Task 4.6 Develop recommendations for improved components and systems as evaluated in Task 2, based on defined performance characteristics, and defined acquisition, installation and commissioning costs

Summary of recommendations:

In the course of Task 2 of this project, three technologies were identified as having the potential to achieve greater market share, if certain barriers could be overcome. These technologies were the prototyped load-shed ballast, occupancy sensors, and an innovative easily-commissioned photosensor. To maximize their market potential, these technologies must all demonstrate their cost-effectiveness, their practicality in real installations, and their suitability to the market. Based on subsequent development of these technologies and analysis of the market, we recommend the following courses of action:

Load-shed ballasts:

- Perform large scale field trials of load-shed ballasts. These trials should aim to verify the acceptability of illuminance reductions to occupants, both when the reasons for load shedding have been explained to occupants, and when they have not. The process of informing occupants of the environmental and cost benefits of load shedding is referred to as "biasing".
- Test the electromagnetic compatibility (EMC) of load-shed ballasts in their two normal operating states (i.e., full on and dimmed), and when switching between states.
- Work with one or more ballast manufacturers to produce a commercially viable load-shed ballast based on electronic instant-start technology. To be financially attractive to customers, the price of this ballast should be no more than $9 more than a regular instant-start ballast.
- Test the prototype ballast as part of the LRC's National Lighting Product Information Program (NLPIP), and make the result of the testing available on the NLPIP website.
- Work with one or more ballast manufacturers to develop a suitable method to carry signals from a central controller within the building, to the individual ballasts. ("stage 2" signaling). This signal should not cause disruption (e.g., flicker) to the other lighting in the building.
- Ensure that the signals sent out by electricity suppliers are suitable to be received by lighting load-shed controllers ("stage 1" signaling). Both the format and the medium for these signals should be considered in detail.

- Develop a performance specification for load-shed ballasts that can be easily followed by commercial ballast manufacturers, yet ensures minimum performance standards.
- Leverage current and future market forces to create demand for load-shed ballasts. This can be achieved by promoting the electricity cost savings achieved using load-shed ballasts, and by promoting load-shed ballasts as an environmentally friendly and therefore desirable feature of a building, especially new-builds. This may take place through published articles, seminars, demonstration projects and voluntary accreditation schemes.

Occupancy sensors:

- Publicize the aggregate figures for energy savings compiled as part of Task 4. Everyone in the building industry should be aware of typical figures for energy saving achievable by the use of occupancy sensors.
- Work with control system manufacturers to produce a commissioning standard for occupancy sensors. If all sensors can be commissioned using the same procedure, the likelihood of installers making mistakes on site will be much reduced, and these mistakes account for a lot of the failings of systems in situ.

Easily-commissioned photosensor:

- Continue to use existing market channels, such as the LRC's NLPIP program and outreach education, to support the use of photosensing in those applications for which it is commercially viable. This is usually only in owner-occupied buildings with large window area and high occupation density.

Introduction

Some technologies aimed at reducing lighting energy consumption and cost are already well accepted and reliably implemented by the building community, while others are constrained by real or perceived barriers to more widespread use, such as complexity, reliability or cost.

Examples of the former include “architectural” dimming, occupancy sensing in new-builds, programmed-start ballasts, time-switching, and energy efficient lamps and luminaires. Examples of the latter include photosensing, occupancy sensing in retrofits, and load management systems. The LRC is primarily interested in determining which of these latter technologies may be able to graduate into the mainstream, with the help of technological improvements, human factors research, and market transformation efforts.

We are particularly interested in the comparatively neglected potential of innovative, low-cost, simple systems which may reach a wide market. Load-shed ballasts are a good example of a technology with low cost and potentially high benefit for consumers, electricity suppliers, and the country as a whole. The LRC’s intention is to prepare the way for fast and sustainable market uptake of lighting load shedding systems, by ensuring that they are easy to specify and install, and that the cost-benefits calculations are highly persuasive - especially in an economic climate where companies have little spare cash for non-core investments.

This report deals mainly with load shedding systems. It is important to note that load-shed ballasts and other lighting control systems (such as occupancy sensing) are not mutually exclusive; either or both may be used in a space. Therefore a concentration on load-shedding is complementary to the LRC and DOE’s existing commitments to promote other energy-saving strategies. Furthermore, most US office space is deep-plan therefore not amenable to daylight savings, and occupancy systems may not be appropriate in every space. Load shedding is therefore a complementary technology that may be added to other energy and cost-saving strategies.

This report goes on to deal with ways of expanding the market for occupancy sensors, and the market potential of a design for a new type of easily-commissioned photosensor, which may be much easier to design, install and commission than existing types.

Lighting opportunities in the deregulated power market

At times of peak load, the cost of providing every additional watt of power can be as much as $1. This imposes a high cost on the nation, and should provide a high incentive for consumers to reduce load at peak times, but current electricity pricing structures prevent these costs being visible to consumers, so it is often not financially beneficial for building operators to install power-reducing systems. Forthcoming changes to the structure of electricity pricing, however, are likely to create a market for shedding load.

The Federal Energy Regulatory Commission (FERC) has proposed the following policy;

"*Power markets should accommodate price-responsive load and demand resales, through market rules that give willing [wholesale] customers and their suppliers reasonable opportunity to adjust consumption in response to market conditions…FERC should promote transmission rate designs that reveal the cost of congestion across different times and locations*"[4]

The cost of providing additional power to a consumer at a given location and time is known as the "locational marginal price" (LMP), and is usually measured in dollars per megawatt. LMP comprises the cost of generation, and the cost of transmission (including the fact that power may have to be transported to allow for regional disparities in capacity and consumption).

If consumers were charged the LMP for any extra capacity they required, many of them would ensure that their load was minimized at times of peak demand (and hence peak LMP). This would require an accurate and verifiable record to be kept of their electrical load hour-by-hour or minute-by-minute. Although verifiable timed metering is now comparatively cheap (typically less than $200 to install), consumers have been reluctant to be charged the LMP for their additional power due to the possibility that it might increase their electricity bills and/or cause them to have to change their hours of work.

In the last two to three years, however, some regional transmission organizations (RTOs) have piloted "economic load response" schemes for large consumers (typically those whose peak demand exceeds 1MW). Some of these schemes have gone on to allow consumers to bid in advance (typically one day in advance) for load reductions, thus creating a true market for power, with consumers able to engage in bilateral trading of available capacity. It is anticipated that participation in load response schemes will rapidly be extended to more and smaller consumers as hourly metering and data logging becomes less expensive.

In addition to these *economic* load response schemes, some RTOs have piloted *emergency* load shedding schemes[5]. These schemes are doubly useful in that they not only reduce generation costs, but also ensure adequate power quality and reliability, which are as important to RTOs as cost. The key difference is that, in the economic schemes, consumers have the prerogative to buy or sell capacity or capacity options at their own discretion, whereas in the emergency load shedding schemes, consumers must shed capacity when instructed to do so by the RTO. Although a consumer may take part in both schemes, each separate load must be registered in either one scheme or the other - not both - because for the purposes of emergency load-shed, the RTO must be able to predict in advance the magnitude of the drop in demand.

Another key difference between economic and emergency load response schemes is that it may only be large consumers that find it worthwhile to participate in economic load response

[4] Federal Energy Regulatory Council (FERC). 4 January 2002. *Demand-side resources and regional power markets: a roadmap for FERC (draft 2A)*. Accessed on 13 December 2002 at http://www.ferc.gov/electric/rto/mrkt-strct-comments/02-05-02/FERC-load-response-road-map-02-05-02.pdf

[5] Such as PJM, a regional transmission operator (www.pjm.com)

schemes, because of the overhead costs of personnel and of installing hourly metering in their premises. Emergency load shedding schemes, by contrast, because they are administered by the RTO instead of by the consumer, require little overhead cost and so comparatively small consumers may find it worthwhile to participate.

Small consumers are pivotal to the success of lighting load shedding because there are effectively no large lighting consumers; even a large office building with 1000 occupants will have the potential to shed no more than 50kW – much smaller than the current minimum increment of 100kW commonly used in current economic load response pilots. Therefore emergency load shedding schemes are more likely to be attractive to those seeking to save lighting electricity costs.

Load-shed ballasts

Background: Who benefits from load shedding?

Load shedding is not primarily a way of reducing energy consumption; rather it is a way of reducing the *cost* of providing power at times of peak electrical demand. Load shedding is only envisaged as occurring a few times per year, and only for brief periods (<100 hours/year), so the number of kWh of electricity which can potentially be saved is small. Consequently, the environmental benefit is marginal, although it should be remembered that peak-demand electricity is particularly “dirty” to produce, because older, smaller, and therefore less efficient power stations are used to produce it, and that load shedding at peak times may obviate the need to build new power stations.

Load shedding also helps to relieve transmission congestion, and the need to transport electrical power from one region to another; hence it reduces the inefficiencies associated with the transmission of power, and the need for extra capacity to cover contingencies such as the loss of transmission lines.

The direct beneficiaries of these cost savings would be electricity suppliers, although adjustments to the pricing structure of electricity should ensure that the cost savings are eventually passed on to consumers.

So load shedding would produce cost savings for the economy, and benefits for the environment. Lighting is an important part of any load-shedding strategy because it accounts for around 25% of national electricity consumption. To ensure that individual consumers find it profitable to include their lighting load in economic or emergency load response programs, the lighting industry (in the form of lamp and ballast manufacturers, and the LRC) should become involved in the discussions of pricing structure currently underway within the electricity industry.

Human factors implications

Load shedding using bi-level switching ballasts creates a comparatively fast reduction in workplace illuminance for occupants, taking place over only a few seconds, and lasting for around four hours. It is essential to determine whether these reductions are either noticeable or acceptable to occupants, before investing in the development of load shedding technology.

Experiments were conducted at the LRC to determine what magnitude of illuminance reduction is acceptable to office workers. The reductions took place over a period of around three seconds. The results showed that the degree to which subjects found illuminance reductions acceptable was affected by whether the reason for the reduction was explained beforehand. The reasons consisted of the potential for energy cost saving, and the environmental benefits. Subjects who had previously had the reasons explained to them were known as “biased” subjects. All of the “unbiased” subjects found a reduction in illuminance of 20% acceptable, and 80% of them found a reduction of 50% acceptable. All of the “biased” subjects found a reduction of 50% acceptable, and 80% of them found a reduction of 75% acceptable.

On the basis of this research, and previous research, the LRC has recommended[6] that the development of load-shed ballasts should standardize on illuminance reductions of 33% and/or 50%, since these figures correspond to the switching off of one lamp in a three-lamp luminaire, or two lamps in a four-lamp (or one in a two-lamp) luminaire. These figures could be used as a basis for initial trials.

Field trials in real buildings would be required to verify the findings of the research already undertaken, and to ensure that “real world” factors such as the presence to daylight (perhaps as a brightness referent) do not result in lower acceptability ratings in practice. As stated in Appendix 4.2 – A of the Task 4 report (p.39), “to maximize demand savings, education of the public or affected persons, should be a priority”.

Power quality implications

Sudden changes in electricity consumption, especially for inductive or capacitive loads, can cause harmonic distortions in the line voltage (electromagnetic interference), which can adversely affect other electronic equipment. The sudden reduction in electricity consumption caused by load shedding may produce effects of this kind. Further research should be carried out to ensure that harmonics do not adversely affect either the building’s switchgear, or other connected loads.

Routemap for developing ballast technology

The discussion above suggests that developing a load-shed ballast is both desirable and possible, though it must meet strict performance and cost targets.

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[6] Lighting Research Center (LRC). November 2002. *Reducing Barriers to Use of High Efficiency Lighting Systems, Task 4.2: Investigate ideal lamp light output dimming ratio required for different types of applications.* Troy, NY. Report submitted to US Department of Energy.

The LRC's investigations into the effect of dimming on fluorescent lamp life[7], and the constraints of cost (see below), suggest that electronic instant-start may be the preferred technology base for load-shed ballasts. Instant start is substantially less expensive than other technologies (rapid-start, programmed-start), and does not appear to result in shorter lamp life under standard test conditions of 3 hours on, 20 minutes off.

Operating instant start ballasts at a reduced ballast factor (i.e., dimmed), reduces lamp life marginally; in tests conducted at the LRC, dimming to 67% for 100 hours per year shortened life by less than 20%[8]. These tests suggested that most fluorescent lamps can be operated without significantly reduced lamp life or efficiency, over a wide range of outputs, both below and above their rated output. The energy consumption of a ballast is described by its "ballast factor", where 1.0 means that the ballast is running at its rated output. Many lamps operate without detrimental effect on their life, at ballast factors between 0.7 to 1.3.

A further persuasive reason to build load-shed ballasts on an electronic instant-start platform is that instant-start currently constitutes the largest segment of the ballast market, and is therefore most likely to receive quick acceptance by consumers.

Field trials in real buildings will require prototype ballasts to be developed, leading to a commercially viable mass-produced version, which should be tested under the National Lighting Product Information Program (NLPIP). The LRC will need to work closely with one or more ballast manufacturers in order to achieve this.

The report of Task 4.3 of this project projected that;

"If a load-shed ballast and its associated communication link can be sold…for an incremental cost of $9 over an instant-start ballast…the market for this ballast would be approximately 10% of all ballasts sold in the new-construction / remodeling market."[9]

Routemap for developing communication protocol(s)

Experience from other lighting control technologies clearly shows that the communication protocol is a determining factor in the success or failure of a technology. A protocol must be immune to interference, must allow easy installation and reconfiguration, and compatible components must be widely available from a variety of competing suppliers. It must also be possible to add new components on to an existing system, so the protocol must be backwards-compatible. This means that it is crucial to get the protocol right in the prototype stage, and avoid subsequent changes.

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[7] Lighting Research Center (LRC). November 2002. *Reducing Barriers to Use of High Efficiency Lighting Systems, Task 4.3-4.5: Investigation of the Effects of Dimming on Fluorescent Lamps.* Troy, NY: Lighting Research Center. Report submitted to US Department of Energy.

[8] Ibid.

[9] Ibid, p.75

Two distinct communication signals are required within a load shedding system. Firstly the signal from the electricity supplier or RTO to the building's load-shed coupler (stage 1), and secondly the signal from the load-shed coupler to the individual ballasts (stage 2).

Some utility companies and RTOs have already developed stage 1 systems for sending out real-time price information to consumers via the utility's website, or via email[10]. Such a system could also send out instructions to shed load. For ease of commissioning, it may be preferable to use a standalone system such as cellphone short message service (SMS) to receive stage 1 signals, instead of attempting to link the load-shed coupler to the internet via a company's local area network. Stage 1 signalling should present no technical problems, and the nature of the signal will mainly be determined by the requirements of the electricity supplier or RTO – the LRC need not be overly concerned with stage 1 signals.

For maximum market penetration, stage 2 signals between the coupler and the load-shed ballasts should not require any additional wiring, and should require an absolute minimum of additional hardware, in order to minimize cost. The additional design effort required by electrical engineers and architects should also be minimal, in order not to create reluctance among specifiers toward the provision of load shedding ballasts. For these reasons, development will focus on the use of the building's electrical power network to carry signals to the load-shed ballasts; it would also be possible to implement the signal using wireless technology, but this remains expensive. The LRC recommends that stage 2 rather than stage 1 signaling be the main focus of load-shed signaling development.

In a small number of buildings, there is already a whole-building lighting control system, connected to dimming ballasts via a protocol such as LONworks, BACnet or DALI. These systems (especially DALI) may become more commonly used in the medium term, but it is worthwhile to check whether load shedding could be implemented in such a system using conventional dimming ballasts instead of instant-start load-shed ballasts. In this case, the lighting control system would simply instruct all ballasts to dim down so that their electricity consumption falls to 66% or 50% of maximum (their light output would be a slightly lower percentage of its maximum), so the end result would be the same as in a building equipped with load-shed ballasts.

Should specifications be developed for ballast and communication technology?

Some kind of minimal specification for load-shed ballasts is required, for two reasons: Firstly, if incentives or rebates are used to make load shedding attractive, then some minimum performance specification will be required in order to allow ballasts or luminaires to be classified as qualifying for the incentive; secondly, if ballasts from different manufacturers are used in the same building, they must dim down to approximately the same level in order to preserve

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[10] Independent System Operator New England (ISO-NE). 2002. *ISO-NE Load Response Program Manual*. This system sends information about forthcoming changes in the price of electricity, on an hour-by-hour basis. Load shedding would require minute-to-minute information.

illuminance and luminance uniformity. The LRC currently recommends either 66% or 50% as the target light output level. However, a performance specification should be based around electricity consumption rather than light output, so that energy suppliers obtain a guaranteed reduction in load. The specification could simply require the ballast to reduce its electricity consumption to a certain target value within a narrow margin of error, while also achieving a target value for light output, with a slightly boarder margin of error.

Stage 1 signals are likely to be technologically easy to implement; and to that extent there is little need to worry about achieving a workable solution. Nevertheless, these signals warrant attention because it would be desirable for utility companies and RTOs to use the same medium and the same format for the load-shed instructions or real-time price information they send out to consumers. This would make it much cheaper and easier to implement lighting load shedding nationwide, rather than state-by-state or even provider-by-provider. This will require co-operation between a core of committed utility companies and RTOs at an early stage; the LRC and DOE are well placed to facilitate this process.

Stage 2 signals must be robust, should not cause lamps to flicker, and must not interfere with other building systems. During the early stages of development it may be sufficient to engineer solutions on the fly using a loose specification, but at some stage it will become necessary to develop a formal standard for the stage 2 protocol and signals, in order to ensure interchangeability between components from different suppliers. Developing a standard is a time-consuming process and all parties should be cognizant of the potential for this to delay the market penetration of load-shed ballasts.

Field trials

A prototype load-shed ballast has already been developed by the LRC and OSRAM Sylvania (OSI) for Connecticut Light and Power, based on a programmed-start ballast. Programmed-start ballasts maximize lamp life but may be too expensive to achieve the intended market share for load-shed. Development will therefore concentrate on cheaper technologies, but programmed-start remains an important complementary technology because it will allow load shedding systems to be installed alongside other control systems, such as photosensing.

The powerline signal used to control the existing prototype ballast is simple, requiring a significant change to the waveform for around two seconds; such a simple signal may however interfere with the operation of other connected loads, and might necessitate a completely separate circuit for load-shed ballasts – this would add highly undesirable costs.

For the forthcoming field trial, to be conducted in conjunction with the California Energy Commission, the envisioned prototype will be based on a cheaper instant-start ballast, and a more refined signal will be used. This prototype is likely to be trialed in the LRC’s own offices.

One or more large-scale trials will be required, to ensure that the technology achieves the predicted cost savings, that it can be implemented on a large scale, and that the occupants of a large office behave in the way suggested by the human factors experiments already conducted, i.e., that they find the same magnitude of illuminance reduction acceptable. Such a field trial would have to be conducted with the active involvement of the building owners and occupants, to ensure that the occupants are informed of the reasons for the illuminance reductions.

It may be beneficial to work closely with a ballast manufacturer to find a suitable large office building in which to hold trials. The manufacturer could alert the LRC to forthcoming suitable sites on their order books.

In parallel, it may be desirable to trial a load shedding system implemented using a whole-building lighting control system. This also would require the LRC to liaise with lighting controls manufacturers.

Market transformation

Market forces (rather than legislation, tax breaks or other incentives) are the preferred vehicle for transforming markets. Government agencies repeatedly express their preference for existing or nascent market forces, as the means of bringing about market change[11]. The US in particular has a "successful policy of market reliance."[12] Energy efficiency standards or rebates should be considered only if there is no means by which the technology can be made commercially viable. Also, technologies supported in significant part by legislation or government incentives remain commercially parlous because the structures which support them could be withdrawn or amended at any time.

One feature peculiar to the building industry is that the party buying or specifying the ballast is usually not the same party that will benefit from the electricity cost savings. This is especially true of buildings procured under design-and-build contracts, where no independent advocate for the client exists. This may present a hurdle to the use of market forces to expand demand for load-shed ballasts.

"Market forces" include:

- The electricity cost savings achieved by installing load-shed ballasts;
- The possibility of adding value to the building (in terms of resale or lease price or lettability) by installing a technology that is perceived as valuable either in its own right (such as air conditioning) or as part of a voluntary building accreditation program (such as Leadership in Energy and Environmental Design (LEED)).

In the short term, before electricity price restructuring takes effect, it may be possible to begin to create demand for load-shed ballasts by including them into existing voluntary accreditation programs. These programs give each building a score based on an evaluation of its "green" credentials, and so allow building owners to more effectively market the added value of the

[11] Simons, J. 1992. Energy efficiency standard in a market economy – regulation vs competition? In *Proceedings of the International Energy Agency conference on Use of Efficiency Standards in Energy Policy* 42-51. Paris 1992.

[12] Millhone, J. 1992. The Role of Efficiency Standards in the United States. In *Proceedings of the International Energy Agency conference on Use of Efficiency Standards in Energy Policy* 16-20. Paris 1992.

energy-saving technology in which they have invested. So, tentatively, there are three stages in achieving widespread acceptance of load-shed ballasts by the building community:

1. Collect detailed data on the degree or type of price restructuring or incentive that utility companies, state energy agencies and RTOs offer consumers to install load-shed ballasts.
2. Communicate the financial and environmental benefits of load-shed ballasts to the building community; e.g., by reviewing successful projects in magazines and seminars.
3. Ensure that load-shed ballasts are mentioned in any future mandatory energy-saving legislation, best practice advice, and voluntary environmental accreditation programs.

The first of these stages is an ongoing activity of the LRC[13]. The second of these stages is referred to in the plan for the third year of the Reducing Barriers Project, although within that time frame there may not be any large completed projects. Continued funding will be required to ensure that successful installations are publicized.

The timescale for the third stage is somewhat determined by the slow natural frequency with which energy saving legislation and best practice advice are revised. Within this project, it may be possible to establish a precedent for incorporating[14] load-shed ballasts into the LEED certification[15] for commercial interiors, a document which is still in draft form.

LEED is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings. Acquiring LEED certification for a building demonstrates to potential buyers or tenants that the building has low energy consumption, a high degree or airtightness, and certain environment-oriented facilities of benefit to staff (such as bike racks, showers). The LEED certification is similar to the BREEAM energy rating method developed for commercial premises in the United Kingdom in the mid-1990s. Experience from the BREEAM project suggests that voluntary accreditation can work effectively if the certification is seen to benefit the occupier, and is sufficiently onerous to garner support from environmental pressure groups. Uptake of the BREEAM rating on new-build offices in the UK reached and maintained a level of 25% of floorspace within three years of the scheme's inception, and it remains a widely known and respected indicator of environmental and build quality.

Voluntary accreditation schemes are complementary to price restructuring approach, since price restructuring would affect mainly owner occupiers, while voluntary accreditation would affect mainly property developers and landlords.

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[13] Lighting Research Center (LRC). January 2002. *Reducing Barriers to Use of High Efficiency Lighting Systems*, *Task 4.3 Appendix A: Market Analysis for Load Shedding Ballasts*. Troy, NY: Lighting Research Center. Report submitted to US Department of Energy.

[14] The US Green Buildling Council has indicated that load-shed ballasts could initially be eligible for an "innovation credit" within the LEED scheme, and could then be further considered for formal inclusion.

[15] U.S. Green Buildings Council (USGBC). June 2002. *Rating System for Commercial Interiors*, *Un-balloted Draft for Pilot Program*. Accessed on 7 November 2002 at http://www.usgbc.org/docs/LEEDdocs/LEEDCIvPilot.pdf

Development of the market for occupancy sensors

The technology of occupancy sensors is mature enough to allow accurate data on its energy-saving potential to be gathered. To expand the market, this dataset needs to be communicated to specifiers and end-users.

Figures compiled by the LRC from a wide variety of sources indicate that the potential energy savings achievable by occupancy sensing range from a mean of 25% for shared (e.g., open-plan) spaces, to 40% for privately "owned" spaces such as private or partitioned offices. These figures are for the energy saved in comparison with each area's lighting energy consumption prior to the installation of the occupancy sensing system, relative to an eight to ten-hour working day. In relation to these substantial savings, the occupancy sensor market remains notably underdeveloped.

Widespread publication of these figures in industry magazines and via other communication channels, will bolster market demand for occupancy sensing systems.

A previous investigation[16] conducted by the LRC indicated that the difficulty of commissioning occupancy-sensing systems was a significant barrier to their more widespread use. To overcome this barrier, a commissioning standard should be developed in co-operation with key controls manufacturers (already identified[17]). This standard would include requirements for at least the following; the process by which sensors are commissioned; their functionality; and their labeling. The importance of generating support for this standard among lighting controls manufacturers cannot be overstated.

Easily-commissioned photosensor

The LRC's design for a more easily commissioned photosensor, while innovative and low in cost, still depends on the use of expensive dimming ballasts to adjust the output of the luminaire in response to daylight.

There are several reliability and efficiency issues which hamper the widespread acceptance of full-range continuous dimming ballasts. Firstly, many dimming ballasts have a low efficiency

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16 Lighting Research Center (LRC). January 2002. *Reducing Barriers to Use of High Efficiency Lighting Systems, Task 2.11: Interview key control manufacturers….* Troy, NY: Lighting Research Center. Report submitted to US Department of Energy.

17 Lighting Research Center (LRC). January 2002. *Reducing Barriers to Use of High Efficiency Lighting Systems*, *Task 2.10: Interview contractors and installers to determine installation and commissioning issues….* Troy, NY: Lighting Research Center. Report submitted to US Department of Energy.

when operated at full load, due to the constant heating of the electrodes. Secondly, some ballasts have an adverse effect on lamp life, because they do *not* constantly heat the electrodes. Thirdly, dimming ballasts remain expensive in comparison to non-dimming ballasts. Until the price of dimming ballasts falls to a level where paybacks are achievable over a commercially-viable timeframe, the use of daylight-linked systems will remain limited to a few building owners; those willing to commit to a long return on investment, and those who require dimming ballasts anyway, for reasons other than energy saving. Codes and/or legislation requiring the use of daylight-linked systems could only be justified once the performance and price issues surrounding dimming ballasts have been resolved.

Meanwhile, it remains worthwhile to promote the value of daylighting (high internal daylight levels make photosensing more economic), and to ensure that photosensing is given appropriate credit in voluntary accreditation schemes such as LEED, and in lighting energy legislation. Moreover, photosensors should be considered as part of a daylight system of windows, light fixtures and controls. As such, the incremental cost of photosensors is small.

The LRC is inherently supportive of photosensing, because daylight-linked controls can contribute to integrated architectural lighting design. Daylight-linked controls give the designer the ability to control the balance between natural and electric light in a space, in order to maximize the visibility of daylight, or to minimize the contrast imbalances created by it.

Research suggests that the most effective way of reducing lighting energy use is to ensure that occupants do not turn the lights on in the first instance[18], and these enhanced savings will only be consistently achieved with the advent of a much more subtle and research-based approach to lighting design and daylighting than commonly exists at present.

[18] Lighting Research Center (LRC). 1998. *A field study of lighting controls. Troy, NY:* Lighting Research Center.