TASK 4.1
WORK WITH KEY MANUFACTURERS, INDUSTRY ASSOCIATIONS, GOVERNMENT AGENCIES AND NATIONAL LABORATORIES TO EXPAND THE BEST EXISTING COMMUNICATIONS PROTOCOLS, IF NECESSARY, TO MEET THE NEEDS OF A FULLY INTEGRATED LIGHTING AND WHOLE BUILDING CONTROL PROTOCOL

Introduction

The lighting market in the United States has not experienced wide penetration of the use of whole building integrated lighting controls. While such lighting controls could undoubtedly reduce energy consumption for lighting, it must be realized that other, less expensive, lighting controls are available, and those markets have not seen pervasive utilization either. To determine whether the slow adoption of whole building lighting controls is due to technological barriers or other economic and market forces, it is necessary to take a critical look at the necessity of these controls and what economic benefits they offer. Then, an examination of what is currently available and what is being developed will determine if these needs are being met.

The success of lighting control products on the market must allow systems to achieve three main goals:

1. Achieve sufficient functionality to meet the key requirements of their main market.

2. Allow a significant cost reduction compared to current market standard systems. Cost should take into account: hardware capital cost including wiring, design time required by the specifier and the control system manufacturer, installation time required from the electrician, and commissioning time and remedial time required from the electrician and end user.

3. Minimize ongoing perceived overhead costs and inconvenience to the end user, or in other words, systems should be simple to understand and use.

What benefits do whole building systems provide?

Available control strategies differ widely in terms of functionality and cost; some are much simpler than others. Some operate locally on a small number of fixtures, and some collectively over a large number of fixtures. Some require continuous monitoring and immediate actions, while others are not so time sensitive. For analysis purposes, it is helpful to divide lighting control strategies into two groups based on similar communication needs. The groups are local control and collective control.

Local controls should respond to local conditions. They require continuous monitoring and often immediate (very short time delay) responses. Control strategies in this group include:

Occupancy sensors

Photosensor control

Manual switching and dimming

Collective controls respond to global, or external, signals. Exact timing of actions is not important because no immediate action is required. Many fixtures are often grouped together all responding to the same signal. Control strategies in this group include:

Scheduling (sweep off functions)

Load shed

Local control functions do not need to be integrated into a whole building system in order to work effectively. For monitoring purposes they might be connected, but their value for energy savings is not clear. Problems encountered when trying to integrate local control into large networks include:

1. Too many control nodes: the large number of individual ballasts and lighting fixtures adds excessive cost and complexity to systems. Such individualism is usually not needed anyway because fixtures are mostly operated/controlled in groups as part of an overall lighting design.
2. The need for immediate response/action places excessive demand on bandwidth and processing ability of a networked system. For example, a signal from an occupancy sensor must turn on a light within half a second or less. This is easily accomplished in a local system with a dedicated signal path, but in a networked system, a lot of processing and communication has to be done to determine which sensor is signaling, what action should be taken, addressing each component, receiving confirmations, carrying out network protocols, and gaining access to the communication medium. As more devices are added to the network, the reliability of getting a signal through within a given period of time diminishes.
3. Attention to reliability is of much greater importance for an integrated system than for individual controls, which adds considerable cost. Problems with an integrated system threaten the whole operation of a building, while local control isolates problems to small areas.

Collective controls could benefit by being integrated with other building communication systems. With collective control schemes, the number of control nodes is greatly reduced by collecting individual lighting ballasts/fixtures into groups. This does not strain the limitations of existing networks. Also, large groupings of fixtures usually do not require immediate action/response. The cost-benefit of integrating collective control is that existing hardware and network infrastructure can be shared across all building control systems.

Trying to apply a single solution that is capable of handling all the requirements of the different control strategies is not cost effective. Such a strategy will result in an overbuilt system where most of the resources are hardly, if ever used, and so consequently the system is too expensive and/or complicated to use. Therefore, it should be recognized that whole building lighting control systems might not be appropriate for all buildings now, until costs come down.

The ultimate level of control being pursued by the lighting industry is the individually addressable ballast, ideally with full-range dimming, as well as switching capabilities. Listed below (Table 1) are the key features and applications of a ballast/control system that meets this ideal. Meeting these features goes well beyond ballast design and hardware issues. They are also critically dependent upon the communication protocol used for implementing whole-building control, the commissioning of the system, and other building aspects such as daylight availability and auxiliary control devices.

It is not expected that all buildings need, or even desire this level of control, but the more features that can be packaged into a system presumably increases its market appeal, provided that other factors, namely cost and reliability, are not affected. The other advantage of an all-in-one approach is that makes life simpler for the specifier and improves interoperability because fewer product types need to be offered. Manufacturers also benefit from having to support fewer product lines. Most likely, though, cost and reliability are affected by making a system more universal. In this case the market will eventually sort out what features are most beneficial and cost effective. Assuming that the trends for increasing space use intensification, energy costs, and state and federal building code legislation continue, many of these features that are now considered nonessential may become perceived as mandatory, as they already are to some extent in other countries for intensively used, urban office space.

Table 1 - Key features and applications for individually addressable luminaires[A]

Testing and monitoring of emergency luminaires Load shedding Lamp failure reporting[B] Reduced / zero wiring[C] * See notes for further explanation	Photosensing Control of window shading devices Interchangeability[D] Occupant control from desktop

Notes:

A. Individually addressable luminaires allow end-users to organize workplace lighting into functional groups, so that switching / scene setting corresponds to the organization of the workplace. Intensively-used (usually urban) office space is frequently repartitioned or reorganized to adapt to the changing requirements of businesses and addressable systems allow the lighting to be reconfigured easily as this happens.

The end users should be able to either carry out simple lighting reconfiguration themselves (adding new luminaires, changing functional groups, changing scene settings), or have reconfiguration carried out by their regular qualified electrician, rather than having to contact the control system manufacturer. This is desirable both in order to reduce wasted time for the end-user, and to reduce the overhead costs of lighting controls manufacturers, which are recovered by adding (often very significantly) to the capital cost of lighting controls hardware, thus raising a barrier to more widespread use.

Because large buildings often house high salary workers at high occupancy densities, disruption is costly and, as far as possible, readdressing of luminaires should be carried out without access to the ceiling being required.

B. Lamp failure reporting facilitates quick replacement of failed lamps, which minimizes occupant dissatisfaction, maintains the architectural appearance of the building, and fulfils the end-user's health and safety obligations.

C. Assuming that he cost of electrical and electronic hardware will continue to fall in comparison to the cost of labor, the necessity of installing additional signal wiring will become an increasingly significant barrier to the use of control systems. This problem may soon be solved by wireless communications, but in the short term it is desirable for lighting control protocols either to allow the amount of wiring to be minimized, and/or for their signals to be sufficiently robust to allow signal wires to be run with lighting power in order to minimize the cost or cable or conduit.

Under the National Electric Code (NEC) 2002, conductors of different circuits rated at 600V or less (both ac and dc) are permitted to run in the same cable (300.3(C1)), so - barring regional variations - wiring of this type, though not common, is technically feasible.

D. Interchangeable systems are those in which components from a variety of different suppliers can be used as part of an integrated system. Conversely, proprietary systems are those with which only a single supplier's components are compatible. Due to the technical difficulty of achieving interoperability, and the absence of a perceived need for interoperability among lighting specifiers, proprietary systems remain the worldwide norm for lighting (though not for HVAC systems, which don't require instant responses and usually require far fewer addresses). Nevertheless, interchangeability remains a desirable goal for clients nervous about having only a single source for future replacement or upgraded parts. However, it remains to be seen whether interchangeability will founder on the contractual rocks of having to allocate responsibility or blame when components turn out not to be interchangeable in real life. The related issues of "interoperable" systems are a partial solution not addressed in this report.

Do established and newly-developed protocols meet these functionality requirements at a reasonable cost?

A major cost not included in this discussion is the cost of system commissioning. Currently major systems can be commissioned only by the lighting controls manufacturers (the anticipated cost of this is built into the price quotation), or in rare cases by a professional systems integrator. It is likely that part of the motivation for the development of the DALI system was to transfer commissioning cost from the manufacturers to the contractors, but from the point of view of the client the cost will not change significantly.

Another cost category that is often overlooked in the discussion of whole building controls that must be considered is the foundation costs of controls, including the cost of peripheral control technologies (e.g., photoelectric sensors or manual dimmers) as well as the more expensive dimming ballasts that is needed to provide heat to the electrodes while dimmed. Together, these foundation costs can easily be as much as an additional $150.00 per luminaire.

Analogue 1-10V protocol

Functionality

The 1-10V protocol allows continuous dimming of one or more luminaries, to the same light level. The protocol is technically ill-defined and there is no agreed statement of the exact parameters for impedance or current, and consequently this protocol has developed a reputation for inconsistent and unpredictable light levels from different luminaires, depending on the length (hence signal voltage drop) of each signal wire, and upon the particular permutation of control system and ballast from different manufacturers.

Hardware cost

The 1-10V protocol carries no addressing information, so if luminaries are to be individually addressable, each pair of signal wires must be terminated into a local control system outlet, which in turn is connected to the rest of the system by a different (usually proprietary) addressable bus. To avoid excessively complex wiring, no more than a handful of luminaries can be connected into the same local outlet box, so the 1-10V protocol carries a high overhead of ceiling-mounted lighting hardware, which adds mainly to capital cost but also to design time and installation time. In the absence of any other barriers, this cost barrier is sufficient to prevent the widespread uptake of lighting control systems.

Wiring cost

The signal carried on 1-10V wires is highly susceptible to 60Hz interference, and so should not be run in the same conduit or cable as lighting power. The necessity for different cable routing adds to the wiring cost and the wiring complexity of the system. The maximum length of signal wire permitted before voltage drop begins to severely affect the system is debatable, and depends how much discrepancy in luminaire output the client is prepared to tolerate, as well as the number of ballasts connected. Where this wire length is exceeded, signal repeater units must be used to boost the signal.

Design cost

Usually, not all the luminaries in a given area need to be individually addressable. To save cost in 1-10V systems, luminaries in common areas of the workplace can be grouped together and set to the same dimming level. This is also often the case with a row of luminaries parallel to the windows in a daylight-linked system. In these cases the grouping and wiring of the luminaries must be exactly specified during the design stage, and must satisfy the requirements of both the architect and the electrical engineer. This process involves the issuing of extra drawings and the necessity for additional project group meetings. There is also a need to consult with the control system manufacturer about maximum cable lengths, the necessity for signal repeaters, and potentially other wiring issues.

Reconfiguration cost

If a fully-addressable 1-10V system is installed, it should be as easy to readdress the luminaries, as it would be with any other system. However, 1-10V systems very seldom have full addressability, in which case reconfiguration involves access to the ceiling void and re-wiring of parts of the control system. Usually this is a complex process and would require the original ceiling plan to be referenced.

Non-addressable digital dimming protocols (SuperDim, DSI etc)

These protocols are topologically the same as 1-10V, but provide specific technical advantages, including accurately specified and predictable light output, no problems with voltage drop, zero susceptibility to radiated interference, and the ability to report lamp or ballast failures (either from an individual luminaire, or from somewhere within a group). However, they still do not allow individual dimming and so incur the same high overheads as 1-10V systems. Due to the resistance of the US market to factory-prewired components including modular wiring, these cost overheads are much more significant in the US than in other countries, and are not likely to be overcome.

DALI

Functionality

DALI is a protocol developed by a partnership of major ballast manufacturers. It allows addressing, dimming, grouping, lamp error feedback, and will allow a variety of other functionalities in the future. DALI-compliant ballasts and input devices from different suppliers can be used interchangeably in the same installation.

Hardware cost

The DALI protocol is based on the DSI digital protocol, but with additional bi-directional communication that allows 64 separately addressable luminaires to be connected on a single free-topology bus. This feature allows addressability to be achieved with far fewer ceiling-mounted boxes. The overall cost of DALI components is low because they are standardized between manufacturers. [2]

The facility for emergency testing and monitoring is incorporated into the DALI protocol, and load shedding can be carried out very simply. However, due to the low speed of the bus, DALI's ability to convey continual level signals from photosensors is very limited. This limitation can be overcome by using fewer photosensors (or even just one single photosensor for the whole building), which also minimizes installation and maintenance effort.

The DALI protocol is very rigid in order to ensure interchangeability between ballasts and input devices from any DALI-compliant supplier. Additional functionality can be built into individual systems, but because the protocol has been specifically developed for the lighting industry, writing specialist applications is a specialist business.

Wiring cost

The protocol operates at a low speed of 1200 baud and is therefore highly resistant to interference, so it can be carried in the same conduit or cable as the lighting power. Furthermore, it does not require regular twists in the wires (as is the case with some protocols), so standard (cheap) RJ11 or RJ45 cabling can be used to reduce on-site wiring (though cable insulation must of course be rated for plenum ceilings where relevant). There question of whether low-voltage signal wires can be run in the same cable as lighting power appears to be a gray area – if this were allowed it would further reduce the incremental cost of lighting controls.

Design cost

Because the wiring of the luminaries is not determined by their functional groupings, the time required to design cable routing is minimal, and the routing can be adapted to suit the space requirements of other ceiling services. The absence of voltage drop problems allows more

[2] A low-cost communication interface does not necessarily translate into a low system cost. Dimming ballasts are expensive in terms of lamp operation circuit design, and decreased efficiency in operating the lamp over non-dimming ballast designs. Peripherals that add functionality to the system, such as sensors and user interfaces, also contribute greatly to the overall cost. This can make a DALI system, or any other control system, expensive independent of the isolated communication protocol cost.

flexibility in the siting of boxes remotely from the luminaries they control. Only the electrical engineer need be involved in designing the wiring, so there is little need for consultation between the engineer, the architect and the control system manufacturer.

Reconfiguration cost

Because all major ballast manufacturers support the DALI protocol, electrical contractors are likely to become sufficiently familiar with the system to undertake minor reconfigurations without having to consult the manufacturer of the particular components used. This means that the end-user will likely be able to use their regular electrician, who is already familiar with the building, to carry out the work. Many end-users will be able to carry out the work in-house. In the longer term this will result in a significant saving in post-installation site visits by control system manufacturers, reducing their overhead costs.

LBNL IBECS

Functionality

IBECS is a protocol under development at Lawrence Berkeley National Laboratories. It offers addressability over a twisted pair bus, and potentially the same range of functionality as DALI, with the advantage that the higher baud rate allows more devices to be connected, and allows the attachment of devices such as photosensors which send out continuous level signals.

Hardware cost

IBECS interface chips can be built in to ballasts in the same way that 1-10V and DALI systems are at present, but for much lower cost. (See note in section 4.3.2.)

Due to the fast baud rate of the bus, IBECS is susceptible to the high degree of harmonic and radiated interference produced by high frequency and dimming ballasts. For this reason it is necessary to incorporate an opto-isolator into each module. The opto-isolator adds only marginally to the cost of the system, and apparently solves the interference problem completely.

The interface between the IBECS microLAN and the high level TCP-IP network is made via a readily-available and cheap standard RS232 gateway.

Wiring cost

Up to 100 devices can be connected to each microlan, making the wiring cost comparable with DALI. IBECS can be made to run over a wireless network, probably more cheaply than will be possible with DALI, because the microlan is more akin to standard IT industry networks.

Design cost

As with DALI, because the wiring of the luminaries is not determined by their functional groupings, the time required to design cable routing is minimal, and the routing can be adapted to suit the space requirements of other ceiling services. The absence of voltage drop problems allows more flexibility in the siting of boxes remotely from the luminaries they control. Only the electrical engineer need be involved in designing the wiring, so there is little need for consultation between the engineer, the architect and the control system manufacturer.

Reconfiguration cost

IBECS runs on an IT industry-standard high speed bi-directional bus, known as MicroLAN, which allows a virtually unlimited number of separately addressable luminaries, and a similarly unlimited variety of other potential functions such as emergency testing and monitoring, load shedding, and communication with other components such as shading device actuators. The protocol is potentially much less rigid than DALI, and since it is based on a very common technology, specialist applications are likely to be easier to design. However, for the same reason, some question mark exists over the interchangeability of components.

Summary

Realizing that whole building controls are not the only solution to an assumed latent market demand for energy-saving, and/or comfort-enhancing lighting controls, the added functionality of using such controls for lighting was presented. In terms of this added functionality of the whole-building approach, the capabilities of existing control protocols were analyzed. This analysis reveals that existing lighting controls protocols are functionally capable of meeting the needs of current and future market demand for lighting control systems, though the ease and expense of specifying, designing, purchasing and installing a lighting control system is significantly affected by the protocol choice. The current move in the market is towards protocols, which require fewer pieces of associated lighting control hardware – the ultimate goal being the “addressable ballast”.

In particular, the DALI protocol offers high functionality and low hardware cost, and is well along the road to widespread use outside the US, although the requirements of the National Electrical Code, and inertia associated with electrical engineering practice raise questions over whether it can cheaply be implemented in this country. The IBECS protocol from Lawrence Berkeley National Labs may offer similar functionality at an ever lower cost, though no large IBECS systems have yet been made or tested in the laboratory. Such testing would have to be conducted before IBECS could be viewed as a viable technology for lighting control.

The current market standard 1-10V dimming protocol is widely considered to be unreliable and excessively expensive, and progress in energy-efficient lighting is unlikely to be made until improved technology becomes widely available and widely understood by specifiers and electricians.

The industry drive for individually addressable ballast systems is making progress in the US market despite there being no clear demand at this present time for the functionality it offers. The added cost, complexity, and market wariness associated with dimming ballasts along with the overall high first-costs associated with putting together a complete functional system most likely limits broader acceptance. Continued development and investment to lower these costs is occurring even though the economic drivers behind this investment are not obvious to everyone.

Codes and standards must also be considered because, if adopted, they could radically change the current economic picture, making greater penetration of controls required in new construction and major renovation.