ENVIRONMENT DESIGN GUIDE

ENERGY MANAGEMENT AND OCCUPANT WELL-BEING THROUGH INTEGRATED LIGHTING CONTROL

Steve Coyne

SUMMARY OF

ACTIONS TOWARDS SUSTAINABLE OUTCOMES

Environmental Issues/Principal Impacts

- Reduced greenhouse gas emissions
- Reduced need for greater mechanical plant sizing
- Increased occupant satisfaction

Basic Strategies

In many design situations, boundaries and constraints limit the application of cutting EDGe actions. In these circumstances, designers should at least consider the following:

- Utilise natural lighting to reduce the need for electric lighting.
- Install occupancy detectors to ensure lighting in unoccupied, out of sight spaces is OFF.
- Allow manual control of individuals' task lighting.
- Install lighting zones with switches to avoid large area spaces being lit for reduced occupancy.
- Install a lighting scheduling system where occupancy and function are highly routine.
- Dim lighting to account for initial over-design of lighting levels due to depreciation in lighting output throughout maintenance cycle.

Cutting EDGe Strategies

- Assess all lighting control systems/strategies in terms of triple bottom line, incorporating occupant productivity.
- Maximise daylight usage and link to dimming of electric lighting system.
- High frequency electronic control gear allows seamless dimming and reduced energy loss.
- High frequency electronic control gear is available in a form which allows individual addressing of luminaires.
- 'Intelligent' luminaires provide greater occupant visual comfort, flexibility and efficient energy usage.
- Lighting control systems report on energy usage, lamp failures, and other output parameters useful to facility managers.
- Facility managers utilise more features of lighting control systems that integrate with building management systems.

Synergies and References

- *BDP Environment Design Guide*: GEN 24, GEN 61, TEC 3, TEC 9, DES 1, DES 6, DES 7, DES 61, DES 62, PRO 3, PRO 32, CAS 35

ENERGY MANAGEMENT AND OCCUPANT WELL-BEING THROUGH INTEGRATED LIGHTING CONTROL

Steve Coyne

1.0 INTRODUCTION

There are significant opportunities to effect an improvement in the energy efficiency and energy management of lighting systems in buildings through integrated lighting controls. This is most achievable when lighting is included in the deliberations about the construction or refurbishment of any new or existing building from the planning phase of the project. Particularly important in terms of achieving the established energy efficiency levels is the legacy left for the facility manager endeavouring to operate the facility to its maximum potential in terms of comfort for the occupants and cost effectiveness for the owner and/or tenant.

2.0 OCCUPANT ACCEPTANCE AND ECONOMICS

The critical element in any program seeking to 'automatically' modify the services to a person's work environment is acceptance of the system by that person and their colleagues. In terms of lighting controls, this means that any energy saving strategies will only be successfully implemented and operated if the occupant's comfort (viz visual amenity) is, if not improved, at the very least not compromised.

There are a number of overall or holistic issues which should be considered with regard to the lighting system control at the planning phase of the building project. The decision on each of these issues is ultimately tempered by the impact on the overall cost of the system. Basically the decision on each issue needs to deliver benefits which justify prioritising capital expenditure on lighting. The need for lighting is understood and accepted. The need for quality lighting with a 'valued' integrated control system is not yet accepted as part of the minimum requirements.

3.0 TECHNIQUES

Lighting control is implemented for three main purposes. The first is to reduce the energy consumption of the lighting system. The second is to change the lighting scene for aesthetic endeavours or adjust the lighting for a different function within the space. The final purpose is to avail superior lighting opportunities to the occupants for physical benefits. These are all related but the level of sophistication of the technologies employed depends on the priorities given to each objective.

4.0 EFFICIENT ENERGY STRATEGIES

The main strategies for efficient energy use relate to turning lights off or dimming them when either no-one is present or where there is more than the required light level for satisfactory visual performance of the occupants in the workspace at the time. This means that the required light level is not just limited to the single criterion of illuminance level on the work plane.

All strategies should be considered in terms of likely user acceptance and the payback period (which should also include any savings due to increased maintenance cycles).

The strategies include

- Occupancy sensing
- Scheduling
- Lumen maintenance
- Daylight linking
- Load shedding

4.1 Occupancy sensing

Spaces that are intermittently occupied can save a significant amount of energy through the elimination of unnecessary lighting.

Spaces suited to occupancy sensors generally need to be enclosed spaces. Spaces such as board, conference and meeting rooms where there is a significant power density of 'mood' lighting present have a propensity to save energy through sensing occupancy with a short payback period. Occupancy in small offices with one or two occupants should also be considered as well as open plan office space. Areas such as archive rooms which have a high illuminance lighting installation but very infrequent use also can have feasible savings. Other areas though, for example utility areas and single toilets, which have a modest lighting configuration with very limited number of luminaires may not be feasible, even with very limited occupancy. Analyses need to be conducted on a case by case basis.

4.2 Scheduling

In spaces where there is a definable and reliable chronology of occupancy and function an appropriate method of energy saving is automatic scheduling of the light level for zones within the space.

Scheduling entails automatically setting the light levels (controlling the luminaires) based on the day of the week and the time of day. This then implies knowledge of the lighting requirement for an anticipated activity at a set time. Electrical energy is saved through accommodating regular activities which operate under lower lighting levels (e.g. after hours cleaning).

Manual override is paramount in scheduled systems (as well as other methods of occupancy detection) as there must be the ability for the space to accommodate an occupant's own timetable of work, otherwise the negative productivity factor looms in the payback equation.

4.3 Lumen maintenance

Designing the lighting for a space requires meeting a minimum level of illuminance for the duration of the maintenance cycle. To achieve this, the initial light level has to be higher than the minimum level in order to allow for depreciation in the light output from the lamp with age as well as reductions, due to dirt build up, in the reflectance of the luminaire reflectors and interior office walls before reaching the work plane. Current fluorescent lamps only have about 10% lumen depreciation over their life but dirt build up on reflective surfaces can account for another 20% reduction.

Dimming the luminaires so as to preserve a constant light level throughout the maintenance cycle can save significant electrical energy as demonstrated by the shaded area in Figure 1. The amount of savings is also dependent on the length of the maintenance cycle set for the particular installation.

Lumen maintenance can be utilised on any installation where the lamps are dimmable and have an appreciable reduction in lumen output (or very dirty environment) over the decided maintenance period. Generally the installation needs to be relatively large for the payback period to be feasible. Office and industrial situations with many luminaires to a zone have the shortest payback periods. All the lamps are replaced at the same time.

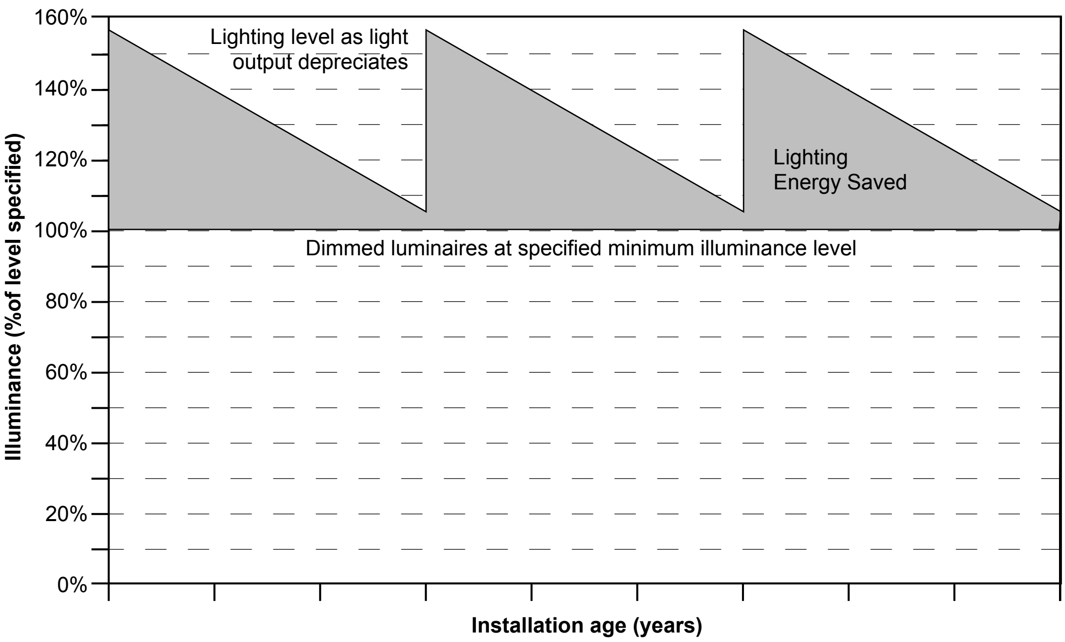

Figure 1. The illuminance level over time of a lighting installation

Lamp	% Lumen Depreciation	at %	of rated life (hrs)
Standard incandescent	12 - 18	50	750 - 2,000
Tungsten halogen	<5	50	2,000 – 6,000
Compact uorescent	14 – 17	40	10,000
Linear uorescent	5 – 10	40	7,500 – 20, 000
Metal halide	22 – 36	40	7,500 – 20, 000

Table 1. Lumen depreciation of lamp types

4.4 Daylight Linking

The utilisation of daylight as a light source within an interior space has the greatest energy saving opportunities for space which is occupied during daylight hours. Daylight linking is the practice of dimming the electric lights in areas where daylight is making a significant contribution towards the specified lighting requirements.

But before a daylight linking system can be determined, the daylight delivery system/strategy needs to have been established. Discussion of the details of daylighting philosophy and daylight technologies is beyond the scope of this paper. EDG note DES 6 *Daylighting of Buildings* contains information on daylighting strategies.

Daylighting systems can be as simple as a window or skylight or as sophisticated as an innovative daylighting technology which redirects and redistributes the daylight deeper into the core of a building.

Skylights provide better scope for daylight distribution throughout the space by virtue of their direct overhead placement.

Sophisticated daylighting devices are designed with the primary aim of redistributing the available daylight collected at the external façade in such a way that the deeper interior areas of the room receive a greater proportion of the daylight. This is achieved by transferring the daylight deemed to be excessive in one area to other under-daylit areas.

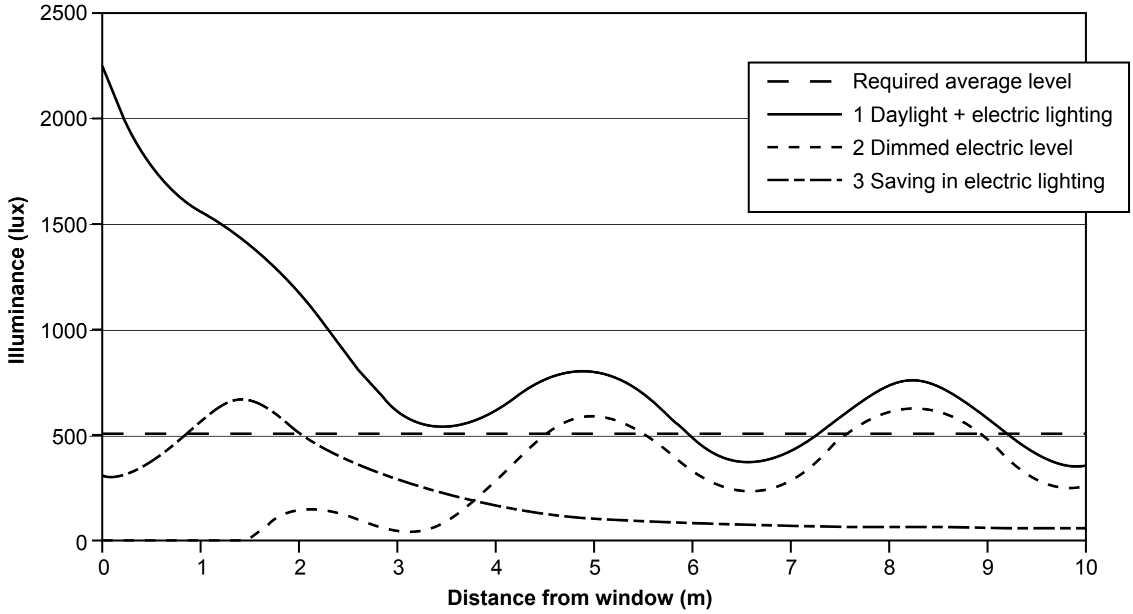

Figure 2. Energy savings through dimming of electric lighting when daylight is available

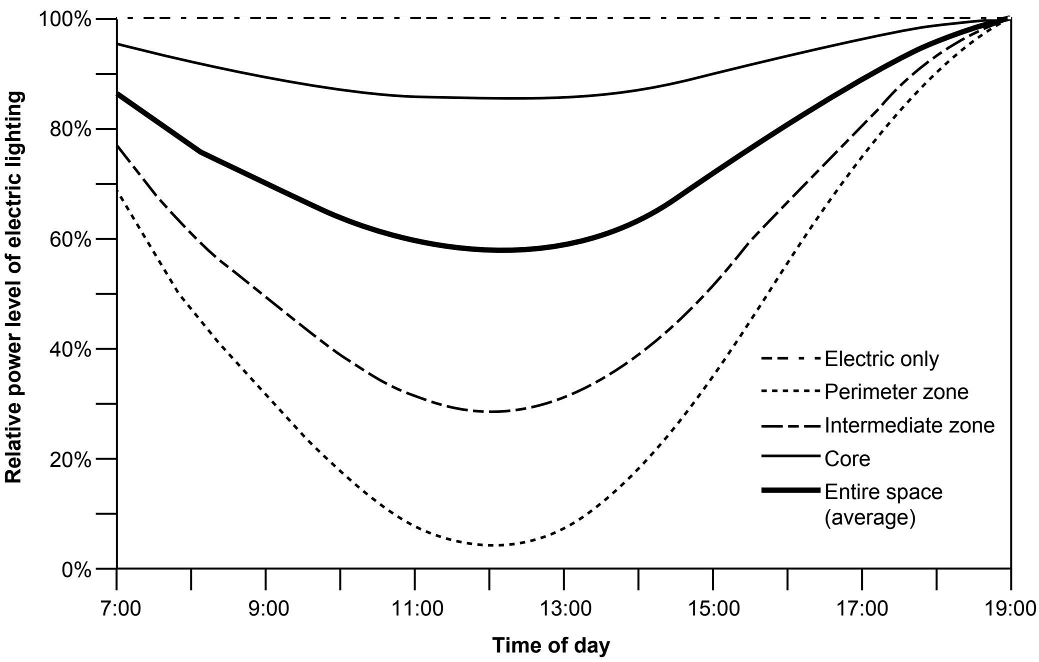

Figure 3. Indicative electric lighting reduction in zones based on available daylight throughout a day

Once the daylight is introduced the electric lighting system has to be able to respond dynamically and dim the luminaires in order to gain energy savings while maintaining the specified light level throughout the entire space. Figure 2 illustrates (Curve 1) the daylight plus non-dimmed electric light level diminishing with distance from the window until the only significant contribution to the light level is from the electric light. With dimming of the electric light (Curve 2, Figure 2) the energy savings realised are illustrated in Curve 3 of Figure 2. Note the diminishing energy saving with distance from the window.

The daylight level throughout the interior is stratified. This stratification has to be zoned into areas of equivalent daylight levels and then all luminaires in each zone will be connected to a single circuit and dimmed together. The assumption made is that the daylight level will be the same throughout a zone and will take the value of the actual minimum daylight level in the zone (this will probably occur at the furthest point from the daylight source). With daylight availability varying throughout the day and year based on weather patterns and solar transit, the prediction of interior daylight levels and even the shape of stratification will change. Generally only one (perimeter) or at the most two (perimeter and intermediate) daylight zones are implemented parallel to the window façade with potential energy savings illustrated in Figure 3. The core is generally perceived as not being economically feasible for daylight dimming due to the very limited energy savings. Overall when averaged over the entire space, the energy saving achieved from dimming of the electric lighting due to the availability of daylight can be as high as 40%.

4.5 Load shedding

The price paid for electricity by the commercial and industrial sector is determined by the amount of electricity consumed (kilowatt hours) and the market price of the load required (kilowatts) during set intervals (see Figure 4).

Electricity in Australia is considered to be cheap when compared with other global markets but as demand increases the spot price increases accordingly. Having a significant effect on demand is the base load created by the strong uptake in recent years of air-conditioning systems in domestic homes. This is due to their affordability through a low initial capital cost and fixed price tariff for the energy cost regardless of the electricity demand. During summer months in northern states, the electricity supply industry struggles to meet demand during the early afternoon period as air-conditioning units are operating at maximum load. The entities within the commercial sector who purchase electricity from the spot market, and are charged according to their peak demand, suffer huge increases in electricity costs.

One way to reduce the cost of electricity during these high demand periods is to limit the electricity load in-house. Basically, this entails either turning off or limiting the electricity usage of equipment and services in the office to a level still considered acceptable to the occupants. One area identified for load reduction is lighting.

Load shedding can be utilised on any installation where the lamps are dimmable or have automated ON/OFF. There needs to be a sufficient number of luminaires (or more correctly, a significant power/load) that can be dimmed or switched off for the payback period to be feasible. Areas with a high lighting power density such as foyers and fronts-of-house where there is a substantial amount of architectural or feature lighting should be considered for load shedding.

5.0 FUNCTION SPECIFIC LIGHTING FOR A MULTIFUNCTION SPACE

In recent times there has been an increasing tendency to utilise interior spaces for multiple functions and the preferred lighting for each of these activities in terms of achieving the desired visual effect can differ dramatically. With lighting control systems there is the opportunity to accommodate these differences to various degrees.

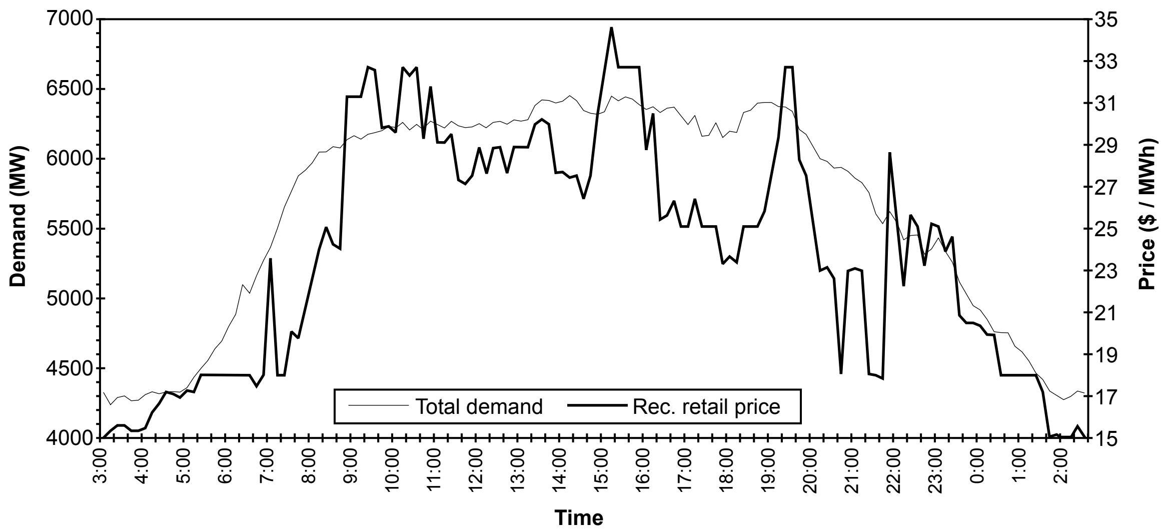

Figure 4. Example of demand driven pricing of electricity

6.0 CHANGING THE LIGHTING SCENES

Changing the lighting in a space to suit the activity is known as changing/setting the lighting scene. In the past it was achieved by having a number of separate lighting circuits and manually switching (ON or OFF) the circuits to reach the permutation closest to the desired lighting effect. Greater flexibility is available through a lighting control system.

An example of a space appropriate for changing of lighting scenes is a board or seminar room. The lighting requirements in either room may range from a task oriented tabletop, to a screen based presentation, to holding an entertainment function.

The latest area of the building industry to take an interest in lighting scene setting is the residential sector. Lighting control systems have been developed specifically for the home with the focus on setting lighting scenes. Uptake is strong and will undoubtedly continue in this increasingly technology-savvy community we live in.

Changing lighting scenes can be as simple as switching different circuits of luminaires ON and OFF. But at the other end of the spectrum are lighting control systems that use all luminaires in the space to create each scene by adjusting the output level of each luminaire individually.

7.0 LIGHTING FOR OCCUPANTS' PHYSICAL BENEFITS

The lighting for a space is, in the first instance, for the occupants of the space. They require two types of lighting: ambient and task lighting. Task lighting is the lighting required to conduct a visual activity at a satisfactory level of achievement. Ambient lighting is effectively for the occupant's visual interaction with the space as a whole. Information about a space gained through the lighting is generally processed subconsciously by an occupant of the space. At times however visual cues in the lighting scene can cause conscious thought processes by the occupant, thereby distracting them from their specific task.

These cues are generally related to the inability to see the task at hand because of inappropriate light levels or the presence of glare. These situations need to be identified and generally manually rectified by the affected individuals, as each situation arises. Two strategies to achieve this are:

- Task tuning; and
- Luminance balancing

7.1 Task tuning

The office space in commercial situations is generally lit to illuminance levels for task lighting throughout the whole space. This facilitates minimal problems associated with lighting when rearranging the office layout, but it also means that non-task oriented spaces are probably wastefully over lit and possibly even lack visual 'luminous' interest. Therefore a lighting scheme which separates the task and ambient lighting will be more energy efficient.

The task lighting can be a fixed illuminance level (to meet Australian Standards) but this level is most likely not to be satisfactory for some occupants. It will be too low for older occupants and those with particular eye conditions. It may also be higher than that preferred by some younger occupants. And all occupants may prefer more task light as the day progresses and they become fatigued.

Providing occupants with adjustable task lighting allows them to set the lighting level to their particular requirements. Dimming for an occupant's preference however should only be incorporated if this control over their lighting does not affect the lighting of other occupants.

7.2 Luminance balancing

In offices where there are transient introductions of significant high luminance sources there can be issues with brightness ratios in an occupant's field of view. This is particularly so if the bright source is a small visual angle from the direction of the task of that person. In order to relieve the person of the high luminance ratios, luminance balancing is required. This should obviously be first attempted by trying to remove or limit the high luminance transient source.

The high luminance sources that most often need to be reduced are from incursions of direct beam sunlight of large area diffuse reflectances such as facades of adjacent buildings. These bright sources are either walls near the window or the window itself. This can be rectified by closing blinds or drawing curtains. But if this is either not possible or not preferable then a lighting based solution is required. The surfaces surrounding bright sources need to be increased in luminance. These surrounding surfaces may either be the workstation itself, the privacy partitions, or the walls near the bright source.

7.3 Circadian linking

The effects on humans of limited exposure to high light levels (daylight levels) for an extended period of time, such as a winter season, have been well documented for many years. This has been recognised as an issue for higher latitude countries where sunrise and sunset in winter occur while workers are inside the office and their travel to and from work is in the dark.

Current research and thinking suggests that there is possibly a measurable improvement in performance and well-being of occupants for all geographic locations when a circadian linked lighting environment is provided. These improvements are thought to be due to more subtle psychological processes in an occupant's continual subconscious appraisal of their visual environment.

Natural lighting has a circadian rhythm. Notwithstanding weather conditions, light levels increase till solar noon then decrease until sunset. (See Figure 5). Also the colour of the daylight is 'cooler'

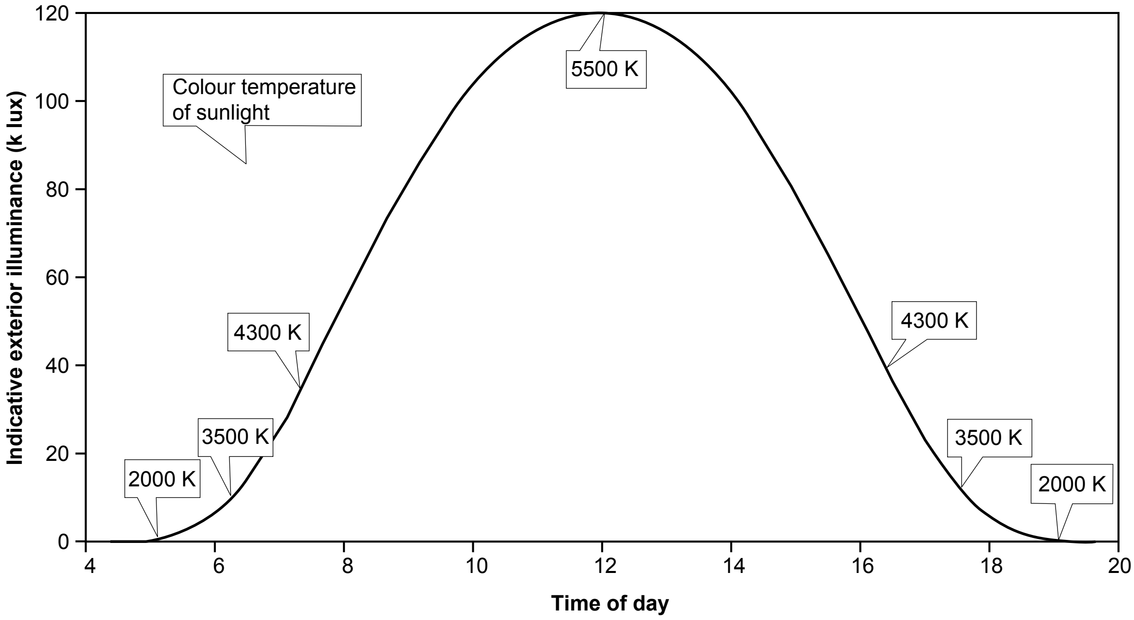

Figure 5. Variation in illuminance levels and colour temperature of daylight with time of day

Lamp	Acceptable Dimming levels (%)	Dimming and Control Gear	Effect on Colour Temperature
Standard Incandescent	100 - 0	Standard dimmer	Becomes warmer
Tungsten Halogen	100 - 10	Standard dimmer	Becomes warmer
Fluorescent (Compact + T5 + T8)	100 - 1	High frequency electronic ballast and lagging edge dimmer	Nil

Table 2. Lamp types and their dimming characteristics

(stated as a high colour temperature) around noon when light levels are high and 'warmer' (indicated by a low colour temperature) at the beginning and end of the day.

Situations where circadian linking may be considered are where there is a possibility of a defined benefit. For workers acquiescing to longer working hours each day this may become more of an issue in retaining their well-being. Also with the standard of office environments continually improving circadian linking may become the process for fine tuning or extending worker performance.

8.0 THE LIGHTING CONTROL SYSTEM

The lighting control system will incorporate a number of the above strategies which have been determined as appropriate and agreed upon for a particular installation. With some of the strategies a mode of operation will need to be determined and, depending on the mode, the appropriateness of particular lamps.

An integrated lighting control system can be considered in two parts:

- The components (i.e. input devices, control processing unit, switches and/dimmers for controlling the output of the luminaire); and
- The communication network to carry the instructions from the processing unit to the luminaire.

8.1 The components

The input devices were discussed in previous sections. They are the technology required to achieve a particular strategy. These vary from a simple switch or dimmer to a sensor which monitors a parameter associated with the particular strategy.

A switch or dimmer can either be manual or automatic in their operation and will depend on the situation. A point worth noting is that when considering the mode of operation of a switch or dimmer, occupants will manually turn lights on or adjust up when required. They will generally not turn lights off when leaving. And they definitely will not dim lights when the light is in excess of that which is required.

As far as dimming is concerned knowledge is required of a lamp's ability to dim, dimming range, and control gear. As a guide Table 2 presents the general situation. For further information consult with the manufacturers as they vary in their recommendations, particularly for Metal Halide lamps (which is why they are not listed in the table).

8.2 Communication strategy

The communication network comprises two parts. These are addressing of the luminaires and the physical route that the communication signal will take.

8.2.1 Cabling

The physical route for communication data is generally a separate pair of low voltage wires. It is known as the 'bus' system. It is a very labour intensive installation particularly for a refurbishment where either the ceiling has to be removed or the installer has to climb through the ceiling space pulling wire to each luminaire.

Other technologies are available where the communication data is delivered to the luminaires via the main power cabling. This requires a coupler and de-coupler for the entry (at the lighting control processor) and exit (at each luminaire) of the communication network from the power network. Past systems encountered problems with interference on the power line entering the building and losses of signal strength through the building. These issues have been overcome by some manufacturers by isolating the lighting power circuit from outside interference and restricting the distance to the luminaire network being controlled.

For areas where cabling is difficult or expensive there are wireless systems which use radio frequency (RF) to communicate between a transmitter which may be a switch or a switch/dimmer, and the receiver that is connected in-line on the power cables to the luminaire (see Figure 6). This is very useful, for example, for constructions from tilt-up concrete slabs where channelling of cable to a switch position on a wall is labour intensive. In these situations an RF receiver can be connected to the power cable to the luminaire and the RF switch surface mounted on the wall.

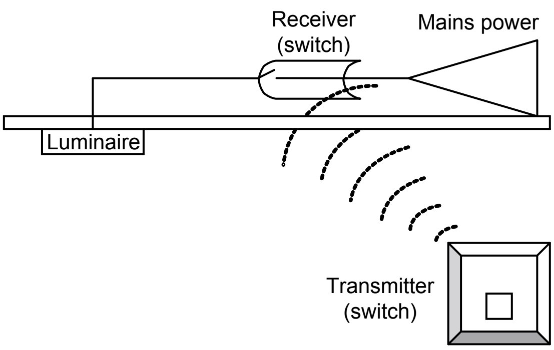

Figure 6. Wireless communication for wall switch

8.2.2 Control signal and addressing

The control signal delivered by the cabling system is in the form of an analog or a digital signal. Analog systems use a 1–10 volt signal which is delivered via two cables to all luminaires on a circuit. Therefore all luminaires have the same light output level at any one time. The analog system is susceptible to line voltage drops and interference.

An advancement on analog control signals is the digital signal in the form of a Digital Serial Interface (DSI). Dimming levels are communicated to the luminaire in the form of an eight bit signal. Due to the nature of digital signals there is much less susceptibility to line drops and interference. As with the analog system all luminaires on a circuit have the same light output.

The latest development in lighting control communication is a Digitally Addressable Lighting Interface (DALI). This system allows the individual addressing of each luminaire in the office irrespective of which 'circuit' it is powered from. The communication wiring just has to be linked to every luminaire. There are no hard wired control circuits. With the individual addressing comes the ability to dim all luminaires to different levels. Virtual circuits can be created (programmed) at the control system and may be different for different scenes. The only limitation to the DALI system is that it only has 64 unique addresses but a number of manufacturers have developed their own control system which operates above the DALI system thereby extending the number of possible addresses to multiples of sixty-four. Another advantage of the full digital capabilities of DALI is feedback from the luminaire in the form of lamp failure, burning hours, dimming level etc.

9.0 PUTTING IT TOGETHER

During the planning phase of the project there needs to be informed discussions of possible options for the delivery mechanisms for the task and ambient lighting which meet the visual objectives of the project team (which must include the owner, tenant, architect, and lighting designer).

Next the life and recyclability of the lighting system and components should be considered. Decisions on these will depend on issues such as ownership or tenancy, duration of occupancy, expected life of installation (i.e. until next lighting refurbishment), recyclability of components if relocated or upgraded.

Building occupation requirements will need to be mapped out in terms of the functions of areas/zones within the floor space and an indication of the percentage utilisation of each area.

The design process should include how to physically achieve the strategies decided upon in the planning process taking into account the recycling philosophy and life of the installation. The longer the life of the installation the greater the opportunity to use advanced technologies in order to maximise energy savings and occupant well-being as well as increasing likelihood of compatibility with future developments.

Sensors for occupancy, daylighting and lumen depreciation need to be carefully considered in their placement. Any operating requirements critical to the correct operation of the system (e.g. recalibration or repositioning of sensors if office furniture/partitions are rearranged) should be stipulated in the design and explained in the documentation handed over after commissioning.

Finally, on completion of the design process a maintenance program for the lighting system including the lighting control system should be delivered to the owner or facility manager. This is critical for their understanding of the lighting system and also for inclusion in any maintenance contract with a third party. Many installations fail to meet their specified performances targets due to contempt for or ignorance of the lighting system's particular technologies or operational strategies.

References

Coaton, J.R. & Marsden, A.M., 1997, *Lamps and Lighting,* Arnold and Contributors, London.

IEA SHC Task 21. 2000, *Daylighting in Buildings*, Lawrence Berkeley National Laboratory, Berkeley, California.

Julian, W.G., 1999, *Lighting – Basic Concepts*, Department of Architectural and Design Science, University of Sydney, University of Sydney Printing Press.

Lawrence Berkeley National Laboratory, 1997, *Tips for Daylighting with Windows*, (http://windows.lbl.gov/pub/designguide/).

Murdoch, J.B., 2003, *Illuminating Engineering: from Edison's Lamp to the LED*, Vision Communications, New York.

Rea, M., (Ed) 2000, *The IESNA Lighting Handbook*, The Illuminating Engineering Society of North America, New York.

Biography

Steve Coyne is a physicist who lectures in optics at QUT and is a director of ISN Scientific, a company which consults in optics, photometry and daylighting. He has over 17 years experience in daylighting and dimming control systems, as an educator/trainer, researcher and consultant. Professional memberships include the Illuminating Engineering Societies of Australia & New Zealand, and North America and the Australian Optical Society.