the benefits for all of the stakeholders when maximizing the use of electric energy with lighting controls.

The most obvious measure is the cost of the electricity used to operate the lighting system. The cost of electricity is measured in $/kWh. Depending upon the retail power supplier and the type of C/I customer, this rate will typically vary between $0.06/kWh and $0.12/kWh. Both the amount of power needed to operate the lighting and the time the lights are operated will affect the annual cost of operating the lighting. Static, on-off lighting controls can reduce both the time of operation and the number of systems operating. Dimming (step or continuous) controls can reduce the power required to operate the lighting system.

Another common measure is based upon the building peak energy use during a billing period. These peak demand charges are presently used to support the cost of installing and maintaining power infrastructure to the C/I customer. Before deregulation of the utility industry, peak demand charges also included the cost of generating and supplying power during peak periods of operation, but this is no longer the case. Static, on-off lighting controls can reduce peak demand by turning off unnecessary lighting. Dimming controls can reduce power demand without turning the lights completely off.

Both of these measurements are in place in most C/I applications and are reasonably well understood by all stakeholders when performing economic analyses. Depending on the cost of energy and peak demand, reflected in the utility billing structure, the C/I customer will or will not select lighting controls for installation. It is fair to say, however, that these measures have not been major drivers to the penetration of lighting controls into C/I applications. Less than 2% of C/I applications have more than simple manual switching for lighting control.

Although the cost of electric energy and peak demand are important, these are not the only measures that can affect the value of lighting controls. The cost of purchasing power can vary throughout the day and throughout the year. The cost of power is strictly a matter of supply and demand. As demand increases and base load is exhausted, the cost of adding additional electric power increases, sometimes exponentially. It has been estimated by the New York State Public Service Commission that during the hottest day of the year 2000, the last 100MW of power demanded in NYC cost ratepayers $100M. This is $1/W! If that peak demand for power could be reduced or if the real cost of using power during the peak was passed on to the customers that use it, the yearly average energy-use rate paid to electric utilities by C/I customers could be significantly reduced. Unfortunately, this is not the case, because there is no strong incentive to customers to eliminate wasteful energy use during peak periods of system demand. Moreover, as wasted lighting energy increases, the need for additional power generation increases to meet the ever-growing peak demand. To pay for this added capacity, the average electricity rates increase, creating increased operating costs for all C/I customers and a net economic downturn. Lighting controls offer a significant potential benefit to ratepayers, and to the economy, if two things occur. First, the peak system demand must be reduced reliably and predictably. Second, customers demanding power during peak periods should actually pay for the added costs of supplying that power, either in the bidding process or for construction of new power-plants.

It is not necessarily obvious, however, how guaranteed peak load reductions could be obtained in C/I applications. Certainly no employer would want to turn off computers, copiers, or even lights in most spaces. Few would want to increase ambient temperatures in air-conditioned spaces during hot summer days when peak demand is greatest. However, it is possible to dim the lighting in these spaces without significantly compromising the productivity of employees. In fact, no other technology that depends upon electricity is so readily amenable to load reductions. Not only will people accept some dimming, the technology for dimming is largely in place. Moreover, utility real-time pricing communication systems have been developed and are already being used in some applications. Neither the dimming nor the communication systems have been optimized and integrated.

Table 1 provides several dimming fluorescent lighting control scenarios using current pricing structures for electric energy and power demand, together with the value of avoiding expensive power and costs of adding new generating capacity. For example, consider a New York City office with luminaires containing two 32-watt lamps that are dimmed by 30% during peak demand. The price of energy is $0.10/kWh and demand charges are $18.00/kW/month. Demand charge savings would be $4.08 per year and energy savings are $1.62 per year for that dimmed luminaire, plus the value of the system demand reduction is $1.81. If the lamps are operated 50 hours a week and are dimmed 33% of this time, the ten-year present value of a load-shedding ballast would be $55.34. The cost of a dimming electronic ballast is currently between $50.00 and $60.00, while a static electronic ballast is about $20.00. Thus, the incremental cost of a dimming electronic ballast is between $30.00 and $40.00. In this example the payback for dimming electronic ballasts is at least five years. It is important to note, however, that the estimated incremental cost to manufacturers for producing a load-shedding electronic ballast that would dim to just 30% is currently between $0 and $10. This would significantly shorten payback periods to between six months and two years.

Table 1 shows that there is a value to ratepayers for *not* using electric energy for lighting. Presently, however, there are several barriers to capturing that value. First, the cost of dimming is prohibitive for several reasons. The first cost for all load-shedding control technologies is high, especially for fluorescent dimming systems. Architectural dimming ballasts cost 100% more (or higher) than static, on-off ballasts. Installation and commissioning costs are also quite high, as is the perceived increased risk for poor performance due to lamp-ballast compatibility. Second, presently there is no infrastructure (hardware and software) that guarantees load shedding from lighting controls when it is needed. In the late 1980s, guaranteed energy savings were ensured through utility rebate programs that removed less efficient (T12/magnetic ballast) lighting systems for more efficient (T8/electronic ballast) lighting systems. Without guaranteed savings from lighting controls, there is little chance for significant market penetration of lighting controls systems. New communication technologies need to be developed and coordinated with dimming fluorescent lighting systems. Third, the people who would pay for technologies that garner energy savings and load reduction are often not the ones who would benefit from those investments. High demand during peak hours is averaged over all ratepayers, rather than assigned to those who actually create the high demand. New methods of billing, such as real-time pricing, need to be implemented before there is a significant cost incentive for load reduction and energy savings. Fourth, utility rate structures only pay for load offset from current generation and transmission, not for the potential for new power plant and transmission corridor planning and construction. The US Department of Energy's Annual Energy Outlook forecasts the need for at least 1300 new power plants nationwide by 2020, about half of which could be avoided by increased energy efficiency. Yet there is no way to capture the value of lighting controls when offsetting construction of new power generation and transmission systems.

Clearly then, a combination of technical and policy barriers must be overcome before the value of lighting controls can be captured.

Table1: Dimming fluorescent lighting control scenarios for electric energy and power demand

											10 year present value	***10 year present value***	***10 year present value***	***10 year present value***
measure	power	occupancy	dim on demand	measure penetration	***measure savings***	energy rate	demand charge	demand savings	energy savings	turn off when needed	enery savings PV	demand savings PV	turn off when needed	total 10 year PV/6%int
2 lamp/ 20% dimming	**63**	**50**	**20**	**33**	**12.6**	**0.10**	**18.00**	**2.72**	**1.08**	**1.21**	**7.96**	**20.03**	**8.90**	**36.89**
2 lamp/ 20% dimming	**63**	**50**	**20**	**33**	**12.6**	**0.10**	**13.00**	**1.97**	**1.08**	**1.21**	**7.96**	**14.47**	**8.90**	**31.33**
3 lamp/ 20% dimming	**93**	**50**	**20**	**33**	**18.6**	**0.10**	**18.00**	**4.02**	**1.60**	**1.79**	**11.75**	**29.57**	**13.14**	**54.46**
3 lamp/ 20% dimming	**93**	**50**	**20**	**33**	**18.6**	**0.10**	**13.00**	**2.90**	**1.60**	**1.79**	**11.75**	**21.36**	**13.14**	**46.24**
2 lamp/ 30% dimming	**63**	**50**	**30**	**33**	**18.9**	**0.10**	**18.00**	**4.08**	**1.62**	**1.81**	**11.94**	**30.05**	**13.35**	**55.34**
3 lamp/ 50% dimming	**93**	**50**	**50**	**33**	**46.5**	**0.10**	**18.00**	**10.04**	**3.99**	**4.46**	**29.36**	**73.92**	**32.86**	**136.14**
2 lamp/ 20% dimming	**63**	**50**	**20**	**33**	**12.6**	**0.08**	**18.00**	**2.72**	**0.86**	**1.21**	**6.37**	**20.03**	**8.90**	**35.30**
2 lamp/ 20% dimming	**63**	**50**	**20**	**33**	**12.6**	**0.08**	**13.00**	**1.97**	**0.86**	**1.21**	**6.37**	**14.47**	**8.90**	**29.73**
3 lamp/ 20% dimming	**93**	**50**	**20**	**33**	**18.6**	**0.08**	**18.00**	**4.02**	**1.28**	**1.79**	**9.40**	**29.57**	**13.14**	**52.11**
3 lamp/ 20% dimming	**93**	**50**	**20**	**33**	**18.6**	**0.08**	**13.00**	**2.90**	**1.28**	**1.79**	**9.40**	**21.36**	**13.14**	**43.89**
2 lamp/ 30% dimming	**63**	**50**	**30**	**33**	**18.9**	**0.08**	**18.00**	**4.08**	**1.30**	**1.81**	**9.55**	**30.05**	**13.35**	**52.95**
3 lamp/ 50% dimming	**93**	**50**	**50**	**33**	**46.5**	**0.08**	**18.00**	**10.04**	**3.19**	**4.46**	**23.49**	**73.92**	**32.86**	**130.27**
2 lamp/ 20% dimming	**63**	**50**	**20**	**33**	**12.6**	**0.12**	**18.00**	**2.72**	**1.30**	**1.21**	**9.55**	**20.03**	**8.90**	**38.48**
2 lamp/ 20% dimming	**63**	**50**	**20**	**33**	**12.6**	**0.12**	**13.00**	**1.97**	**1.30**	**1.21**	**9.55**	**14.47**	**8.90**	**32.92**
3 lamp/ 20% dimming	**93**	**50**	**20**	**33**	**18.6**	**0.12**	**18.00**	**4.02**	**1.92**	**1.79**	**14.09**	**29.57**	**13.14**	**56.81**
3 lamp/ 20% dimming	**93**	**50**	**20**	**33**	**18.6**	**0.12**	**13.00**	**2.90**	**1.92**	**1.79**	**14.09**	**21.36**	**13.14**	**48.59**
2 lamp/ 30% dimming	**63**	**50**	**30**	**33**	**18.9**	**0.12**	**18.00**	**4.08**	**1.95**	**1.81**	**14.32**	**30.05**	**13.35**	**57.72**
3 lamp/ 50% dimming	**93**	**50**	**50**	**33**	**46.5**	**0.12**	**18.00**	**10.04**	**4.79**	**4.46**	**35.24**	**73.92**	**32.86**	**142.02**

Assumptions: controls reduce demand at times of peak demand of both the building and the system.

Assumption: $8/kW/mo given to shed load when needed to offset new plant construction and current power at expensive rates.

V. Preliminary Recommendations

The following recommendations are ordered in terms of the relative effort needed to overcome identified barriers to the penetration of lighting controls into C/I markets. The first two recommendations are focused on existing, on-off lighting controls that have been demonstrated to be cost effective and reliable. These two recommendations can be implemented immediately. The remaining recommendations represent significant investment of resources to support widespread penetration of fluorescent dimming systems. As noted in this document, there are many significant barriers to the use of dimming fluorescent systems in C/I applications. These barriers will not be overcome using traditional economic models, and should not be attempted without a much stronger financial incentive. A new economic model that incorporates the cost to society for building new power generation infrastructure does offer a realistic financial foundation for overcoming the barriers to fluorescent dimming systems.

1. Support data collection that provides fixed numbers for expected energy savings and load reductions for various static on-off lighting control technologies in various applications.

2. Support programs that overcome the inertia to first costs to static on-off lighting controls, working with building owners, professional societies, code developers, ESCOs, and conservation program developers.

3. Support functional and substantive means of communication among lamp-ballast manufacturers, controls manufacturers, controls installers, building automation system manufacturers, utilities, and government agencies charged with maintaining public benefit. The economics of load management needs to be widely understood by all stakeholders in lighting controls. The first task would be to identify key decision-makers in these different sectors, and then to provide incentives for those disparate groups to cooperatively work together. These incentives could be in the form of demonstration projects specifically designed to cooperatively link the key sectors. Incentives could also include support for cooperative technology development. In particular, two development projects are immediately envisioned:
   3a. Develop an inexpensive, highly efficacious dimming ballast that responds to load-shed signals from the utility.
   3b. Support development of open communications systems that link utility need for shedding load to building fluorescent dimming systems. This implies a standard ballast-utility interface for load shedding.

4. Support a human factors research program that establishes the principles for dimming levels and dimming rates in occupied spaces.

5. Develop a long-term labeling and testing program that provides assurances to all stakeholders that (a) the dimming ballast reliably operates the lamp under all conditions, (b) all control system components work reliably together, (c) installation and commissioning of dimming systems are reliable, (d) articulates the value of lighting controls for energy and cost savings that reflect their social value by ensuring an inexpensive and reliable supply of electrical power.

Task 3 – Identification of Manufacturing Partners – The recipient shall identify and gain commitment from manufacturing, industry, and /or standard setting partners to assure that the assessment is correct and that the proposed solutions developed in Task 2 are reasonable and will reach target markets.

The LRC submitted the recommendations summarized in the white paper to the peer review group members. A meeting with the peer review group was held on December 12th 2001. Minutes of the meeting are below. In summary, the peer review group suggested that there are currently two distinct, viable categories of lighting controls: (1) automatic shut-off and (2) dimming controls. It was consensus that automatic shut-off controls are a robust technology ready for widespread installation, while dimming controls still have substantial technical barriers and are dependent upon changes in electricity pricing systems to be cost-effective in many applications.

Minutes of the Peer Review Group Meeting
Revised February 2002

Meeting date: December 12, 2001

Location: Lighting Research Center, Troy, NY

Time: Noon to 4:00 pm

Participants: David Bay (OSRAM SYLVANIA)
Jim Benya (Benya Lighting Design)
Jennifer Brons (LRC)
Andrew Bierman (LRC)
Mariana Figueiro (LRC)
Claudia Hunter (LRC)
Russ Leslie (LRC)
Ron Lewis (USDOE) – unavoidably late
Peter Morante (Northeast Utilities)
Dave Peterson (WattStopper)
Steve Purdy (independent consultant) – unavoidably late
Mark Rea (LRC)
Mike Stein (consultant – Universal Ballast)

The meeting started at 12:30 pm. Mark Rea presented the agenda (see attached) for the afternoon and set the goals for the meeting, which included achieving consensus on a set of priorities for the project, setting a date for the round table to be held in February, and developing a list of invitees for that meeting.

All the participants introduced themselves. Mark Rea summarized the barriers of lighting control usage and the recommendations described in the white paper. A copy of the presentation is attached.

Russ Leslie opened the discussion for comments and suggestions. He clarified that the goal of the meeting was to define what to do – not how to do it.

Four members were asked to give their perspectives on issues that would complement the information included in the white paper.

Jim Benya (Understanding the triad of building operations: owner, manager, and tenant):

- Energy-efficient retrofit: There is a triangle among the building owner, manager and tenant. Each has a different financial budget, and the largest barrier is convincing each that it is worth spending additional resources on implementing an energy management strategy. The owner is concerned about the investment of capital, the manager is concerned about the effective operation of the building, and the tenant is concerned about the cost of the lease and the electric bill. One building in LA, for example, has been losing about $2 million per year because the owner, manager and user each have different interests. It is important to find mechanisms that address everyone in that triangle.

Mike Stein (Updates on status of standards):

- Update on standards pertaining to dimming:
- As fluorescent lamps dim, their behavior changes. Europeans have standardized the characteristics of lamp filaments for linear T5 and most of the single ended lamps. A dimming standard proposal for these lamps based on the "Sum of Squares" method developed at IEC workshops will be issued shortly. ANSI C78 committee will be adopting these IEC standards as ANSI standards.
- The US manufacturers would like to standardize filaments for T8 lamps, but the design and manufacturing equipment for T8 lamps in this country is very different, thus a standard may not be viable. When dimming lowers the light level below the 50% threshold, filament characteristics affect performance. Resolution to this problem appears distant.
- IEC and ANSI have analog (0 –10v) dimming ballast standards. The market is heading toward digital control (DALI). Europeans have been working on this standard for 10 years. The IEC standard is about to be approved, and ANSI will probably adopt this IEC standard.
- Controls: Nothing has been written about controlling the DALI ballast. Theoretically, the ballast, not controls, should be interchangeable. Ballast and control manufacturers are discussing the possibility of matching the ballast and controls. Bacnet is considering working to become compatible with DALI.

Jim Benya made two criticisms of DALI – it has limited zone capability and the protocol characteristics are based on European building design. Dave Peterson added that manufacturers need the same ballast suppliers and that DALI has reduced capability (up to 64 addresses) due to commissioning. Benya cautioned that we might be racing to a digital solution to solve an analog problem. He added, however, that the important matter at hand is to define the standard for protocol, and to determine later whether an analog or digital approach is appropriate.

Dave Peterson (Updates on penetration of controls on C/I markets):

- Dave Peterson showed the results of a market research survey on lighting controls, which indicated that lighting contributes substantially to energy use. In educational facilities, lighting energy use ranges from $0.38/ft^2/year to $0.92/ft^2/year.
- Of the $131 million market for lighting controls, daylight controls represent a small piece ($1 million), panels represent $71 million, and occupancy sensors represent $59 million.
- New construction (added or renovated space) accounts for 65 billion square-feet. Three to four percent of the lighting control market is used for new construction.
- Commercial office space, which includes school and retail office space, has a penetration of about 2 to 5%, perhaps 10%. Specifiers say that in education, 65% of floorspace in educational facilities and 60% of floorspace in commercial spaces (new construction) has some type of lighting control.
- Factors influencing the use of lighting controls are the owners' requests, increasing energy savings, and complying codes. Currently, there is a low level of interest for low shedding of power supplied by a utility.
- The vast majority (94%) of control users are using occupancy sensors. Sixty percent are using scheduling systems.
- Satisfaction: The least acceptable control strategy is daylighting controls usage, and the most acceptable is time clocks.
- Scheduling systems usage is the least problematic control strategy, and daylighting is the most problematic.
- Occupancy sensor: The number one barrier is failure to maintain detection, followed by non-familiarity.
- Photosensors: The number one barrier is that users desire for more lighting with photosensors.
- Impact on industry: The communications protocol systems did not work together. Another barrier is the cost of dimming ballasts. Plug-and-play solutions (integrated solutions) are starting to be known.
- How would one do it? The majority would use step, rather than continuous, switching due to cost, though continuous is preferable because it is less perceivable.
- In summary, 1) Controls are being used in new construction. 2) There is low interest in load shedding. 3) A strong attraction to dimming exists, but high cost is a barrier.

Mark Rea: Although load shed interest is low, if customers were aware of what they were being charged, they may become interested. The key is to change the way pricing costs are delivered to the customer.

Peter Morante (The customer's perspective on load management):

- A copy of the presentation is enclosed.

- There is a customer pull for lighting controls. The customer wants to keep the building operating. In terms of the pricing signal, there is currently no deregulation. In the future, states will be deregulated.
- Currently, under regulation, the customer pays the highest month's the demand charge for each of the12 months. Customers are unaware of this charge. They still do not understand how to achieve savings. The key issue is to define who pays the bill, who pays for the investment, and who has the incentive.
- The problem with electricity is that its price is determined by the capacity of the system. Electricity cannot be stored, thus, it must be paid for on a daily basis. Price doubles on normal days when the capacity reaches its maximum. At 100% capacity, the price can reach $1000 MWh.
- In Peter Morante's opinion, customers will start requesting load management when they understand how much they are paying during peak demand.

Jim Benya: The California energy crisis caused increase concern about energy savings. The market is not all that free yet. Deregulation has ended in the northwest. Electricity has a very high price. The demand for the technology will rapidly increase when customers understand how much they are paying for energy use. Cost is the number one barrier, followed by lack of standards and familiarity. Incentive finances will help overcome the cost barrier. Benya thinks we need to help eradicate the cost and familiarity barriers. External forces, such as deregulation, will help.

There are no barriers for the use of static controls (automatic shut-off). California will eliminate the below 5000 square-foot exemption for required automatic controls from Title 24 in 2005. The technology is cost-effective. The lighting industry does not have enough data to support how much energy can be saved with controls. The technology exists, and is cost effective.

Mark Rea: Static controls (automatic shut-off) are robust, should be implemented, and there are no major barriers. Consensus of the group regarding that recommendation: New construction and retrofit should be considered separately. Hard numbers can have an impact on retrofit. An educational aspect is necessary to help increase the market. Support programs should overcome barriers of installation and awareness. The term “Automatic shut-off controls” should be used rather than “static controls.”

Recommendation 3 (Load shed management):

Dave Peterson: A strong economic model of the multitude of benefits from load-shed management is needed.

Mike Stein: It is important to differentiate between dimming and step dimming. A step dimming solution may be achieved more rapidly.

Jim Benya: Step dimming already exists in California. Lack of standard protocol is the reason why dimming ballasts will not be required in the 2005 Title 24 code revisions.

David Bay: Minimal lamp and ballast R&D efforts are required to achieve lamp/ballast compatibility when dimming from 100% down to 75%. Some R&D effort will be required to achieve lamp/ballast compatibility dimming down to 50%. A significant amount of lamp and ballast R&D will be required to achieve lamp/ballast compatibility for dimming to levels below 50%.

Peter Morante: The customer's opinion regarding load management is important. The design community has accepted automatic shut-off. We need supporting programs that help overcome lack of awareness.

Jim Benya – The dimming ballast is the back end. We need to focus on the front end as well, which is how the signal is generated. No controls industry exists to deal with the problem. An industry needs to grow in order to provide the front end (controls). Integration is a problem. He handles the wiring technique by being open-minded and envisioning technologies that are easy to install and commission. Other obstacles exist besides the ballast.

Ron Lewis questioned the interactions of lighting and heating and cooling.

David Bay: The focus on end user is missing. Build in Jim Benya's triangle (explained above).

Mark Rea: Is it worth worrying about societal benefit? It is clear that we need a near-term strategy that will try to articulate more clearly and succinctly the automatic shut-off controls. Is it worth worrying about dimming today? What are we doing about dimming?

Jim Benya: Dimming is a good option for energy and management. We should work on a low-cost ballast and prepare the market for these technologies. It is important to speed up standards to use dimming.

Consensus

Automatic shut-off controls are ready for implementation. There is a need to conduct demonstrations projects that will help increase the impact of this technology in the retrofit market. An educational program to increase awareness of the benefits of these products is also necessary.

Load management strategies: Research and development activities are still necessary to help develop a technology that is low-cost, easy to install and commission, and reliable. In parallel, it is necessary that the customer understands how much he is being charged for energy, which will increase interest and demand for load-shedding.

Next Steps

The next roundtable was set for February 5th in Washington, DC (NEMA's headquarter). Mark will contact each member to sketch out an agenda and finalize the list of invitees individually.

The LRC will sort out some of the economic models, address customer perspectives, and revise the white paper accordingly.

Postscript to the minutes

The LRC staff followed up with everyone at the meeting, including those who could not attend. Impressions of the meeting were obtained and additional suggestions were solicited. Everyone was complementary but felt there was too little time to discuss all the issues. Based upon this feedback it was decided, in full collaboration with the peer review group, to concentrate on the automatic-off controls on February 5, 2002 and on load-shed ballast specifications on January 23, 2002. In late February or early March of 2002, a meeting will be held to discuss future strategies for peak load reduction amongst regulators, electric power suppliers, and controls manufacturers. In August 2002 a general meeting will be held to integrate all three of these "break-out" sessions.

The LRC staff participated in a meeting with James Gallagher (Chief, Retail Competition Section, Office of Electricity & Environment – Public Service Commission, New York State), a member of the peer review group. They had an in-depth discussion on the future for peak load reduction and how load-shed, lighting controls could play an important role in reducing energy use and peak demand in commercial and industrial applications. They also outlined an agenda for a meeting in the first quarter of 2002. Invitees will share their perspective on load management and will develop an action-plan for integrating lighting controls into load management strategies.

In addition, the LRC staff has set up a meeting of key people in the manufacturing side (David Bay, OSRAM SYLVANIA; Al Russeau, Philips Lighting; Bob Erhardt and Sree Venkit, Advance Lighting; Mike Stein, Universal ballast; Ed Yandek, GE Lighting) on January 23 in Troy, NY to develop performance specifications for load-shed ballasts. This new technology would require a very small incremental cost but would be able to reduce electric power on demand.

Load-shed Management

The peer review group recommended that the project be bifurcated and that automatic shut-off be treated separately from dimming. As a result, the LRC decided to conduct two roundtables: one on barriers to widespread use of automatic shut-offs; the other on load-shedding technologies. The LRC held a meeting on January 23rd 2002 with the three major lamp and ballast manufacturers to discuss the development of a performance specifications for load-shed fluorescent systems. This new technology would require a very small incremental cost but would be able to reduce electric power on demand.

In the meeting held on January 23rd 2002, manufacturers helped develop a performance specification for load-shed fluorescent systems. The representatives of the manufacturers agreed to go back to their organizations and get feedback on the issues discussed in the meeting.

LRC agreed to gather information from utility personnel involved with communications (power line carriers - PLC) on current performance of utility-to-customer signaling strategies. In addition, the LRC will also contact parties specifically interested in load management to talk about future pricing of energy to the customers.

The LRC plans to bring these three groups of people together late in 2002 to discuss the ways to overcome the barriers to the widespread use of load-shed dimming controls.

Meeting Minutes

Load Shed Ballast Performance Specification Drafting

January 23, 2002

Project: Reducing Barriers to Efficient Lighting Systems

Sponsor: US Department of Energy

Meeting attendees

Ed Yandek (GE Lighting)
Mike Stein (Universal Ballast)
David Bay (OSI)
Roger Hunt (OSI)
Al Rousseau (Philips)
Stuart Berjansky (Advance Transformer)
Mark Rea (LRC)
Andrew Bierman (LRC)
Francisco Garza (LRC)
Mariana Figueiro (LRC)
Conan O'Rourke (LRC)
Russ Leslie (LRC, arrived late)

The meeting started at approximately 9:00 am

Mark summarized the project, its goals and objective, its tasks, and its outcomes.

At this point in the project, there are two distinct activities: Automatic shut-off controls and dimming/load shedding. For automatic shut off there are no barriers for new construction, but some barriers on retrofit. Meeting on Feb 5th to try to reduce these barriers.

This meeting concentrated on load shedding. We are trying to be ahead of the curve, because we believe that there will be a greatly increasing market for load-shedding in the near future. Mark will be meeting with parties specifically interested in load management to talk about future pricing of energy to the customers. The unregulated side of the utility is going to be the primary focus of the discussion at this time. We see a potential penetration of controls for load management if we are ready with a technology that the market wants.

Mark asked Ed to summarize discussions from the previous evening.

Ed: We have a choice. Either do typically what we have been doing, that is, moving slowly (glacial movement) and working apart, or we can get a group of people together and get things to happen more quickly and show how things are going to happen. A consortium can make an impact (e.g., Bluetooth) if we decide that's what we want to do, and be committed to do it.

To make things happen quickly we need a complete system, that is, specify how the whole system works from A (utility) to B (building) to C (ballast)

David: Bold is to look into the future and at technology at the same time.

Ed: Utilities must be committed to implement this type of load shedding.

David: Who is going to benefit from it [this new load shed technology]?

Mark: Reduce the power consumption during peak demand – utility customers and society as a whole will benefit

Roger: It takes a large volume to make this type of product financially possible. It's not only about the product, but all the pieces involved with the product.

Mike: We need to, as an industry, know what we are doing and propose a solution that all of us agree on and go to them with a solution. We have to come up with a solution that benefits the manufacturers too.

Roger: There are a limited number of ballasts and sockets…what are you going to displace by using load shed ballast?

Mark: It depends on whether you think load management is important to people in the future. If we don't believe that, we are wasting our time. We think that load management is going to rise in importance and popularity and be a major economic driver in the near future.

Stewart: Utilities already have a rebate program for load shed on air conditioners and heaters.

Al: An upfront approach may be more beneficial than waiting until things happen.

Ed: Using IT [information technology] model, we [the lighting industry] are going to design a protocol and put it in the market. We don't work that way historically. The forces are lining up and we are getting ready to provide the market with a solution.

Mark: We would be in a much stronger negotiation position if we come together as an industry and present a solution.

David: This could be similar to what happened with the FCC regulations for high frequency lamp operation. In that case we got together and presented a plan to the FCC, which they adopted, to all our benefit.

Two drivers: regulated and unregulated side. Reducing peak demand for power is already a market. The regulated side is still unclear, but we are anticipating that they are going to real time pricing.

Andrew: Let's work on the definition of load shed. What is it? Is it a load management device controlled by whoever is responsible for the building? Is it a system that is fairly secure, or do you need to give this access to the facility manager so that he can, for example, react to real-time pricing?

Ed: Guidelines – control the range of operating scenarios. Outside this range is not included in the guarantee [on the performance of the system, e.g. lamp life].

Mark diagrammed the signaling path for load shed from A (utility) to B (building) to C (ballast).

Mike: There might be a D and E, not just a C. In other words, inside the building there could be many parts.

Mark: Let's work on the curve [cost versus amount of dimming]. How much dimming can we get at a reasonable cost? Then we can work on the specification, then on the signal to the ballast (what are we putting in the ballast that makes it a load-shed ballast).

How much can lamps be dimmed? 50%?

[General question and discussion] 50% of what ballast factor? What is the baseline ballast? Most commercial ballasts have a ballast factor of 0.88. T-8 lamps are designed for operation on a reference ballast at 260 mA. Typical full output of commercial high frequency ballasts range from 140 to 180 mA. Lamps are optimized for conditions that are rarely used.

Ed: If this [load-shed] becomes a big thing, I can imagine optimizing the lamp for load shed. This provides an incentive to re-optimize T-8s to run, at say, 180 mA.

Andrew: We can look at two scenarios; load shed often and load shed rarely.

Ed suggested that we base the amount of load shed on Peter Morante's data of actual building load curves.

Assumption – we can go down lower if load shed occurs less frequent. Based on Peter Morante's data for an office building, if 30% of load is shed, this will happen 12% of the time.

Mike: We must keep in mind that we don't want to rob occupants of proper light levels.

Ed: Let's test this on a less expensive solution (only the 20% reduction with an instant start system) and test the solution with the utilities. If it works, we can expand the work. Program start ballasts are being pushed to the people that are using occupancy sensors. Programmed start can be used for greater dimming because it heats the electrodes.

Andy presented data from Specifier Reports. In going to a rapid start system there is a loss in efficacy. However, we don't know about life. We can get the demand savings, but the cost of running may be higher.

[General consensus] We can do 20% now without affecting lamp life so much. In the future we can try to go lower, if this is successful.

Mike: The 0.88 ballast factor is the platform we should agree on. Concerned that we are talking about 50% dim. 25% of ballasts have a ballast factor of 0.78.

David wrote the following list on the blackboard.

"Plus" HF		1.2	260 mA	
Full light	60Hz	1.0	260 mA	
Full Light	HF	1.0	210 mA	
	HF	0.88	180 mA	(70% of market)
	HF	0.78	155 mA	(25% of market)

Load shed <200 hrs 100 mA (1% of the time)

200 – 1000 hrs	120 mA (5% of the time)
1000 – 2000 hrs	140 mA (10% of the time)

Above table is for rated life of 20,000 hours. Rated life is for 3 hrs on, 20 minutes off. Nobody actually operates lamps on this short a cycle, so life is extended.

As long as lamp current stays above 140 mA, the 10% of the time operation could be 90% without decreasing life.

A safety margin is important for line voltage fluctuations, component tolerances and temperature variations.

Ed drew a graph showing how life slowly decreases as current is reduced up until some threshold, or knee in the plot (130 mA) where life decreases rapidly with further reductions in current. 130 mA is the lower limit of his comfort zone.

Mike: The system to consider must be for a retrofit scenario – ballast factor of 0.88, 180 mA as baseline.

Assume that we want to do it at 5% of the time. There will be zero risk, minimal impact on lamp life if it goes down to 120mA at nominal line voltage (120 V) for on average 5% of the time (off a 0.88 ballast factor instant start ballast).

Magnetic market is about 80%, but it is difficult to know for sure. 50% of sales are still magnetic ballasts. Maybe we can motivate the market to retrofit the magnetic ballast. 66% installed or more is T12.

Russ Leslie and others did some calculations of demand savings using data presented at the DOE project roundtable meeting in December, 2001 (Table 1 of handout). As an example, a 3-lamp ballast capable of reducing power by 30% corresponds to a $6/ballast/year building demand savings and a $3/ballast/year system demand reduction savings. The future value of such savings would be about $65 over a 10 year ballast life. The above numbers assume a $8/kW/month utility incentive to shed load when needed and an $18/kW/month building peak demand cost.

The 5% of time limitation placed on dimmed lamp operation easily absorbs all the time of high system demand when load shedding would occur under a real-time pricing scenario.

We need to go to the utilities' people and ask them if the technology excites them and if they are willing to support that. Everyone here needs to go back and check the proposed loadshed specification.

We need to talk to the utility industry about their rebate and load control programs.

The discussion turned to the topic of signaling and communications

Power line carriers (PLC) may be a solution. How low cost can it be? Once I am in the building, everybody will do the same thing. The advantage is that we are talking about little information. We want to minimize interference. Look at the utility programs and determine what are the signals and equipment that they are using. This may be used for the lighting signal.

Search on the products that are out there before making any assumptions on the types of signals, etc.

Ballast receives a signal every 10 minutes.

Must have means so cycling the power on/off does not defeat that load shed.

How well can PLC signals be isolated within buildings and for a particular tenant? Problems may arise when signals extend beyond the building/tenant.

Zoning becomes too costly though.

The problem can be solved with contracting. The utility will know whether the demand was actually reduced.

Signaling, metering, PLC technology - people from utilities that understand about these issues can help us solve the problem. Push a lot of the information/intelligence to the control; instead of on the ballast is a good idea. Keep the ballast as low cost as possible. Basically the ballast only contains a switch and the necessary circuitry to decode the PLC signal.

Two inputs to the controller may be needed to initiate load shed: one based on building power demand and one for a utility generated signal. This could be implemented as a simple or-gate.

Next, go to utility people to discuss with them interfacing with large customers. They will validate our economical perspective as well. They can share with us what works and what does not work.

Utilities will likely want a pilot program.

David: Incremental cost is around $1 a ballast; incremental price is $2 a ballast for PLC reception.

Summary

- Assignment – manufacturers to go back and make sure those are likely numbers.
- Signaling- ballast is only able to decode the signal it is receiving. Manufacturers need to go back and find out the cost of the options. Minutes to be distributed by end of business day on Friday. Two weeks for the manufacturers to get back with information.
- LRC will gather information from utility personnel involved with communications (PLC) on current performance of utility-to-customer signaling strategies.
- Next meeting may be in a utility site in a month to discuss this specification.
- A Phase 2 could potentially include T8 and T5 lamps (T5 is optimized for lower current).

Automatic Shut-off

The LRC has been working with market transformations groups, federal and state agencies, and manufacturers to promote the development of programs that will increase the widespread use of automatic shut-off controls. A short white paper was developed summarizing the findings during the first year on automatic shut-off and a few recommendations were made to increase the market penetration of automatic shut-off controls in retrofit applications. The findings and recommendations detailed in the white paper were distributed to all the round table participants and discussed during the meeting. A summary of the recommendations that the group agreed upon is provided below.

The white paper summarizing the findings and recommendations for automatic shut-off controls is below.

Overcoming Barriers to Widespread Use of Lighting Controls in Commercial/Industrial Applications

Part 1: Automatic Shut-off Controls

Background

Under funding from the US Department of Energy, the Lighting Research Center (LRC) is identifying barriers to the widespread penetration of lighting controls in commercial and industrial (C/I) applications and making recommendations to overcome these barriers. Since fluorescent lamps are the predominant technology in C/I applications, the focus of this project is the control of fluorescent lighting systems.

The LRC reviewed existing research, technology, patents, and market data related to lighting controls, interviewed control manufacturers, surveyed control installers, and conducted a peer group review to improve and validate a set of preliminary recommendations. Two distinct categories of controls were identified, each with their own set of barriers: dimming controls (architectural dimming, load shed dimming, and photosensor-activated daylight dimming) and automatic shut-off controls (occupancy sensors and timers). Dimming controls still have substantial technical barriers and are dependent upon changes in electricity pricing systems to be cost-effective in many applications. Automatic shut-off controls, however, are technologically robust, less expensive, and ready for widespread installation.

Because these differences between dimming controls and automatic shut-off controls need to be addressed by different stakeholders, the peer group review recommended a bifurcation of the project. This paper and roundtable only addresses the barriers to the widespread penetration of automatic shut-off controls. A parallel effort is being made to reduce the barriers to widespread use of dimming controls.

Penetration of automatic shut-off controls for fluorescent lighting systems into C/I applications can be increased, particularly if market transformations groups, specifiers, government agencies, and manufacturers collaborate to help reduce the remaining barriers to the use of this robust control technology.

Automatic shut-off controls

Automatic shut-off controls turn off lamps when a signal is received from an occupancy sensor (“unpredictable scheduling”) or from a time-of-day scheduling device (“predictable scheduling”). There are several different ways this can be accomplished, including the use of building automation systems, energy management systems, individual time clocks, wallbox mounted devices, and various combinations of relays, sensors and control panels. Since lamps are not dimmed the increased cost of the dimming ballast and controller is avoided. There are several issues relevant to widespread deployment of automatic shut-off controls:

Market Penetration: Retrofit vs. New Construction

Automatic shut-off controls are becoming commonplace in new construction; some estimates indicate that 60% of commercial projects now utilize them. Current and planned energy-code provisions, the ease of installation in new construction, and the potential energy savings will continue to increase the penetration of automatic shut-off controls in new construction. To capture additional penetration of automatic shut-off controls in new construction, the most effective approach to widespread penetration includes specifier education and more pervasive code requirements and/or enforcement.

However, according to the Energy Information Agency, annual new construction represents only 1-2% of the total floor space lit in the US. Penetration of automatic shut-off controls in existing buildings is poor.

Retrofitting existing buildings with automatic shut-off controls presents several barriers not present in new construction:

- Wiring is usually more difficult and expensive in a completed building compared to wiring while a building is under construction;
- In new construction, automatic controls can be purchased instead of manual controls; in retrofit construction, the manual controls they are replacing have already been purchased;
- Lighting and electrical plans are drawn for new construction, providing an opportunity where automatic controls can be easily considered and integrated into the plans. Electrical or lighting plans for renovations in existing buildings are seldom redrawn, especially for minor alterations.
- Energy code provisions often do not apply to existing buildings unless they are undergoing major renovations;
- “Hassle factor” is perhaps the greatest barrier. Building owners and tenants are focused on their businesses and seldom have the time or interest to consider redoing their lighting or control systems.

The overwhelming sentiment among the installers of automatic shut-off controls is that they can make controls work, but there is a small market demand in existing buildings. They believe that some agency needs to repeatedly and effectively communicate the value of lighting controls to building owners and facility managers. Partnerships between manufacturers and public benefit market transformation parties need to be formed to develop programs to retrofit buildings with automatic shut-off controls. These partnerships are necessary to reap the large untapped, energy savings potential in existing buildings.

Lamp/Ballast System Reliability

As a consequence of the energy crisis of the 1970s, significant improvements in the efficacy of fluorescent systems were achieved in the last two decades of the 20th century. The physical, electrical, and photometric properties of fluorescent lamps and ballasts were continually optimized during this era to improve not only efficacy, but also to give them smaller size, better maintenance (lumen depreciation and life), lower mercury content, and higher visual quality (better color rendering and reduced flicker). This evolving sophistication has led to higher and higher expectations for fluorescent system performance in terms of energy efficiency, maintenance, visual satisfaction and, of course, low initial cost. One down side of this sophistication, however, has been the proliferation of products that provide poor system reliability. Lamps operated on ballasts that do not have optimized starting and operating electrical properties for those lamps will fail prematurely, leading to dissatisfaction among specifiers, owners, and facility managers. This was a common situation in the 1980s and early 1990s as the electronic ballast manufacturers learned how to operate lamps produced by the “big three” global manufacturers: GE, Philips and OSRAM, but those days are essentially over for C/I on-off fluorescent lighting systems, largely because the global manufacturers have taken control of the specifications for ballasts that operate their lamps. Today, the stories of poor reliability mostly refer to fluorescent systems operated with dimmers and/or residential-grade products.

The remaining lamp/ballast compatibility issue for automatic shut-off controls is the effect of frequent switching on lamp life. BAS, panel controls, and timers are usually not configured so that the lamps are frequently switched. On the other hand, occupancy sensors set for short time delays and located in frequently used locations such as stairways, large restrooms, and hallways could cause frequent switching and therefore, shortened lamp life. Premature lamp failures in these instances could create a generalized barrier to the use of automatic shut-off controls.

The Human Element: Manual On and Overrides

Some important principles for automatic shut-off controls have emerged from research into lighting controls. The goal of automatic shut-off controls is to turn lights off when no one is in the space. This strategy will not annoy the occupant or compromise the worker’s productivity in the space because the space is unoccupied. In general, manual controls should be used to turn lights on when needed; automatic controls should be used to them off when no one occupies the space. This manual on/automatic off approach reduces false triggering of occupancy sensors and prevents lights from being turned on needlessly when daylight is sufficient for the occupants or when the lights are not otherwise needed in the space.

Because no technology is completely foolproof, however, it is essential that there be a local, manual override to any automatic strategy. For example, if a worker is working late one evening and the automatic time clock initiates an “off” command, the worker must be able to manually override the automatic command in the work space and in areas needed for exiting the work space. However, engineers and facility managers seem hesitant to provide manual override, because it is assumed that people will use them too often and energy savings will be lost. To address their concern, manual overrides capabilities should be designed to automatically reset to automatic shut-off mode after each use.

Programs to Overcome Barriers

First cost remains a barrier for lighting controls. Often the person or department that pays for the installation of lighting equipment does not receive the benefit from the reduced electrical bills.

Also, in existing buildings, managers do not want the "hassle factor" of implementing a change. First cost and hassle factor have been overcome for other energy-efficient lighting technologies with demand-side management (DSM) incentive programs, market transformation procurement programs, shared-savings marketing by energy service companies (ESCOs), and new code requirements. Combinations of these approaches increase market demand for energy-efficient lighting products, leading to lower product cost and market transformation. Products such as T8 lamps, electronic ballasts, and LED exit signs are examples of successful lighting market transformations. Lighting controls, however, have yet to benefit substantially from these market forces, at least in part, because of the difficulty in predicting the energy savings resulting from control use.

DSM program developers and evaluators, code developers, and ESCOs do not have adequate information to predict expected savings by control measures. They need to know, for example, when and for how long the control switches off the lights. There are case study examples, but robust control use factors need to be developed that will afford the program developers confidence that a specific control installation will deliver a specific energy savings. With this confidence, controls will more likely find their way into lighting incentive programs, code provisions, and ESCO strategies.

Again, there are no technical or human barriers to turning the lights off in unoccupied spaces to achieve energy savings. There is simply "a failure to communicate" that *automatic shut-off lighting controls that turn lights off in unoccupied spaces are reliable and cost effective.* These principles consistently meet the demands for occupant satisfaction and energy savings.

Preliminary Recommendations

Aggressively encourage the widespread deployment of automatic shut-off lighting controls in existing and new C/I buildings.

The following actions, listed in descending order of priority, overcome the identified barriers to the penetration of lighting controls into C/I markets. They are focused on existing, automatic shut-off lighting controls that have been demonstrated to be cost effective and reliable. These recommendations can be implemented immediately.

1. Bring together various stakeholders interested in increased penetration of automatic shut-off lighting controls (manufacturers, specifiers, government, public benefit energy efficiency groups, building owners) to prioritize approaches and form implementation partnerships that overcome the hassle factor and/or first cost barriers to automatic shut-off lighting controls in existing buildings, such as:
    a. campaigns for specifiers and customers
    b. education/training of qualified technicians
    c. rebate programs
    d. procurement programs for large real estate
    e. labeling programs that will assure quality of the products
    f. model specifications and standards.
2. Support data collection that provides fixed numbers for expected energy savings and load reductions for various automatic shut-off lighting control technologies in various

applications. Develop simple guidelines for setting time delays on occupancy sensors used in spaces that frequently change from occupied to unoccupied.

   a. research and development

   b. demonstrations and evaluations.

3. Encourage use of automatic shut-off controls that:

   a. have manual on/automatic off capabilities

   b. reset to automatic off mode after each manual override

   c. for retrofit occupancy sensors, can be installed without power wiring in a switch run and operate fluorescent lighting systems.

4. Encourage more stringent code provisions requiring automatic shut-off lighting controls for new construction and substantial renovations.

Roundtable: Recommendations from Attendees
February 5, 2002

Despite the diverse backgrounds of the attendees, there was much agreement about the most important aspects of automatic shut-off lighting controls. In general, the group agreed that industry should aggressively encourage the widespread deployment of automatic shut-off lighting controls in existing and new C/I buildings. Specific recommendations were focused on five main aspects, 1) the need for outreach/education, 2) the need to provide more information for decision makers, 3) the importance of code requirements, 4) the need for technology performance specifications, and 5) the need for a coordinated effort.

1. Outreach / Education

- Develop "best practice" documents: Specifiers and installers need best practice documents based on consensus. This document would explain which technologies are most appropriate for each class of application, how/where they should be installed, and appropriate features.

2. Decision making

- Collect data: Building owners / decision makers need defensible estimates about how much they can expect to save in *their* building. Data collection is necessary, to provide fixed numbers for expected energy savings and load reductions for various automatic shut-off lighting control technologies in various applications.
- Owner focus group: A focus group with large customers needs to be convened.
- Aggregate data and articulate to decision makers: Present the value of automatic shut-off lighting controls to decision makers, in their terms.

3. Code compliance

- Encourage nationwide code requirements: More stringent code provisions and enforcement need to be established, requiring automatic shut-off lighting controls for new construction and substantial renovations.

4. Technologies

- Develop, peer review, and disseminate performance specifications for automatic shut-off lighting controls.

5. Coordinated effort

- Establish coordination: Under direction from DOE, identify a national market transformation group to bring together all the stakeholders interested in increased penetration of automatic shut-off lighting controls. This group would prioritize approaches and form implementation partnerships between manufacturers, specifiers, government, public benefit energy efficiency groups, and building owners.

The round table was the last deliverable of this first year. A project review meeting was held on February 6^{th} 2002 in Washington DC.

Appendix 2.1 A

List of Patent Assignee Names and Preliminary Key Words Used for Patent Search

Company name
ABB Control Inc.
ACE Compact Electronics
ADB Airfield Solutions
Ademco Sensor Co (ASC)
Advance Transformer
Advanced Control Technologies Inc
Agilent Technologies
Alerton Technologies, Inc.
American-De Rosa Lamparts Inc
Amperlite Company Inc
AMX (consolidated into PANJA Inc)
Andover Controls Corporation
Antron Compact Electronics Inc
Architectural Lighting Management
Aromat (Panasonic)
Automated Logic Corporation
AVAB America Inc
B & L Technologies Ltd
Blackbird
Bryant Electric (Hubbell)
Colortran (Leviton)
Cooper Lighting
Crestron
Cutler Hammer (Eaton)
Delta Controls Inc
Denki Corporation of North America
Douglas Lighting Controls Inc
EBW Electronics Inc
Echelon Corporation
Electronic Lighting Inc
Electronic Theatre Controls Inc
Elk Products Inc
Energy Savings Inc.
Fulham Company Inc
Future Wave Technologies
GE Industrial Systems
GE Lighting
Genlyte - Lightolier Controls
Genlyte / Thomas
GE-Smart
Gilbert Manufacturing Company Inc
H I Solutions Inc
Harrison Toshiba Lighting USA, Inc
High End Systems Inc
Honeywell
Horton Controls / Watt Stopper
Howard Industries Inc
HUB Electric/Vara-Light/Dimatronics
Hubbell and Hubbell Lighting
Hunt Controls Systems Inc
IBM Mylonas Lighting Company

Irideon Inc (purchased by ETC)
Johnson Controls Inc
JRS Technology Inc
Keegan Wireless
Kelar Controls Inc
Kingtec Inc
K-Tronic Ballasts
Lawrence Berkeley Labs
Company Name
LEAX Lighting controls
Lehigh Electric Products
Leviton (LON products group)
Leviton Lighting Control Division
Lighting & Power Source, LP
Lithonia Lighting (controls)
Lithonia Lighting Canada
Lumion Corporation
Lutron Electronics Co Inc
MagneTek Lighting Products Group
Marco Electronics (now NSI Corp)
Marinco Industrial Group
Marlin Controls Inc
MaxLite
Microlites Scientific
Molex Incorporated
MYTEC Corporation
N.V. ADB-TV Tech S.A. (Siemens)
NexLight

North Point Engineering (now Nexlite)
Novar Controls Corporation
Novitas Inc
Osram Sylvania/ Ballast Division
Panja Inc
Paragon Electrical Products
Pass & Seymour/ Legrand
PCI Lighting Control Systems Inc
PLC Multipoint Inc
RAB Electric Mfg Co Inc
Robertson Worldwide
Semper Fi Power Supply Inc
SensorSwitch Inc
Siebe Environmental Controls (Invensys)
Siemens Automation
Siemens Building Technologies Ltd
Sine Systems/Pyle Connector Corp
SLI Lighting Inc
SLS Industries/UNIDIM
Smart America
Square D Company
Sterner Controls
Strand Lighting Canada Inc
Strand Lighting Inc
Sunpark Electronics Corporation
The Watt Stopper / Pass & Seymour
Thomas Lighting
Tork

Touch-Plate Lighting Controls
Trane
Trend Group Inc
Triatek Inc
Tridonic Inc. (North America)
Unenco (Hubbell)
Vantage
Vantage Lighting Inc
Veam
Visonic Inc
X-10 USA Inc
Xitron Technologies Inc
Key Words
Adaptation compensation
Addressable ballasts
BacNet
Ballasts
Building automation
Commissioning
Communications
Control interoperability
Control panels
Controls
Daylight
Daylighting

Dimming ballasts
Dimming electronic ballasts
Home Automation
Intelligent controllable ballasts
Lighting relay panels
Load shedding
LonWorks
Lumen maintenance
Manual dimming
Occupancy
Peak demand limiting
Photosensors
Power line carriers
Programmable relay panels
Scheduling
Sensors
Smart building controls
Standard protocols
Task tuning
Theatrical controls
Time clocks
Timers
Tuning
Wall controllers
Whole building integrated control systems

Appendix 2.1 B

Patent Listing Sorted by Technology Categories

U.S. Patent Number.	Applicant/Company	Category	Subcategory	Patent Title
6121734	Barna Szabados	Ballast	Ballast control	Apparatus for dimming a fluorescent lamp with a magnetic ballast
6072284	Duro-Test Corporation	Ballast	Ballast control	Three-way compact fluorescent lamp ballast and lamp holder incorporating same
5828182	Electronic Lighting Inc.	Ballast	Ballast control	Apparatus for supplying power from a ballast circuit to an auxiliary load
5936357	Energy Savings, Inc.	Ballast	Ballast control	Electronic ballast that manages switching frequencies for extrinsic purposes
6137239	Energy Savings, Inc.	Ballast	Ballast control	Electronic ballast with selective load control
6177769	Energy Savings, Inc.	Ballast	Ballast control	Electric Ballast with selective power dissipation
6181072	EZ Lighting, LLC	Ballast	Ballast control	Apparatus and methods for dimming gas discharge lamps using electronic ballast
5701059	General Electric Company	Ballast	Ballast control	Elimination of striations in fluorescent lamps driven by high-frequency ballasts
5703441	General Electric Company	Ballast	Ballast control	Multi-function filament-heater power supply for an electronic ballast for long-life dimmable lamps
5965985	General Electric Company	Ballast	Ballast control	Dimmable ballast with complementary converter switches
5994840	General Electric Company	Ballast	Ballast control	Controlling the transmission of light from light sources
6008593	International Rectifier Corp.	Ballast	Ballast control	Closed-loop/dimming ballast controller integrated circuits

5838116	JRS Technology, Inc.	Ballast	Ballast control	Fluorescent light ballast with information transmission circuitry
6107755	JRS Technology, Inc.	Ballast	Ballast control	Modular, configurable dimming ballast for a gas-discharge lamp
6181086	JRS Technology, Inc.	Ballast	Ballast control	Electronic ballast with embedded network micro-controller
6218787	JRS Technology, Inc.	Ballast	Ballast control	Remote dimming control system for a fluorescent ballast utilizing existing building wiring
5949196	Lumatech Corp.	Ballast	Ballast control	Method and system for switchable light levels in operating gas discharge lamps with an inexpensive single ballast
6040661	Lumion Corp.	Ballast	Ballast control	Programmable universal lighting system
5841239	Lutron Electronics Co., Inc.	Ballast	Ballast control	Circuit for dimming compact fluorescent lamps
5864212	Lutron Electronics Co., Inc.	Ballast	Ballast control	Control system for providing power to a gas discharge lamp
6060842	Ming-Chao Lin and Liu-Chih Wang	Ballast	Ballast control	Electronic ballast lighting power control device
6133697	Mitsubishi Denki Kabushiki Kaisha	Ballast	Ballast control	Dimming apparatus for fluorescent lamps
6194841	Mitsubishi Denki Kabushiki Kaisha	Ballast	Ballast control	Discharge lamp lighting device
6181085	Ole K. Nilssen	Ballast	Ballast control	Electronic ballast with output control feature
6037722	Pacific Scientific	Ballast	Ballast control	Dimmable ballast apparatus and method for controlling power delivered to a fluorescent lamp
5866993	Pacific Scientific Co.	Ballast	Ballast control	Three-way dimming ballast circuit with passive power factor correction

6011360	Philips Electronics North America Corp.	Ballast	Ballast control	High efficiency dimmable cold cathode fluorescent lamp ballast
6118228	Sandor Pal	Ballast	Ballast control	Electronic ballast for fluorescent lamps
6168289	Suresh H. Shah	Ballast	Ballast control	Straight fluorescent tube that has an electronic ballast housed in the sockets on both sides
6172466	The Hong Kong University of Science and Technology	Ballast	Ballast control	Phase-controlled dimmable ballast
6208122	Triatek, Inc.	Ballast	Ballast control	High frequency pulse width modulation of AC current for control of lighting load power
6094016	Tridonic Bauelemente GmbH	Ballast	Ballast control	Electronic Ballast
6051938	U. S. Philips Corp.	Ballast	Ballast control	Dimmable ballast with active power feedback control
6078147	U. S. Philips Corp.	Ballast	Ballast control	Discharge lamp ballast circuit with duty cycle dimming control
6084362	Wen-Shin Chao	Ballast	Ballast control	Electronic ballast capable of linear and stepless light regulation
6176594	Herbert Lagin	Ballast	Ballast fixturing	Streamlined fluorescent lamp ballast and mounting assembly
5908235	JRS Technology	Ballast	Ballast fixturing	Ballast fixture for fluorescent lighting
5788527	MagneTek	Ballast	Ballast fixturing	Electrical connector with improved safety latching for a fluorescent-lighting ballast
5907218	The Whitaker Corp.	Ballast	Ballast fixturing	Fluorescent lighting assembly with integral ballast
5872431	Ahmed;Zahir M.	Ballast	Lamp operation	Efficient power transfer in electronic ballast
5900701	Allied Energy Services International.Inc.	Ballast	Lamp operation	High frequency electronic ballast for lighting

6107751	Billings;Keith	Ballast	Lamp operation	Current fed, parallel resonant ballast
5801492	Bobel;Andrzej	Ballast	Lamp operation	Electronic ballast for gas discharge lamp having primary and auxiliary resonant circuits
6175189	Bruce Industries,Inc.	Ballast	Lamp operation	Floating reference fault protection circuit for arc discharge lamp ballast
6091210	Cavolina: Alejandro	Ballast	Lamp operation	Electronic ballast with boost converter
6137233	Electro-Mag International, Inc.	Ballast	Lamp operation	Ballast circuit with independent lamp control
6028399	Electro-Mag International,Inc.	Ballast	Lamp operation	Ballast circuit with a capacitive and inductive feedback path
6069455	Electro-Mag International,Inc.	Ballast	Lamp operation	Ballast having a selectively resonant circuit
6100645	Electro-Mag International,Inc.	Ballast	Lamp operation	Ballast having a reactive feedback circuit
6100648	Electro-Mag International,Inc.	Ballast	Lamp operation	Ballast having a resonant feedback circuit for linear diode operation
6127786	Electro-Mag International,Inc.	Ballast	Lamp operation	Ballast having a lamp end of life circuit
6160358	Electro-Mag International,Inc.	Ballast	Lamp operation	Ballast circuit with lamp current regulating circuit
6181082	Electro-Mag International,Inc.	Ballast	Lamp operation	Ballast power control circuit
6181083	Electro-Mag International,Inc.	Ballast	Lamp operation	Ballast circuit with controlled strike/restart
6222326	Electro-Mag International,Inc.	Ballast	Lamp operation	Ballast circuit with independent lamp control
5635825	Electronic Lighting,Inc.	Ballast	Lamp operation	Power factor corrected feed forward coupled DC power supply
5789866	Energy Savings, Inc.	Ballast	Lamp operation	Electronic ballast with reversibly wound filament winding

5493180	Energy Savings,Inc.	Ballast	Lamp operation	Lamp protective, electronic ballast
5493181	Energy Savings,Inc.	Ballast	Lamp operation	Capacitive lamp out detector
5500576	Energy Savings,Inc.	Ballast	Lamp operation	Low height ballast for fluorescent lamps
5747941	Energy Savings,Inc.	Ballast	Lamp operation	Electronic ballast that monitors direct current through lamp filaments
5925990	Energy Savings,Inc.	Ballast	Lamp operation	Microprocessor controlled electronic ballast
5973455	Energy Savings,Inc.	Ballast	Lamp operation	Electronic ballast with filament cut-out
5982113	Energy Savings,Inc.	Ballast	Lamp operation	Electronic ballast producing voltage having trapezoidal envelope for instant start lamps
6023132	Energy Savings,Inc.	Ballast	Lamp operation	Electronic ballast deriving auxiliary power from lamp output
6049177	Fulham Co. Inc.	Ballast	Lamp operation	Single fluorescent lamp ballast for simultaneous operation of different lamps in series or parallel
5517086	General electric Company	Ballast	Lamp operation	Modified Valley fill high power factor correction ballast
5635800	General electric Company	Ballast	Lamp operation	Ballast circuit with a japed transformer flyback converter providing driving energy for start , glow and run modes of a lamp
5703439	General electric Company	Ballast	Lamp operation	Lamp power supply circuit with electronic feedback circuit for switch control
5814976	General electric Company	Ballast	Lamp operation	High power factor electronic ballast
5838117	General electric Company	Ballast	Lamp operation	Ballast circuit with synchronization and preheat functions

5847508	General electric Company	Ballast	Lamp operation	Integrated starting and running amalgam assembly for an electrodeless fluorescent lamp
5859504	General electric Company	Ballast	Lamp operation	Lamp ballast circuit with cathode preheat function
5877595	General electric Company	Ballast	Lamp operation	High power factor ballast circuit with converter switches
5877596	General electric Company	Ballast	Lamp operation	Universal electronic ballast for a family of fluorescent lamps
5889373	General electric Company	Ballast	Lamp operation	Fluorescent lamp ballast with current feedback using a dual-function magnetic device
5910708	General electric Company	Ballast	Lamp operation	Gas discharge lamp ballast circuit with complementary converter switches
5910709	General electric Company	Ballast	Lamp operation	Fluorescent lamp ballast control for zero-voltage switching operation over wide input voltage range and over voltage protection
5917289	General electric Company	Ballast	Lamp operation	Lamp ballast with triggerless starting circuit
5952790	General electric Company	Ballast	Lamp operation	Lamp ballast circuit with simplified starting circuit
5986410	General electric Company	Ballast	Lamp operation	Integrated circuit for use in a ballast circuit for a gas discharge lamp
6011363	General electric Company	Ballast	Lamp operation	Constant wattage electric ballast circuit for lamp
6018220	General electric Company	Ballast	Lamp operation	Gas discharge lamp ballast circuit with a non-electrolytic smoothing capacitor for rectified current
6051934	General electric Company	Ballast	Lamp operation	Gas discharge lamp ballast circuit with high speed gate drive circuitry

6111363	General electric Company	Ballast	Lamp operation	Ballast shutdown circuit for a gas discharge lamp
6144173	General electric Company	Ballast	Lamp operation	Single switch electronic ballast
6147455	General electric Company	Ballast	Lamp operation	Gas discharge lamp ballast circuit with electronic starter
6150769	General electric Company	Ballast	Lamp operation	Gas discharge lamp ballast with tapeless feedback circuit
5874809	Hagen;Thomas	Ballast	Lamp operation	Constant light output ballast circuit
6031399	Hewlett-Packard Company	Ballast	Lamp operation	Efficient electronic ballast for fluorescent tubes
5825139	Hubbell Incorporated	Ballast	Lamp operation	Lamp driven voltage transformation and ballasting system
6166492	Hubbell Incorporated	Ballast	Lamp operation	Lows loss, electronic ballast
35994	IceCap,Inc.	Ballast	Lamp operation	Variable control , current sensing ballast
5828184	International Rectifier Corporation	Ballast	Lamp operation	Lamp ballast drive circuit having a resistor in place of boot strap diode
5932974	International Rectifier Corporation	Ballast	Lamp operation	Ballast circuit with lamp removal protection and soft starting
6002214	International Rectifier Corporation	Ballast	Lamp operation	Phase detection control circuit for an electronic ballast
6005354	International Rectifier Corporation	Ballast	Lamp operation	Ballast IC with shut-down function
6008592	International Rectifier Corporation	Ballast	Lamp operation	End of lamp life or false lamp detection circuit for an electronic ballast
6031342	International Rectifier Corporation	Ballast	Lamp operation	Universal input warm-start linear ballast
6150773	International Rectifier Corporation	Ballast	Lamp operation	Module and method for high-frequency electronic ballast design

6215253	International Rectifier Corporation	Ballast	Lamp operation	Inductorless ballast
5519289	JRS Technology Associates, Inc.	Ballast	Lamp operation	Electronic ballast with lamp current correction circuit
5930130	JRS Technology, Inc.	Ballast	Lamp operation	Inrush protection circuit
6034484	Korea Tronix Co, Ltd,	Ballast	Lamp operation	Piezoelectronic ballast for fluorescent lamp
6060844	LapLaz Lighting Co,	Ballast	Lamp operation	Method and apparatus of an improved electronics ballast circuit
6083021	Lau;Kenneth	Ballast	Lamp operation	Fluorescent light ballast lamp mounting socket construction
6094124	Lee;Kyung-Soo	Ballast	Lamp operation	Ballast for discharge lamp and method and apparatus for manufacturing the same
6034488	Lighting Control, Inc.	Ballast	Lamp operation	Electronic ballast for fluorescent lighting system including a voltage monitoring circuit
551561	Lumion Corporation	Ballast	Lamp operation	Power factor correction circuitry
6137240	Lumion Corporation	Ballast	Lamp operation	Universal ballast control circuit
6111368	Lutron Electronics Co, Inc.	Ballast	Lamp operation	System for preventing oscillations in a fluorescent lamp ballast
6114810	Mass Technology(H.K) Ltd,	Ballast	Lamp operation	Electronic ballast circuit for fluorescent lamps which have a high Q factor and high resonance voltage
5789871	Massachusetts Institute of Technology	Ballast	Lamp operation	Series-capacitor electronic ballast
5920155	Matsushita Electric Works, Ltd,	Ballast	Lamp operation	Electronic ballast for discharge lamps
6054815	Matsusita Electric Industrial, Ltd,	Ballast	Lamp operation	Ballast for a discharge lamp
6008587	Mills; Robert	Ballast	Lamp operation	Fluorescent lamp electronic ballast control circuit

6181087	Mitsubishi Denki Kabushiki Kaisha; Mitsubishi Electric Lighting Corporation	Ballast	Lamp operation	Discharge lamp operating device
5969483	Motorola	Ballast	Lamp operation	Inverter control method for electronic ballasts
5770925	Motorola Inc.	Ballast	Lamp operation	Electronic ballast with inverter protection and relamping circuits
5834924	Motorola Inc.	Ballast	Lamp operation	In-rush current reduction circuit for boost converters and electronic ballast
5869935	Motorola Inc.	Ballast	Lamp operation	Electronic ballast with inverter protection circuit
5869937	Motorola Inc.	Ballast	Lamp operation	High efficiency electronic ballast
5872430	Motorola Inc.	Ballast	Lamp operation	Single switch electronic ballast with low in-rush current
5883473	Motorola Inc.	Ballast	Lamp operation	Electronic Ballast with inverter protection circuit
5945788	Motorola Inc.	Ballast	Lamp operation	Electronic ballast with inverter control circuit
5982109	Motorola Inc.	Ballast	Lamp operation	Electronic ballast with fault-protected series resonant output circuit
5998930	Motorola Inc.	Ballast	Lamp operation	Electronic ballast with two-step boost converter and method
5841241	Nilssen; Ole K.	Ballast	Lamp operation	Electronic ballast for fluorescent lamps
5977721	Nilssen; Ole K.	Ballast	Lamp operation	Controlled power-factor-corrected ballast
6002210	Nilssen; Ole K.	Ballast	Lamp operation	Electronic ballast with controlled-magnitude output voltage
6107749	Nilssen; Ole K.	Ballast	Lamp operation	FET-bipolar electronic ballast
6121733	Nilssen; Ole K.	Ballast	Lamp operation	Controlled inverter-type fluorescent lamp ballast

6144445	Nilssen; Ole K.	Ballast	Lamp operation	Electronic ballast products and systems
6150768	Nilssen; Ole K.	Ballast	Lamp operation	Ballast with active power factor correction
6211619	Nilssen; Ole K.	Ballast	Lamp operation	Electronic ballast cathode heating circuit
6211625	Nilssen; Ole K.	Ballast	Lamp operation	Electronic ballast with over-voltage protection
5969484	Optimum Power Conversion, Inc.	Ballast	Lamp operation	Electronic ballast
5821699	Pacific Scientific	Ballast	Lamp operation	Ballast circuit for fluorescent lamps
5798617	Pacific Scientific Company	Ballast	Lamp operation	Magnetic feedback ballast circuit for fluorescent lamp
5955841	Pacific Scientific Company	Ballast	Lamp operation	Ballast circuit for fluorescent lamp
5982111	Pacific Scientific Company	Ballast	Lamp operation	Fluorescent lamp ballast having a resonant output stage using a split resonating inductor
6078144	Patent-Treuhand-Gesellschaft fuer elektrische Gluehlampen mbH	Ballast	Lamp operation	Electronic ballast with inrush current limiting
5834906	Philips Electronics North America Corporation	Ballast	Lamp operation	Instant start for an electronic ballast preconditioned having an active power factor controller
5907223	Philips Electronics North America Corporation	Ballast	Lamp operation	Two-frequency electronic ballast system having an isolated PFC converter
5923126	Philips Electronics North America Corporation	Ballast	Lamp operation	Fluorescent lamp electronic ballast with rapid voltage turn-on after preheating
5973437	Philips Electronics North America Corporation	Ballast	Lamp operation	Scheme for sensing ballast lamp current

6020689	Philips Electronics North America Corporation	Ballast	Lamp operation	Anti-flicker scheme for a fluorescent lamp ballast driver
6100646	Philips Electronics North America Corporation	Ballast	Lamp operation	Ballast feedback scheme
6100647	Philips Electronics North America Corporation	Ballast	Lamp operation	Lamp ballast for accurate control of lamp intensity
6181079	Philips Electronics North America Corporation	Ballast	Lamp operation	High power electronic ballast wit an integrated magnetic component
6184630	Philips Electronics North America Corporation	Ballast	Lamp operation	Electronic lamp ballast wit voltage source power feedback to AC-side
6072282	Power Circuit Innovations, Inc.,	Ballast	Lamp operation	Frequency controlled quick and soft start gas discharges lamp ballast and method therefore
6088249	Power Circuit Innovations, Inc.,	Ballast	Lamp operation	Frequency modulated ballast with loosely coupled transformer
6181066	Power Circuit Innovations, Inc.,	Ballast	Lamp operation	Frequency modulated ballast with loosely coupled transformer for parallel gas discharge lamp control
6222322	Q Technology Incorporated; New Athony, Inc.,	Ballast	Lamp operation	Ballast with lamp abnormal sensor and method therefore
5977723	Samsung Display Devices Co., Ltd.,	Ballast	Lamp operation	Ballast circuit for fluorescent lamp
5770926	Samsung Electronics Co., Ltd.,	Ballast	Lamp operation	Feedback control system of an electronic ballast which detects arcing of a lamp
5786671	Samsung Electronics Co., Ltd.,	Ballast	Lamp operation	Electronic ballast circuit having voltage reducing transformer
6005355	Siao; Susan Yeung: Anne Chon My	Ballast	Lamp operation	Electronic ballast system for fluorescent lamps
6091206	Siao;Susan Yeung:Anne Chon My	Ballast	Lamp operation	Electronic ballast system for fluorescent lamps

5705894	Siemens Aktiengesellschaft	Ballast	Lamp operation	Method for operating at least one fluorescent lamp with an electronic ballast, as well as ballast therefore
5834899	Tapeswitch Corporation of America	Ballast	Lamp operation	Fluorescent apparatus and method employing low-frequency excitation into a conductive-resistive inductive medium
5930126	The Genlyte Group Incorporated	Ballast	Lamp operation	Ballast shut-down circuit responsive to an unbalanced load condition in a single lamp ballast or in either lamp of a two-lamp ballast
5825137	Titus;Charles H.,	Ballast	Lamp operation	Electronic ballasts for plural lamp fluorescent lighting without feedback circuitry
6107747	Toshiba Lighting & Technology Corporation	Ballast	Lamp operation	Self ballasted fluorescent lamp and lighting fixture
6166491	Toshiba Lighting & Technology Corporation	Ballast	Lamp operation	Lighting device and display equipment
5936359	Trojan Technologies,Inc.,	Ballast	Lamp operation	Apparatus for efficient remote ballasting of gaseous discharge lamps
6069453	U.S. Philips Corporation	Ballast	Lamp operation	Ballast circuit for reducing striations in a discharge lamp
6188184	U.S. Philips Corporation	Ballast	Lamp operation	Electronic ballast with reduced operating frequency after lamp ignition
6147459	Vossloh-Schwabe Elektronik GmbH,	Ballast	Lamp operation	Voltage-controlled ballast for discharge lamps
6011358	Vossloh-Schwabe GmbH,	Ballast	Lamp operation	Ballast for independent parallel operation of low-pressure gas discharge lamps
6043612	Vossloh-Schwabe GmbH,	Ballast	Lamp operation	Electronic ballast with automatic restarting

5834765	Ledalite Architectural Products, Inc.	Controls	Combined sensors	Integral ambient light and occupancy sensor having a linear array of sensor element and a segmented slit aperture device
435473	Leviton Manufacturing Co., Inc.	Controls	Combined sensors	Combined dimmer, switch, IR receiver, thermostat, ambient light sensor and passive infrared motion sensor
5406173	The Watt Stopper	Controls	Combined sensors	Apparatus and method for adjusting lights according to the level of ambient light
5455487	The Watt Stopper	Controls	Combined sensors	Movable desktop light controller
5598042	The Watt Stopper	Controls	Combined sensors	Movable desktop load controller
6000810	Eagle Energy Systems, Ltd.	Controls	Dim/Sw Systems	Low voltage storage warehouse lighting system
5530322	Lutron Electronics Co., Inc.	Controls	Dim/Sw Systems	Multi-zone lighting control system
5637930	Lutron Electronics Co., Inc.	Controls	Dim/Sw Systems	Wall-mountable switch and dimmer
5949200	Lutron Electronics Co., Inc.	Controls	Dim/Sw Systems	Wall mountable control system with virtually unlimited zone capacity
5990635	Lutron Electronics Co., Inc.	Controls	Dim/Sw Systems	Multi-zone lighting control system
6046550	Lutron Electronics Co., Inc.	Controls	Dim/Sw Systems	Multi-zone lighting control system
6188181	Lutron Electronics Co., Inc.	Controls	Dim/Sw Systems	Lighting control system for different load types
4972125	Lee Colortran, Inc.	Controls	Dimming	Plug-in dimmer module for lighting control systems
5485058	Leviton Manufacturing Co., Inc.	Controls	Dimming	Touch dimmer system

5798581	Lutron Electronics Co., Inc.	Controls	Dimming	Location independent dimmer switch for use in multiple location switch system and switch system employing same
5808417	Lutron Electronics Co., Inc.	Controls	Dimming	Lighting control system with corrugated heat sink
6005308	Lutron Electronics Co., Inc.	Controls	Dimming	Electrical switch and dimmer control device
5585713	Molex, Inc.	Controls	Dimming	Light dimmer circuit with control pulse stretching
5283516	Pass and Seymore Legrand	Controls	Dimming	Low voltage dimmer with no-load protection
369348	The Watt Stopper	Controls	Dimming	Light level controller
5402040	The Watt Stopper	Controls	Dimming	Dimmable ballast control circuit
5742131	The Watt Stopper	Controls	Dimming	Dimmable ballast control circuit
5699243	Hubbell, Inc.	Controls	Occupancy sensor	Motion sensing system with adaptive timing for controlling lighting fixtures
5764146	Hubbell, Inc.	Controls	Occupancy sensor	Multifunction occupancy
5946209	Hubbell, Inc.	Controls	Occupancy sensor	Motion sensing system with adaptive timing for controlling lighting fixtures
5984513	Hubbell, Inc.	Controls	Occupancy sensor	Very low current microcontroller operated motion sensor
6151529	Hubbell, Inc.	Controls	Occupancy sensor	Motion sensing system with adaptive timing for controlling lighting fixtures
5739753	Leviton Manufacturing Co., Inc	Controls	Occupancy sensor	Detector system with adjustable field of view
5623172	Leviton Manufacturing Co., Inc.	Controls	Occupancy sensor	Two wire PIR occupancy sensor utilizing a rechargeable energy storage device

5786644	Leviton Manufacturing Co., Inc.	Controls	Occupancy sensor	Two wire PIR occupancy sensor utilizing a rechargeable energy storage device
5128654	Lightolier, Inc.	Controls	Occupancy sensor	Preset light controller including infrared sensor operable in multiple modes
401175	Mytech Corporation	Controls	Occupancy sensor	Occupancy sensor
404325	Mytech Corporation	Controls	Occupancy sensor	Occupancy sensor
404326	Mytech Corporation	Controls	Occupancy sensor	Occupancy sensor
430056	Mytech Corporation	Controls	Occupancy sensor	Ultrasonic occupancy sensor
435798	Mytech Corporation	Controls	Occupancy sensor	Ultrasonic occupancy sensor
5986357	Mytech Corporation	Controls	Occupancy sensor	Occupancy sensor and method of operating same
6078253	Mytech Corporation	Controls	Occupancy sensor	Occupancy sensor and method of operating same
6078253	Mytech Corporation	Controls	Occupancy sensor	Occupancy sensor and method of operating same
6078253	Mytech Corporation	Controls	Occupancy sensor	Occupancy sensor and method of operating same
6222191	Mytech Corporation	Controls	Occupancy sensor	Occupancy sensor
5489827	Philips Electronics N.A. Corp.	Controls	Occupancy sensor	Light controller with occupancy sensor
6215398	Platner, Brian P.	Controls	Occupancy sensor	Occupancy sensors for long range sensing within a narrow field of view
360842	The Watt Stopper	Controls	Occupancy sensor	Motion Sensor
5221919	Unenco, Inc.	Controls	Occupancy sensor	Room
5973996	Visonic Ltd.	Controls	Occupancy sensor	Ultrasound intrusion detector

6211522	Visonic Ltd.	Controls	Occupancy sensor	Passive infra-red intrusion sensor
370863	Visonic, Ltd.	Controls	Occupancy sensor	Passive infra-red sensor
6025679	Harper; Raymond G.	Controls	Photosensor	Lighting space controller
4538218	Honeywell Inc.	Controls	Photosensor	Skylight sensor and control system
5701058	Honeywell Inc.	Controls	Photosensor	Method of semiautomatic ambient light sensor calibration in an automatic control system
5039853	Multipoint Control Systems, Inc.	Controls	Photosensor	Constant-current light-sensing system and improved sensor housing
5942814	Echelon Corporation	Controls	Switching	Module for controlling current to a load including sensing of the position of a switch
4042903	Hunt Electronics Company	Controls	Switching	Power control slide switch
376130	Novitas Incorporated	Controls	Switching	Ultrasonic wall switch
380452	The Watt Stopper	Controls	Switching	Wall-mounted switch
5804991	The Watt Stopper	Controls	Switching	Zero crossing circuit for a relay
5508878	Paragon electric Company, Inc.	Controls	Time Clock	Electronic timer using zero power while off
5598000	Popat, Pradeep P.	Controls	Window treatment	Dual-mode automatic window covering system responsive to AC-induced flicker in ambient illumination
5663621	Popat, Pradeep P.	Controls	Window treatment	Autonomous low cost automatic window covering system for daylighting applications
6084231	Popat, Pradeep P.	Controls	Window treatment	Closed-loop daylight sensing automatic window covering system insensitive to radiant spectrum produced by gaseous discharge lamps

416910	AMX Corporation	Design	Product specific	Remote Control
6166640	Hubbell Incorporated	Design	Product specific	Bicolor indicator lamp for room occupancy sensor
5934451	Leviton Manufacturing Co., Inc	Design	Product specific	Illuminated rocker switch cover assembly employing electroluminescent lamp member
6011326	Leviton Manufacturing Co., Inc	Design	Product specific	Dual switch and/or dimmer system illuminated with single neon lamp
6089893	Leviton Manufacturing Co., Inc	Design	Product specific	Illuminated electrical receptacle employing electroluminescent lamp member
6145998	Leviton Manufacturing Co., Inc	Design	Product specific	Demonstration display for lighting controls
344264	Lutron Electronics Co., Inc.	Design	Product specific	Control panel for a lighting control unit
381632	The Watt Stopper	Design	Product specific	Desktop electrical apparatus control unit
6122678	Leviton Manufacturing Co., Inc.	Systems	Combined sensors	Local network based multiple sensor device with electrical load control means and with temperature sensor that is exposed to ambient air by diffusion
6104963	Johnson Controls Technology Co.	Systems	Communication methods	Communication system for distributed-object building automation system
6119125	Johnson Controls Technology Co.	Systems	Communication methods	Software components for a building automation system based on a standard object superclass
6141595	Johnson Controls Technology Co.	Systems	Communication methods	Common object architecture supporting application-centric building automations systems

6154681	Johnson Controls Technology Co.	Systems	Communication methods	Asynchronous distributed-object building automation system with support for synchronous object execution
6167316	Johnson Controls Technology Co.	Systems	Communication methods	Distributed object-oriented building automation system with reliable asynchronous communication
6028998	Johnson Service Co.	Systems	Communication methods	Application framework for constructing building automation systems
4355303	Westinghouse Electric Corp.	Systems	Communication methods	Receiver for a distribution network power line carrier communication system
5408550	Wireless Control System, Inc.	Systems	Communication methods	Remote fiber optic electrical switch using light pulse signals
5844888	Echelon Corp.	Systems	Control networks	Network and intelligent cell for providing sensing, bidirectional communications and control
5703442	Electronic Lighting Inc.	Systems	Control networks	Method and apparatus for interfacing a light dimming control with an automated control system
4209840	Honeywell Inc.	Systems	Control networks	Data processing protocol system
5971597	Hubbell Corp.	Systems	Control networks	Multifunction sensor and network sensor system
6192282	Intelihome, Inc.	Systems	Control networks	Method and apparatus for improved building automation
5528215	Landis & Gyr Powers, Inc.	Systems	Control networks	Building automation system having expansion modules
5786993	Landis & Gyr Technology Innovation Corp.	Systems	Control networks	Apparatus for and method of controlling and/or regulating process parameters of an installation

6138241	Leviton Manufacturing Co., Inc.	Systems	Control networks	Apparatus for and method of inhibiting and overriding an electrical control device
6144993	Matsushita Electric Works, Ltd.	Systems	Control networks	Building automation system using common platform program and common function package for controlling facility loads and monitoring terminals
5572438	TECO Energy Management Services	Systems	Control networks	Energy management and building automation system
5696695	TeCom Inc.	Systems	Control networks	System for rate-related control of electrical loads
5475360	Thomas Industries, Inc.	Systems	Control networks	Power line carrier controlled lighting system
6216956	Tocom, Inc.	Systems	Control networks	Environmental condition control and energy management system and method
6061602	Creative Lifestyles, Inc.	Systems	Home automation	Method and apparatus for developing application software for home automation system
5621662	IntelliNet, Inc.	Systems	Home automation	Home automation system
6140987	IntelliNet, Inc.	Systems	Home automation	User Interface for home automation system
6091320	Microsoft Corp.	Systems	Home automation	Automated home control using existing electrical lines as a communications medium
5544036	Rober J. Brown, Jr. et al	Systems	Home automation	Energy management and home automation system
5761083	Robert J. Brown, Jr., and James D. Romanowiz	Systems	Home automation	Energy management and home automation system
5579221	Samsung Electronics Co., Ltd.	Systems	Home automation	Home automation system having user controlled definition function
5822012	Samsung Electronics Co., Ltd.	Systems	Home automation	Home automation apparatus using a digital television receiver

APPENDIX 2.2 A
Controls Manufacturers

Company Name	Phone Number	Fax Number	Web Address	Address	City	State
ABB Control Inc.	888-385-1221	940-397-7085	www.abb-control.com	1206 Hatton Road	Wichata Falls	TX
ACE Compact Electronics	800-375-6355	817-624-8915	www.ace-ballast.com	2506 Tillar Street	Fort Worth	TX
ADB Airfield Solutions	614-861-1304	614-864-2069	www.sas.siemens.com/	977 Gahanna Parkway	Columbus	OH
Ademco Sensor Co (ASC)	800-467-5875	502-429-0678	www.ademco.com	1230 S. Hurstbourne Pkwy, Ste 100	Louisville	KY
Advance Transformer	800-372-3331 847-390-5000	847-390-5382	www.advancetransformer.com	650 W. Grand Ave, Suite 304	Elmhurst	IL
Advanced Control Technologies Inc	317-337-0100	317-337-0200	www.act-solutions.com	8076 Woodland Drive	Indianapolis	IN
Agilent Technologies	800-235-0312	408-654-8575	www.agilent.com	PO Box 10395	Palo Alto	CA
Alerton Technologies, Inc.	425-869-8400	425-869-8445	www.alerton.com	6670-185th Avenue NE	Redmond	WA
American-De Rosa Lamparts	800-777-4440/ 323-726-6300	323-728-0300	www.lamparts.com	1945 Tubeway Ave	Commerce	CA
Amperlite Company Inc	800-752-2329/ 201-864-9503	201-864-3955	www.amperite.com	600 Palisade Avenue	Union City	NJ
AMX (consolated into PANJA Inc)	800-552-6955	469-624-7163	www.panja.com	3000 Research Drive	Richardson	TX
Andover Controls Corporation	978-470-0555	978-470-0946	www.andovercontrols.com	300 Brickstone Square	Andover	MA
Antron Compact Electronics Inc	800-375-6355/ 800-529-1597	817-624-8915/ 800-529-1597	www.ace-ballast.com	2506 Tillar Street	Fort Worth	TX
Architectural Lighting Management	888-446-9137/ 847-860-1490	847-860-0959	www.almsys.com	2480 Delta Lane	Elk Grove Village	IL
Aromat (Panasonic)	908-464-3550	908-771-5656	www.aromat.com	629 Central Avenue	New Providence	NJ
Automated Logic Corporation	770-429-3000	770-429-3001	www.automatedlogic.com	1150 Roberts Boulevard	Kennesaw	GA
AVAB America Inc	707-778-8990	707-778-8996	www.avab.com	434 Payran Street	Petaluma	CA
Blackbird	812-944-0799	812-941-8830	None	219 Grant Line Center	New Albany	IN

Company Name	Phone Number	Fax Number	Web Address	Address	City	State
Colortran (Leviton)	503-682-1941	503-404-5600	www.leviton.com (old site for reference www.nsicorp.com)	20497 SW Peton	Tualatin	OR
Cooper Lighting	847-956-8400	847-956-1537	www.cooperlighting.com	400 Busse Road	Elk Grove Village	IL
Crestron	800-949-3465/ 847-437-6650	847-437-6052	www.crestron.com	415 West Golf Road, Suite 27	Arlington Heights	IL
Cutler Hammer (Eaton)	630-789-5980 / 1800-272-8202	630-789-4999	www.cutlerhammer.eaton.com/apc,www.eaton.com	601 Oakmont Lane, Suite 310	Westmont	IL
Delta Controls Inc	800-335-8221/ 604-574-9444	604-574-7793	www.deltacontrols.com	17850 - 56th Avenue	Surrey	BC
Denki Corporation of North America	800-908-8882/ 201-393-0722	201-393-0692	www.denkicorp.com	377 Route 17 South, Suite 118	Hasbrouck Hgts	NJ
Douglas Lighting Controls Inc	514-342-6581/ 604-873-2797	514-342-0133/ 604-873-6939	www.douglaslightingcontrol.com	345 Isabey Street	St Laurent	QC
EBW Electronics	800-787-0575	616-786-0513	www.ebw-electronics.com	701 Commerce Court	Holland	MI
Echelon Corporation	408-938-5200	408-328-3800	www.echelon.com	4015 Miranda Ave	Palo Alto	CA
Electronic Lighting Inc	800-395-5767/ 510-795-8555	510-795-0870	www.elinet.com	37200 Central Court	Newark	CA
Electronic Theatre Controls Inc	800-688-4116/ 608-831-4116	608-836-1736	www.etcconnect.com	3030 Laura Lane	Middleton	WI
Elk Products Inc	800-797-9355	828-397-4415	www.elkproducts.com	3266 US 70 West	Conelly Springs	NC
Energy Savings	847-925-8400	847-925-8490	www.esavings.com		Schaumburg	IL
Fulham Company	323-779-2980	323-754-9060	www.fulham.com	12705 South Van Ness	Hawthorne	CA
Future Wave Technologies	604-990-5325	604-990-0066	www.futurewavetechnologies.com/	133 East Main Street	Marbouough	MA
GE Industrial Systems	800-852-2778/ 800-TLC-ASST	401-886-6470	www.geindustrial.com	225 Service Avenue	Warwick	RI
GE Lighting	800-435-4448 (GE LIGHT)	800-327-0663	www.gelighting.com	1975 Noble Road	Cleveland	OH
Genlyte / Thomas	800-215-1068/ 508-679-8131	508-674-4710	www.gennlyte.com			
GE-Smart	505-251-6000		www.ge-smart.com	2100 Summet Court	LasCruces	NM
Gilbert Manufacturing Company Inc	804-447-8223	804-447-7434	none	PO Box 309	South Hill	VA

Company Name	Phone Number	Fax Number	Web Address	Address	City	State
Harrison Toshiba Lighting USA, Inc	877-399-8100/ 847-229-8100	847-229-8124	www.toshiba-lighting.com	1003 Commerce Court	Buffalo Grove	IL
High End Systems Inc	512-836-2242	512-837-5290	www.highend.com	2217 West Braker Lane	Austin	TX
Honeywell	805-581-5591	805-581-5032	www.cas.honeywell.com	2162 Union Place	Simi Valley	CA
Horton Controls / Watt Stopper	205-271-3400	205-969-0605	www.hcontrols.com	4128 Crosshaven Drive	Birmingham	AL
Howard Industries Inc	800-956-3456/ 601-422-0033	601-422-1652	www.howard-ballast.com	PO Box 1590	Laurel	MS
HUB Electric/Vara-Light/Dimatronics	815-455-4400	815-455-1499	none	6207 Commercial Road	Crystal Lake	IL
Hubbell and Hubbell Lighting	203-882-4900	800-255-1031	www.hubbell-ltg.com, www.hubbell.com	185 Plains Road, Milford Pl Corp Ctr	Milford	CT
Hunt Controls Systems Inc	970-484-9048	970-493-4125	www.huntdimming.com	200 Rome Court	Fort Collins	CO
IBM Mylonas Lighting Company				302 A Street	LaPorte	IN
Irideon Inc (purchased by ETC)				301 Regal Row	Dallas	TX
Johnson Controls	414-274-4000	414-524-4443	www.johnsoncontrols.com	507 East Michigan Street	Milwaukee	WI
JRS Technology Inc	888-922-5527/ 607-748-4800	607-748-7949	www.jrstechnology.com	1061 Perimeter Rd W, Bldg 11	Endicott	NY
Keegan Wireless	800-451-2012	909-594-7813		749 South Lemon Street	City of Industry	CA
Kelar Controls Inc	800-728-3443	408-365-3289	www.kelarcontrols.com	404-C Umbarger Rd	San Hose	CA
Kingtec Inc	800-448-5483	201-229-4672	www.kingtec.com (under const)	85 Challenger Rd	Ridgefield	NJ
K-Tronic Ballasts	888-458-7664	201-488-8480	www.k-tronic.com	290 Vincent Avenue, 3rd Floor	Hackensack	NJ
LEAX Lighting controls	970-927-4845	970-927-4845	www.leaxcontrols.com/CM 3	180 Fiou Lane	Basalt	CO
Lehigh Electric Products	610-395-3386	610-395-7735	www.lehighdim.com	6265 Hamilton Blvd	Allentown	PA
Leviton (LON products group)	1-800-824-3005	1-800-832-9538	www.leviton.com	59-25 Little Neck Parkway	Little Neck	NY
Leviton Lighting Control Division	800-996-2276/ 512-927-7711	512-927-7799	www.leviton.com	9013 Tuscany Way, Bldg 100	Austin	TX

Company Name	Phone Number	Fax Number	Web Address	Address	City	State
Lithonia Lighting (controls)	770-922-9000	770-860-3183	www.lithonia.com	One Lithonia Way	Conyers	GA
Lithonia Lighting Canada	514-639-3571	514-639-3570	www.lithonia.com	1100-50th Avenue	Lachine	QC,Canada
Lumion Corporation	416-299-5134	416-299-7025	www.lumion.com	30 North Wind Place	Scarborough	ON,Canada
Lutron Electronics Co Inc	888-588-7661/ 610-282-3800	610-282-8321	www.lutron.com	7200 Suter Road	Coopersburg	PA
MagneTek Lighting Products Group	615-316-5100/ 800-BALLAST	615-316-5162	www.magnetek.com/ballast	26 Century Blvd, Suite 600	Nashville	TN
Marco Electronics (now NSI Corp)	503-404-5500	503-404-5600	www.nsicorp.com	20497 Southwest Teton	Tualatin	OR
Marinco Industrial Group	800-767-8541/ 707-226-8600	707-226-9670	www.marinco.com	2655 Napa Valley Corporate Drive	Napa	CA
Marlin Controls, Inc	800-788-5750/ 214-553-5700	214-553-1011	www.marlincontrols.com	11011 Regency Crest Drive, Ste 200	Dallas	TX
MaxLite	800-555-5629/ 973-256-3330	973-256-9444	www.maxlite.com	60E Commerce Way #E	Totowa	NJ
Microlites Scientific	800-263-8902/ 416-299-5301	416-299-1309	www.microlites.com	2370 Midland Avenue Unit A8	Scarborough	ON,Canada
Molex Incorporated	708-969-4550	708-512-8620		2222 Wellington Court	Lisle	IL
MYTEC Corporation	800-MYTECH-C	512-450-1215	www.mytech.com	706 Brentwood	Austin	TX
N.V. ADB-TV Tech S.A. (Siemens)	32-2-722-17-11	32-2-722-17-64		Leuvensesteenweg 585	Zaventem, B 1930	Belgium
North Point Engineering (now Nexlite)	218-828-3700	218-824-1568	www.nexlight.com	1621 College Road South	Baxter	MN
Novar Controls Corporation	330-670-1010	330-670-1029	www.novarcontrols.com	3333 Copley Rd	Copley	OH
Novitas Inc	310-568-9600	310-568-9697	www.novitas.com	5875 Green Valley Circle	Culver City	CA
Osram Sylvania/ Ballast Division	800-654-0089/ 847-726-6200	847-726-6211	www.sylvania.com	800 North Church Street	Lake Zurich	IL
Panja Inc	800-222-0193	469-624-7160	www.panja.com	3000 Research Drive	Richardson	TX

Company Name	Phone Number	Fax Number	Web Address	Address	City	State
Pass & Seymour/ Legrand	800-223-4162/ 315-468-8281	800-223-4196/ 315-468-8388	www.passandseymour.com	PO Box 4822	Syracuse	NY
PCI Lighting Control Systems	800-767-3674/ 802-658-6445	802-658-6934	www.pcilightingcontrols.com	6 Green Tree Drive	South Burlington	VT
PLC Multipoint Inc	425-353-7552	425-353-3353	www.plcmultipoint.com	3101 - 111th Street SW, Suite F	Everett	WA
RAB Electric Mfg Co Inc	888-722-1000/ 201-784-8600	888-722-1232/ 201-784-0077	www.rabweb.com	170 Ludlow Avenue	Northvale	NJ
Robertson Worldwide	800-323-5633/ 708-388-2315	708-388-2420	www.robertsonww.com	13611 Thornton Road	Blue Island	IL
Semper Fi Power Supply Inc	603-656-9729	603-656-9752	www.semperfipowersupply.com	21 West Auburn Street	Manchester	NH
SensorSwitch Inc	800-727-7483/ 203-265-2842	203-269-9621	www.sensorswitchinc.com	900 Northrop Road	Wallingford	CT
Siebe Enviornmental Controls (Invensys)	815-637-3140	815-637-3000	www.invensys.ibs.com	1354 Clifford Avenue	Loves Park	IL
Siemens Automation	770-871-3863	770-448-5662	www.sea.siemens.com/power/product/pdprodlc.html	5405 Metric Place (suite 100)	Norcross	GA
Siemens Building Technologies Ltd	847-215-1000	847-215-9907	www.sbt.siemens.com	1000 Deerfield	Buffalo Grove	IL
Sine Systems/Pyle Connector Corp	630-832-4600	630-782-0700	www.sineco.com	650 W. Grand Ave, Suite 304	Elmhurst	IL
SLS Industries UNIDIM						
Smart America	831-466-9999	831-439-5585	www.smart-america.com	125 Bethany Drive	Scotts Valley	CA
Square D Company	800-392-8781/ 615-287-3500	615-287-3409	www.squared.com	295 Tech Park Drive, Suite 100	LaVergne	TN
Sterner Controls	disconnected					
Strand Lighting Canada Inc	800-387-3403/ 905-677-7130	905-677-6859		2430 Lucknow Drive, Unit 15	Mississaugo	ON,Canada
Strand Lighting Inc	800-487-0175/ 310-637-7500	310-632-5519	www.strandlight.com	18111 S. Sante Fe Avenue	Rancho Dominguez	CA
Sunpark Electronics Corp	888-478-6775/ 310-320-7880	310-320-7875	www.sunpkco.com	1815 W. 205th Street, Suite 104	Torrance	CA

Company Name	Phone Number	Fax Number	Web Address	Address	City	State
Thomas Lighting	502-894-2400	502-894-2450	www.thomaslighting.com	4360 Brownsboro Road, Suite 300	Louisville	KY
Tork	914-664-3542	914-664-5052	www.tork.com	1 Grove Street	Mount Vernon	NY
Touch-Plate Lighting Controls	219-424-4323	219-420-3651	www.touchplate.com	1830 Wayne Trace, Ste 9	Fort Wayne	IN
Trane	651-407-3800	651-407-3940	www.trane.com	4831 White Bear Parkway	St Paul	MN
Trend Group Inc	908-757-3535	908-756-3636	www.trendgroup.com (under const)	200-214 West 4th Street	Plainfield	NJ
Triatek Inc	888-242-1922/ 770-242-1922	770-242-1944	www.triatek.com	2976 Pacific Drive	Norcross	GA
Tridonic Inc. (North America)	770-717-0556	770-717-7969	www.tridonic.com	4405 International Blvd Suite B103	Norcross	GA
Unenco (Hubbell)	800-245-9135	800-543-0538 203-876-3675	www.hubbell-unenco.com	185 Plains Road, Milford Pl Corp Ctr	Milford	CT
Vantage	801-229-2800	801-224-0355	www.vantagecontrols.com	345 East 800 South	Orem	UT
Vantage Lighting Inc	800-445-2677/ 415-507-0402	415-507-0502	www.vanltg.com	175 Paul Drive	San Rafael	CA
Veam	860-274-9681	860-274-4963	www.littonveam.com	100 New Wood Road	Watertown	CT
Visonic Inc	800-223-0020/ 860-243-0833	860-242-8094	www.visonic.com	10 Northwood Drive	Bloomfield	CT
X-10 USA Inc	201-784-9700	201-784-9464	www.x10.com (www.x10pro.com)	91 Ruckman Road, Box 420	Closter	NJ
Xitron Technologies Inc	858-530-8099	858-530-8077	www.xitron-tech.com	9770-A Carroll Centre Road	San Diego	CA

APPENDIX 2.3 A
Manufacturers and their Supporting Protocols

Item	Company Name	Business Category / Focus	Supporting Protocol
1	ABB Control Inc.	Industrial controls and Instruments	Custom, BACnet, Modicon and LON
2	Advance Transformer	Ballasts / Transformers	0-10VDC, 2-wire
3	Advanced Control Technologies Inc	Manufacturer of interfaces	LonWorks Independent Developer
4	Agilent Technologies	HP Subsidiary / Lamps (bulbs)	LAN/WAN Ethernet
5	Alerton Technologies, Inc.	DDC Systems for HVAC and lighting	BACnet, Modbus, Ethernet
6	Andover Controls Corporation	Controls / BAS	BACnet, Ethernet, LON
7	Architectural Lighting Management	Controls / dimming	DMX-512
8	Automated Logic Corporation	Controls / BAS	Supports all major communication protocols including BACnet, LONworks, MODbus and SNMP.
9	Cooper Lighting	Fixtures / Inteligent System (ESI ballast)	ESI digital protocol
10	Crestron	Controls / Software	LAN/WAN/Internet connection
11	Cutler Hammer (Eaton)	Controls / Home Automation	X-10, CEBus, RS232, INCOM
12	Delta Controls Inc	Controls	BACnet and ORCAview
13	Douglas Lighting Controls Inc	Controls /Software	LonWorks
14	Easylite	Ballast	
15	Echelon Corporation	Protocol - system developer	LONworks
16	Electronic Theatre Controls Inc	Controls	DMX 512, ETCnet, ETClink, MIDI, BACNet, LONWorks
17	Elk Products Inc	Controls and components for Home automation	RS232, RS485, SIMPLE
18	Energy Savings Inc.	Ballast/Controls	Custom
19	GE Industrial Systems	Lighting Controls	Ethernet, MODbus, RS485/232, LONworks

20	GE Lighting	Ballast (Magnetek)	See MagneTek
21	Genlyte - Lightolier Controls	Controls	RS232, RS485, BACNet, DMX512
22	H I Solutions Inc	Controls/Software	LAN Ethernet, RS485
23	Honeywell	Controls / BAS	RS232, ARCnet, Ethernet, BACNet, Modbus, Allen Bradley Data Highway, Modbus plus, and a wide variety of other common protocols are available.
24	Horton Controls / Watt Stopper	Controls	LONworks
25	Hubbell and Hubbell Lighting	Fixtures / Controls	0-10VDC, 2-wire
26	Hunt Controls Systems Inc	Controls	0-10VDC, 2-wire, ESU super dim
27	Johnson Controls Inc	Controls / BAS	BACnet, LONworks, Ethernet and most other major protocols.
28	JRS Technology Inc	Ballasts/Controls	LONworks, 0-10VDC
29	LEAX Lighting controls	Lighting Controls	LONworks, DMX512, RS232, Analogue Input, Volt free, 2wire, DALI, 0-10VDC, DSI
30	Lehigh Electric Products	Controls	LONworks, DALI, DSI, 1-10VDC
31	Leviton (LON products group)	Building Control System / Components	0-10VDC, DMX512, LONworks, BACnet
32	Leviton Lighting Control Division	Controls	LONworks, BACnet, 0-10 VDC, LAN/WAN Ethernet
33	Lithonia Lighting (controls)	Fixtures / Controls	BACnet, DMX512, 0-10VDC, 10-30VDC
34	Lutron Electronics Co Inc	Controls	0-10VDC, 2-wire line coltage control, 3-wire line coltage control, DMX 512
35	MagneTek Lighting Products Group	Ballasts	0-10VDC, DMX 512, DALI
36	MYTEC Corporation	Controls/Software	2-wire, 24VDC
37	NexLight	Building Control System / Components	2-wire, BACnet
38	Novitas Inc	Sensors / Controls	0-10VDC
39	Osram Sylvania/ Ballast	Ballasts	0-10VDC, DALI

	Division		
40	Panja Inc	Controls	DMX512, Ethernet, BACNet
41	Pass & Seymour/ Legrand	Controls	2-wire
42	PCI Lighting Control Systems Inc	Controls/Software	RS232, RS 485, DMX 512
43	PLC Multipoint Inc	Sensors / Controls	Direct Serial RS232, FIBER OPTIC COMMUNICATION, LOCAL MULTI-DROP COMMUNICATION BUS
44	SensorSwitch Inc	Sensors /Controls	1-10VDC
45	Siemens Building Technologies Ltd	Controls	BACnet, MODbus, LONworks, DMX 512
46	Smart America	Controls/Software	Ethernet
47	Square D Company	Controls	RS232, RS 485, MODbus, Ethernet 10Base T Connectivity with TCP/IP Protocols
48	The Watt Stopper / Pass & Seymour	Sensors / Controls	0-10VDC, LONworks
49	Tork	Controls	
50	Touch-Plate Lighting Controls	Controls	BACnet
51	Triatek Inc	Controls	TRIATEK Link, BACnet, MODbus, Ethernet TCP/IP, RS 485, DALI
52	Tridonic Inc. (North America)	Ballast	Digital, DSI, DALI
53	Vantage	Controls (Home Automation)	RS232
54	Xitron Technologies Inc	Controls	RS232