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Design and Management of Lighting in Modern Workplace

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Abstract

Change is omnipresent in the modern workplace. Property and infrastructure inherited from the past is therefore increasingly constraint businesses and building users, and requires the provision of higher flexible arrangement to alleviate the impact of change on the workplace. Flexible measures for property and infrastructure usually requires a vast amount of capital investments. And greater emphasis is placed on the capital cost rather than operating cost. Consequently, innovative solutions for improving the degree of flexibility in the workplace and their long-term benefits to organisations and their employees are always overlooked.

Space planning and management is a core competence of facility managers. The concept of flexibility has been widened in this respect in order to achieve an effective space utilisation. Reconciling with the changing space arrangement, flexible building services designs are also essential in the workplace. Although there are a number of flexible building services designs that have been extensively adopted in the modern workplace, the utilisation of flexible lighting system is standstill. Exceptionally high capital cost is the main reason that building owners and investors evade to innovate their obsolete lighting system.

For many years, building owners and investors placed too much emphasis on the energy issue of the lighting system. As facility management is a profession that brings together a wide range of property- and user-related functions, facility managers should provide a strategic lighting system which can improve individual well-being and economic interest. Flexibility and manageability are also important issues on designing a strategic lighting system.

Three lighting systems models are compared based upon a commercial building in terms of their physical, functional and financial performances. The two innovative lighting systems, C-Bus and Digital Addressable Lighting Interface (DALI) lighting management systems, are conspicuously superior to the conventional lighting system. With the use of these two innovative systems, both manageability and flexibility are significantly improved with desirable payback period. Furthermore, DALI system is the best choice that can maximally satisfy building owners, investors and building occupants.

Facility managers, who have a sound management experience and knowledge, should participate in the briefing and design stages so as to establish a strategic lighting regime for the better management of lighting. To reduce constraints and open up opportunities, facility managers should inform the stringency of manageability and flexibility to the design process and meanwhile ensure that the clients and investors recognise this essentiality.

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Glossary of Terms

Churn A measurement of change of workplace, where the number of workplace moves carried out in one year, is expressed as a percentage of the number of workplaces provided.

Convertibility This method of managing change is to reassemble interchangeable sub-components into new configurations or new functional assemblies, which use system furniture, modular walls and modular utility systems.

Rearrangeability The ability to cope with change by moving and rearranging equipment or furnishings, such as storage, worksurfaces, tables, lighting, within a given room or space, as it is the way they are laid out that provides the flexibility to support different activities.

Versatility The ability of the space to handle different functions without physical change

Workplace The desk or workstation configuration provided to an individual member of staff, be it enclosed or open plan.

Workspace The usable area remaining after support and ancillary areas have been deducted from the net usable area. This is the space required for the individual workstations, personal filing and meet requirements.

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1. Introduction

1.1 Background to the Study

Many of buildings in the past were designed to suit the particular needs and usages of specified organisations. Inside these buildings, building services systems are of little concerns, and only simple and fixed air conditioning system, lighting system and power sockets are provided due to over-commitments in long-lease on the basis of optimistic expectations for high economic growth in the past. However, the subsequent emergence of a long period of economic downturn incurred surplus capacity in property provision for many organisations. Those buildings designed for specified usage have resulted in high levels of premature obsolescence, driven by functional and locational factors rather than by age, physical deterioration and depreciation alone (Nutt and McLennan 2000).

To date, business and public initiatives of all kinds will be reliant on the support and improvement of existing buildings and infrastructure through the better management and the physical modification and adaptation along the first part of the property trail (Nutt 2000). As such, attention has been directed to the improvement of adaptability and flexibility for re-use and mixed use of existing property and infrastructure.

Minimizing the risk and capital investment for owning the property, organisations are now looking for flexible space and off-site project space. Thus outsourcing office is a strong trend. Serviced offices with a fully furnished and functional office facilities provide a ‘hotel for business’ with flexible lease terms and flexible lease space to different kinds of organisations so that their businesses are no longer locked into the long-term leases as conventional offices. Frequent reconfiguration and renovation could be conceived particularly in those serviced office. With reconfiguring space arrangements of buildings, it is inevitable to reconfigure the building services systems together. As a consequence, those serviced offices or offices with frequent organisational change should not only afford flexible space, but also provide flexible building services systems suited to the changing office layouts. The cost for renovation and reconfiguration of fixed building service systems is burdensome and hence should not be disregarded.

It is generally realised that higher flexible arrangement of property and infrastructure requires higher investment from clients. Is this argument valid to all aspects? Is there any system providing flexibility with rational life cycle cost? In my own opinion, this argument is partly correct. This is because owners and investors place too much emphasis on the capital cost while operating cost is of little concern in consideration of the cost-effectiveness of a system.

There is no lack of flexible building services designs that are extensively being used in offices, for instance, underfloor power distribution system, demountable and movable partitions and wireless internet service. Compared with the aforesaid systems, the utilisation of flexible lighting system still lags behind by reason of its exceptionally high capital cost even though there are a number of new lighting management/control systems that provide flexible solutions for lighting available in the market.

1.2 Previous Work

The application of automatic lighting control systems has been very common for many years. Automatic lighting control systems in the past were solely intended for reducing energy use.

In the 1960s, on/off photocell control systems in which a number of chemical compounds exhibit a photo-electric characteristic have been already designed for some office buildings. However, the disturbance from occupants always lowered the performance of on/off photocell control systems and as a consequence these systems were often overridden. At the same time, dimming using resistance dimmers was not cost-effective. This is because those dimmers dissipates heat and therefore waste energy, and are load specific.

The energy crisis due to the rapid increase of oil price in the early 1970s triggered further incentive for energy conservation. In the meantime, a great deal of study on lighting control systems was emerged. Greater emphasis was placed on the utilisation of daylight. And the daylight linked dimming system was cost effective.

To enhance the monitoring and control of the built environment, building automation was the focus from the 1980s in order to develop an intelligent building. Building management systems were used for a better environment control by means of signal transmission technology.

Attention has been directed to ecological and "green" issues in the 1990s. Lighting accounts for a large proportion of total energy consumption. If unwanted lighting could be switched off automatically, both energy and greenhouse gases could be saved. Therefore energy management was addressed to achieve energy saving with the use of advanced technology, such as choosing efficient light sources and control gears, balancing daylight and artificial light by light sensors, automatically switching off lighting which is not required by occupancy sensors etc.

Looking forward to the future, lighting control systems not only focus on energy conservation but also broaden their scope to cater for the changing space utilisation on account of new business needs. With the application of electronic and digital technology available in the market, the energy saving and functional performance of lighting management/control systems can be further enhanced.

1.3 Workspace Strategies

As the lighting design is closely related to the space planning, the change of spatial layout would normally force the lighting arrangement to modify as well. As a consequence, it is crucial to figure out the contemporary workspace strategies.

In the past, buildings were built and designed for single occupancy with a long-term lease so that space was supplied to fit the needs of the 'first-hand' business and user. Today, business is changing continuously and rapidly with the impact of technology and new work practices. Work can be arranged to be coincident in space but not necessarily in time. 'Touch-down' and 'drop-in' facilities that support multi-venue working arrangements are an example here (Nutt and McLennan 2000). Additionally, satellite office working is feasible with the support of video conferencing. These new work practices are leading to reductions in the aggregate demand for space in the existing property and infrastructure.

Space planning and management, which is a subset of facility management functions, is vital to afford a comfortable, safe and productive workplace so as to enable building occupants to perform at their best. Now, attention has been directed to the better management and utilisation of the existing property and infrastructure inherited from the past, and thereby space management should place the emphasis on the use of the existing space.

Every occupied space would inextricably incur an occupancy cost for an organisation. For an effective space management, an optimum match between the needs of an organisation (demand) and the provision of appropriate workplace (supply) should be accomplished. The process of matching supply to demand comprises essentially space planning and space management issues, involving the interface between business units (i.e. the customers) and the real estate/facilities function (i.e. the service provider) (McGregor and Then 1999). A 'demand-led' approach should be adopted in place of a 'supply-led' approach in the past and as a result organisations can get rid of space deficiency and surplus to current needs.

To meet the changing occupancy levels and pattern of varying occupiers rather than contemporary occupancy levels and pattern of current occupiers, flexibility in space utilisation that can meet current and future work demands is imperative to optimise the match between demand and supply of space. Flexibility will be the hallmark of effective workspace strategies where most will encompass a combination of core and elastic workspace, in their attempts to address business volatility and fluctuating levels of demand (McGregor 2000).

1.4 Benefits of the Study

A wide range of benefits to facility managers, building owners, tenants and building users can be brought by the utilisation of advanced and innovative lighting technologies. As mentioned above, tenants want to occupy buildings that provide a flexible working environment that support the changing needs of organisations. As a result, building owners can drive their occupancy rates up by marketing this feature to prospective tenants, and hence it can lead to higher lease income as well as increased occupancy when marketed correctly. When tenants move out or expand to adjacent spaces, building owners benefit from the lower churn cost and faster completion of tenant improvements with the aid of advanced lighting control systems.

Adaptable lighting management systems give facilities managers the information necessary to effectively manage their lighting. Through the use of lighting controllers, lighting control systems keep facility managers well-informed, providing a variety of operating feedback. Up to now, more and more lighting control systems provide the means to interface to building management system. Therefore, the information for the lighting control system associated with other aspects of building control such as heating, air conditioning and security can be accessed from single control system. This centralisation of information gives facility managers the capability to simultaneously monitor multiple building systems and to respond rapidly to any system malfunctions. Further, the lighting control system itself and its accessories are capable of integrating with air conditioning systems, fire systems, window blinds and access control to reduce installation complexity. For example, it is possible to use the occupancy sensor to trigger both lighting and air conditioning system switching on or off. Additionally, lights can be switched on to maximum in case of fire and unwanted entry detected.

Building tenants also profit from advanced lighting technologies. A desirable lighting design is generally able to provide a healthy and comfortable workplace to building occupants due to enhanced monitoring and control of lighting. A higher degree of comfort can enhance the productivity of building occupants. Moreover, tenants will have lower costs due to energy cost savings and to the lower churn costs resulting from increased flexibility for expanding, replacing or reconfiguring office suites.

2. Literature Review

2.1 Overview of Lighting Engineering

2.1.1 Technical Information of Fluorescent Lamps

There are fundamentally three generations for linear tubular fluorescent lamps (Figure 2.1) so far. Wu and Lam (2003) describes the generations as follows:

a) 1st generation: T12 lamp with a diameter of 38 mm (1.5") and with a length dictated by the wattage (20 W, 30 W, 40W and 65 W). Its efficacy is about 70 lm/W. These lamps are stabilised by electromagnetic ballasts and have been widely replaced by the T8 lamps.

b) 2nd generation: T8 krypton-filled lamp with a diameter of 26 mm (1") and with a length dictated by wattage (18 W to 70 W). Its efficacy is about 80 lm/W. These lamps can be stabilised by both electromagnetic and electronic ballasts.

c) 3rd generation: T5 lamps with a diameter of 16 mm (5/8"). The standard wattage of the T5 lamps, which is mainly used in offices, is 14 W, 21 W, 28 W and 35 W while high output versions are also available for some special applications. T5 lamps have superior luminous efficiency outputs (efficacy about 100 lm/W) and can enhance economy in high frequency operation with electronic ballasts. Additionally, T5 lamps are especially designed for operation with electronic ballasts for greater efficiency.

Figure 2.1 Physical Appearance of T12, T10, T8 and T5 Fluorescent Lamps

2.1.2 Technical Information of Ballasts

Lamps with electromagnetic ballasts operating at low frequencies (about 50 Hz or less) inevitably produce flicker, which is a visible light modulation to most people and even stroboscopic effects in some cases. Different frequency and amplitude of the modulation affect the perceptibility of flicker. And flicker can result in discomfort and distraction and may even cause epileptic seizures to some people. Lamps driven by high frequency supplies overcome these drawbacks in that all significant low frequency modulation below 100 Hz is eliminated (CIBSE 1994). Therefore, the use of electronic ballast enables flicker-free operation of fluorescent lamp.

Fluorescent lamps operating at high frequency (above 20 kHz) with electronic ballasts can obtain greater efficacy. As indicated by Wu and Lam (2003), the overall lighting system efficacy can be increased by 20 to 30 percents due to three main factors:

- Improved lamp efficacy at high frequency operation.
- Reduced circuit power losses.
- Lamp operates closer to optimum performance temperature in most luminaires (i.e. 25°C for T12 and T8, 35°C for T5).

Although there is a spectrum of advantages over using the electronic ballasts, the use of electromagnetic ballasts is still predominant in many lighting installation projects. Some possible reasons for the lack of extensive adoption of the electronic ballasts are (Chung 2001):

- Electronic ballasts are more expensive than electromagnetic ballasts so that the installation of a system using electronic ballasts will result in higher initial costs.
- Designers and building owners may not be convinced that electronic ballasts are reliable.
- The energy savings and the occupant comfort that can be achieved by using electronic ballasts are difficult to quantify.

2.1.3 Lighting Control Systems

To save energy, lighting control systems can be applied to the built environment, especially for offices, in addition to the use of efficient lighting sources. Ure (1980) carried out quantitative and qualitative analyses of four lighting control systems in open plan offices in relation to the technical, functional and economic viability. These systems have automatic daylight linked controls. It was found that lighting control systems can be cost effective. Furthermore, with the provision of individual control including local manual or infrared switching, the lighting control systems can have better performances in terms of energy savings, user satisfaction, flexibility in use and payback period.

A recent research performed by Chung, Wu and Burnett (2001) demonstrated that energy savings, higher light levels and better power quality are the major benefits obtainable from an office lighting retrofit using digital dimmable electronic ballasts and sensor with integrated light level detection, presence detection and infrared remote control.

Offices are probably the most important places for the application of lighting control, and are also the places where individuals have strong opinions. Simpson (2003) reveals that some lighting control systems installed in offices with the best of intention, i.e. to provide a comfortable working environment and to save energy, have been unsuccessful to the extent that users have disconnected the automatic element, or even the entire lighting control. Examples of the problems encountered are (Simpson 2003):

- Systems which attempt to balance daylight with artificial light do not always work in the way expected because of the way the eye works.
- Some lighting source and interface combinations incorporating control do not actually save significant energy when set to a low output.
- Individual users can have different preferences, and get upset if they are not allowed for. A "uniform" approach to automatic lighting control may be unacceptable.
- Arrangements which control lighting automatically in the interests of energy saving may well have negative results in respect of security and personal safety.

Automatic lighting control systems not only contribute to energy saving but also reduce operating cost on emergency lighting. A case study using the maintenance system for emergency lighting demonstrates that the automatic testing is performed in place of the manual testing. Existing practice requires a team of maintenance staff to carry out the test manually at each lighting point, which is unreliable, inefficient and tedious, whereas an innovative maintenance system has several advantages over the existing practice, such as high reliability, cost effectiveness and user friendliness (Tse, Chan and Lai 2003). In virtue of the approximately zero operating cost (zero labour cost) and short payback period of this system, it is worthwhile to promote the automatic maintenance system for the entire lighting system including both normal and emergency lighting.

The correct choice of a lighting control system can provide an effective, responsive, user friendly lighting controls which can change the existing lighting system instantly to meet the needs of different users and variety of tasks (Littlefair and Jaunzens 2001). The market is set to change with the wider use of electronic gear, especially involving digital addressable lighting interface (DALI). According to a survey by Frost & Sullivan in 2000, the new interface will effectively merge all the superior aspects of the lighting management systems and control gear markets, allowing complete lighting control and improved light output (Booty 2001).

2.1.4 Recommended Design Guidance

To provide sufficient and suitable lighting for the performance of a range of tasks without waste of energy, CIBSE (1994) recommends the design criteria for office lighting summarised in Table 2.1:

Table 2.1 Design Criteria for Office Lighting

	Standard Maintained Illuminance (lux)	Limiting Glare Index
General offices	500	19
Computer work stations	300 – 500	19
Conference rooms	500	19
Print rooms	300	19
Public area	300	19

2.2 Lighting Energy Management

As defined by Liebel and Brodrick (2005), an energy-efficient lighting design is one that optimises luminaire photometric distribution and system efficacy to generate the most visually effective light with the least amount of light input.

For facility managers, there are three basic steps to lighting energy management as listed below (Turner 2001):

1. *Identify necessary light quantity and quality to perform visual task* – proper lighting quantity and quality is essential to any illuminated space. However, the concept that the brighter the better has existed for a long time. Facility managers always ignore this basic step even if the workplaces are too bright and as such create many sources of glare. Consequently, offices are often kept over-illumination and thereby waste energy.
2. *Increase light source efficiency if occupancy is frequent* – light source upgrades encompass not only lamps but also ballasts and luminaire design. Replacing obsolete

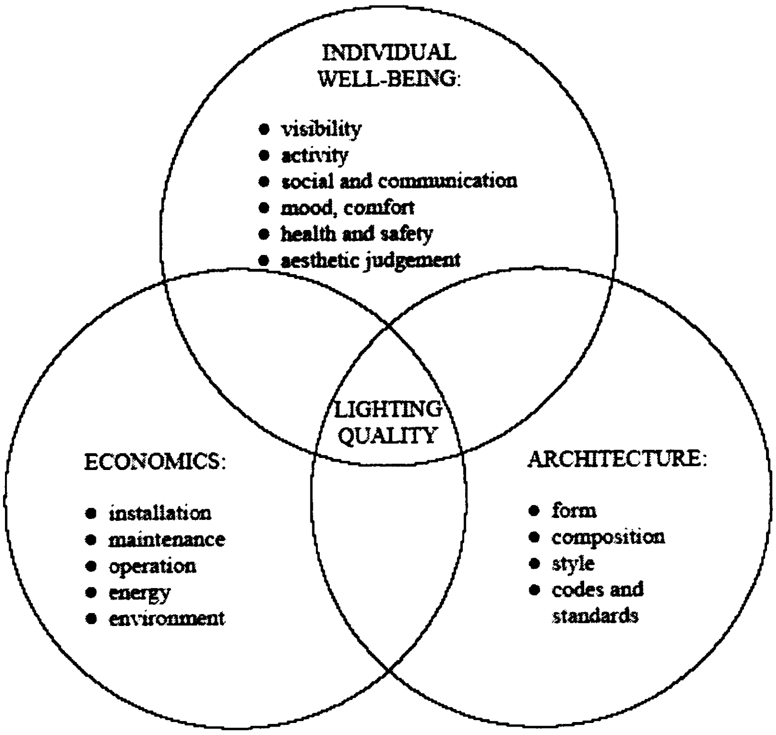
installations with more efficient light sources and introducing high frequency control gear can be taken to minimise energy consumption and electricity bill (Booty 2001). These measures undoubtedly increase the efficacy (lumen per watt) of light sources. In addition, luminaire efficiency can also be improved with the installation of reflectors and/or louvers.

3. *Optimise lighting controls if occupancy is infrequent* – in addition to local manual switching, lighting controls can be optimised by integrating with daylight sensors, occupancy sensors, infrared remote control units and timers that can regulate the on/off and dimming of a lighting system. The intention is to achieve energy saving by reducing operating hours of lighting.

Steps 2 and 3 are options that can be implemented individually or together, but often the two options are economically mutually exclusive. If a lighting system can be turned off for the majority of time, the extra expense to upgrade lighting sources is rarely justified. Remember, light source upgrades will only save energy (relative to the existing system) when the lights are on (Turner 2001).

2.3 Individual Well-being and Lighting Quality

Figure 2.2 Lighting Quality: The Integration of Individual Well-being, Architecture and Economics



Veitch (2000) summarises the lighting quality as the integration of architecture, individual well-being and economics as shown in Figure 2.2. Being a subset of lighting quality, it is worthwhile to explore how to reinforce the individual well-being so as to accomplish a quality lighting design.

Appropriate and sufficient lighting is an essential component of a working environment. This is because too much light causes glare and eyestrain while too little light creates vision problems as well as a depressing environment (Vischer 2005). In addition, higher light levels can facilitate social and communication. Sanders et al. (1974) observed louder communication in naturally-occurring groups in a university corridor near areas where the lamps are on than in delamped areas, and concluded that higher arousal associated with the brighter areas caused the effect.

Glare resulting from reflected images of luminaire in visual display units (VDU) screens and veiling reflections due to high background light levels would reduce task contrast. Veitch (2000) indicates that lighting conditions that reduce task contrast will adversely affect visibility in the workplace. To prevent such problems, parabolic louvers can be employed to reduce glare and improve the performance of luminaires as well.

Lighting quality can be classified into three levels of environment comfort. These human comforts at work should work and merge together as a continuum to achieve occupant satisfaction and well-being. These three levels of comfort are (Vischer 2005):

1. *Physical comfort* – this is the basic needs. Light levels are provided in accordance with indoor illumination standards and guidelines, but where these are incompletely applied, or where building uses change over time, there may be higher rates of fatigue and headaches, and people with formerly good eyesight may have to wear corrective lenses.
2. *Functional comfort* – this is the task-related needs. Conventioal wisdom has held that the more invariable (constant) and intense the light, the better it is for workers (Vischer 1989). However, owing to the variety of tasks performed in modern offices and the range of colours, textures and equipment, the uniformity of much office lighting results in inappropriate conditions for many workers. Appropriate and sufficient light levels should be provided based upon the type of activities or tasks rather than provide uniform light levels for all occupants.
3. *Psychological comfort* – this is the emotional needs. People are affected by size of, view from and proximity to windows. Worker morale tends to be poor in windowless environments, in spite of the fact that natural light is not required for the performance of most office tasks.

With the prevalence of building automation, many modern buildings place control in centralised automatic systems which deny individual control for occupants in the indoor environment. Very often, these 'pure' automatic systems do not work well and result in discomfort for occupants. Leaman and Bordass (2005) state that people are more forgiving of discomfort if they have some effective means of control over alleviating it.

In the interest of health and safety, improvement on lighting can eliminate headaches, eyestrain, fatigue and sick building syndrome, as well as accidents. For instance, headaches may sometimes be caused by lamp flicker due to the use of magnetic ballasts operating at the frequency of the electrical supply (50 Hz). Kuller and Laike (1998) indicate that flicker can also cause stress in people in some cases. Electronic ballasts operating at high frequencies of around 25 kHz do not exhibit flicker, resulting in reduced incidence of headache (Wilkins et al. 1989).

To heighten the aesthetic judgement of lighting, a versatile lighting control system should be used. As a variety of light sources is often employed in the modern workplaces, individual lamp is needed to be set to different levels to achieve a required lighting balance. Besides, some area in modern workplaces, such as conference room, may need different scenes at different times of day to serve various tasks and activities. A nimble manner to change the lighting from one scene to another is therefore necessary. Simpson (2003) summarised the essence of the aesthetic role of lighting control as follows:

- It allows the balancing of different light sources to ensure that the overall result is pleasing.
- It is the mechanism for transition between one lighting state and another.

2.4 Importance of Flexible Working Environments

As mentioned in Section 1, a strong trend is towards outsourcing office. Nutt and McLennan (2000) indicated that procurement priorities seem to be changing in many corporate organisations recently, with greater emphasis on the procurement of buildings for leasing rather than for owner occupation. Market and professional attention has switched to partnership procurement strategies. Client demands for a wider range and greater variety of types of building space, to support changing functions, mixed use requirements at distributed locations are arising increasingly. Consequently, greater emphasis is given to the needs of business for highly flexible arrangements for building occupancy, use, operation and management, with increasing preference for renting under shorter and flexible leases, backed up by the occasional use of serviced offices, temporary accommodation and other informal arrangements, to meet the exceptional and unpredictable periods of demand. Organisational clients now need to weigh up business advantage of flexible tenure with less or no investment and disposal risks, against the disadvantage of higher operating and serving costs that flexible property arrangements entail.

Traditionally, the use of space and office layout has not adapted to support changing needs of new work processes. The complex, highly articulated buildings have been designed to suit the particular needs of specific organisations (Laing 1993). To date, organisations are more rapidly growing, shrinking and re-organising than before. The office needed to be rethought as a system of multiple activity settings, a series of places suited to the range of tasks undertaken during the day, rather than simply where you had your desk. A flexible design is thus required for space and office layout.

As Rayfield (1994) states that in modified open-plan areas combining elements of both open plan and closed plan, floor-to-ceiling partitions must be demolished and reconstructed. To provide planning flexibility for organisations, all of the related support systems, lighting, engineering, and acoustics as well as floor finishes must be modified to meet the requirements of the new configuration. The demolition and construction of new space is costly, time consuming, and causes disruption to employees during the entire construction period.

In the past workplaces were changing gradually with solely occasional episodes of turbulent change. Buildings were designed to meet the requirements of the first generation of occupants within the traditional approach. However this pattern of change has changed today. On the basis of the changing demand of organisations, the modern workplaces are changing continuously and rapidly with occasional episodes of turbulent change. It is therefore imperative to examine the importance of flexible working environments.

2.5 The Management of Churn

Churn rate is one of the considerations that support the adoption of flexible workplaces with flexible building services systems. McGregor and Then (1999) cites the benchmarking data produced by The Workplace Best Practice Group, indicates that churn rates in the UK range from 20% to 90% per annum, with the majority of businesses falling between 30% to 50% - with a sizable attendant expenditure when the cost per workplace move can be of the order of £2000 per person moved. As a result, incorporating or providing flexibility in workplace design is a common strategy used to accommodate churn. There are various dimensions to the concept of flexibility when applied to the design of workplace layouts and configurations: versatility, rearrangeablility and convertibility (Thatcher and Thatcher 1996).

McGregor and Then (1999) also argues that measures to control and accommodate churn must be planned and, whenever opportunities allow, integrated with the organization's accommodation strategy. In general, initiatives aimed at reducing the cost of churn fall into two options: reduce the rate or frequency of churn, as well as reduce the cost per move. However, churn is a result of an organisation's need to respond to the changes in its market and may be a product of its work processes and culture. In this respect, it may be counterproductive or impractical to reduce the cost of churn by reducing churn itself. As such, facility managers should move their focus towards reducing the cost per move. And it is extremely important to monitor or estimate the churn cost and indicate to business managers the impact of the churn on facilities operating costs, and hence the cost of being in business.

3. Method of Approach

3.1 Aim

To explore and compare innovative lighting systems that can help facility mangers to improve the quality, design and management of lighting in the changing workplaces in a cost-effective way.

3.2 Objectives

1. To review the need of flexible workplace and hence flexible lighting installation.
2. To investigate how to strengthen the energy management in order to optimise the energy saving.
3. To examine the feasibility that the operations and maintenance works is automatically done by the innovative lighting systems.
4. To estimate the churn cost that can be reduced by using a flexible lighting system.
5. To verify that a flexible lighting system can be secured with reasonable payback period.

3.3 Key Questions

1. What is the importance of flexible lighting system?
2. How can the innovative lighting systems benefit facility managers, building owners and occupants?
3. What is the energy saving for the application of more efficient light sources?
4. How do these innovative lighting systems work and result in economic saving?
5. Which innovative lighting system is best to be applied in the contemporary workplaces?
6. How could the innovative lighting systems contribute to the better management of lighting?
7. What management considerations on the lighting systems should inform the design process?

3.4 Cause of the Study

The author of this study was engaged in a lighting design project of a commercial building in Hong Kong a few years ago. The client of this project initially intended to adopt an innovative lighting system, DALI lighting management system. However, the capital investment of this

system was unexpectedly high. As the system was very new at that time, the actual system performance was not practically and widely authenticated. The client therefore cannot anticipate what concrete benefits they would obtain. Consequently the client turned down the adoption of this system to avert the project over the budget.
Following that C-Bus lighting management system which required a lower capital investment was proposed to replace DALI lighting management system. Although C-Bus system was relatively widely adopted in the market, it would still demand a significant amount of capital investment as opposed to the conventional lighting system which does not have any lighting management function. Finally, the conventional system was determined to be used in the project.

In this incident, the author found that the client placed too much emphasis on cost-cutting of capital investment while they lacked for a foresight on the whole life cycle cost of the building. Furthermore, the author believes that the saving on operational cost by using an innovative lighting system outweighs the saving on capital investment by using the conventional lighting system and thereby initiates this study to justify his view.

3.5 Methodology of the Study

The basis of this dissertation is to discuss the impact of the contemporary workplace strategies on lighting arrangements. As mentioned in Section 2.3, the lighting quality is composed of architecture, individual well-being and economics. Therefore the dissertation will intensively investigate the measures for improving the lighting quality in practice with regard to installation, operation and maintenance, energy efficiency, and environmental impact by new lighting regimes that can be developed for office environments in an economic way.

Except the economics needs of building owners and investors, emphasis should also placed on the needs of occupants. New lighting regimes meet not only immediate needs of occupants but also their long-term needs. Thus it is imperative to scrutinise and compare the functional performance of innovative lighting systems that can strength the control and monitoring of the lighting and support the dynamic built environment in the wake of the changing business needs. Additionally, the study will also discuss how advanced lighting technologies can improve individually well-being.

As defined by Rondeau, Brown and Lapides (1995), workstations which are equivalent to workspace are any space for which a function is accomplished. This may be an enclosed space or a space in an open area (e.g., a conference room, an executive office, a coffee station, a reception area and a data input station). A workstation does not necessarily require that a person or persons be assigned to that particular space. As a consequence a workplace covers all area or space which supports a work, process or project within an organisation. The terminology of workplace can be applied to not only office desk but also factory production line, hospital operating room, institutional discussion room and so on. The nature of workplace changes has been discussed in Section 1.3. To ensure this dissertation is feasible and achievable, it would be confined to investigate the lighting arrangements solely for office working environments. To support the changing workplaces and enhance the flexibility of space utilisation, facility managers have to select the most appropriate lighting regimes in the market to suit both current and future needs of their clients and minimise the operating cost as well.

Most of the facility managers are not lighting specialists. It is essential to first describe the components of conventional and advanced lighting arrangements prior to the subsequent development of this research. Three types of lighting regimes are classified in terms of lamps, ballasts and lighting control systems used. Generally, the term "lighting control system" is considered as a lighting system primarily consisting of switches, occupancy sensor and daylight sensor. However, to a broader extent, a lighting control system can also afford time scheduling, zoning control, serviceability status monitoring and so on.

In this study, the consideration of occupancy and daylight sensors in these lighting regimes is excluded. This is because the energy saving through occupancy and daylight sensors is closely related to occupancy levels, fenestration details and locational factors of buildings, which varies from organisation to organisation. More importantly, as stated in Section 2.2, although light source upgrades and the installation of occupancy and daylight sensors can be implemented simultaneously, light source upgrades of the existing system will only save energy when the lamps are switched on. As such, light source upgrades is solely to be considered in terms of cost implication while the influence of occupancy and daylight sensors on energy saving is excluded.

The dissertation adopts two approaches for data collection. A quantitative approach is used for collecting the objective data whereas a qualitative approach is adopted for exploring the subjective opinions. The results can then be compared, analysed and expressed in terms of physical, functional and financial performances of various lighting regimes.

For the quantitative approach, the physical performance of T5 fluorescent lamp associated with electronic ballast and T8 fluorescent lamp associated with electromagnetic ballast is measured through energy meter. Consequently, the energy consumption of these two typical combinations of fluorescent lamp and ballast can be compared and contrasted. The energy saving can then be quantified while sustaining the sufficient illuminance level as recommended by CIBSE. As described above, economics is one of the factors that influence the lighting quality. Using a 15-storey office building in Hong Kong as a basis, the capital costs of two innovative lighting systems are provided from relevant suppliers so that comparison can be accomplished in place. In addition, the operating costs, which comprises operations and maintenance costs, churn costs and energy costs, of the conventional and two innovative lighting systems would be considered.

For the qualitative approach, interviews with suppliers who have expertise on the lighting management systems would be done. The suppliers would be asked to describe the functional performances of their lighting management system. The information obtained in this part would help the readers to figure out how the lighting management systems to save the operational costs as opposed with the conventional lighting system.

4. Results

4.1 Physical Performance

Energy conservation in offices is initially stepped up by the enormous increase of oil price in the 70s. Up to now, the oil price is still growing continuously due to its shortage. As heating apparently consumes more energy than other facilities such as lighting, air conditioning and catering etc., greater emphasis is placed on improving energy efficiency of heating. Nutt et al. (1997) illustrates the breakdown of energy use for heating and lighting in the average office building. Although 75% of delivered energy is used for heating, both lighting and heating consume roughly the same primary energy. More importantly, the fuel cost spent on electricity for lighting is higher than those spent on gas, oil or coal, normally used for heating. As a consequence, energy saving measures for lighting is as important as that for heating.

It is prevalent to use T8 fluorescent lamps and electromagnetic ballasts in commercial buildings for a long period of time. With the introduction of new technology in the market, energy efficient T5 fluorescent lamps and electronic ballasts are recommended to be adopted instead. As it is impossible to figure out the energy saving through changing all lamps and ballasts in the whole building, a small-scale demonstration is implemented to justify the data given by the manufacturer.

A small room with four lighting fittings is chosen to carry out this small-scale demonstration. The technical details of the existing and the recommended lighting fittings are shown in Table 4.1. Both fixtures have similar size which is about 1200 mm x 600 mm (4 feet x 2 feet). However, the internal components of them are different. Two T5 fluorescent lamps and electronic ballasts are in place of the existing three T8 fluorescent lamps and electromagnetic ballasts.

In addition, reflectors with semi-specular double parabolic louvers are installed in the new lighting fittings for optical control. These reflectors are mainly designed to redirect the light to a particular area and minimise the glare effect on computer screens. Ideally, by placing a line source at the focal point of the parabolic reflector, a parallel beam of light is produced on account of its optical property. However, T8 fluorescent lamp which has a relatively large diameter (26 mm) is not an ideal line source and is difficult to provide a parallel beam of light by means of reflector. The existing lighting fittings therefore are installed without any reflector. On the contrary, the smaller diameter of T5 fluorescent lamp (16 mm) is closer to a line source. With T5 fluorescent lamps and reflectors, optical control of lighting fittings is consequently more efficient and precise.

Although only two fluorescent lamps with lower power rating are used in the new lighting fitting, they still provide sufficient illumination at the working plane that meets the requirement from CIBSE. This is because T5 lamps have a superior efficacy which is about 100 lm/W whereas the efficacy of T8 lamps is about 80 lm/W. Moreover integrating with electronic ballasts the efficacy of T5 lamps is enhanced and the circuit power losses are reduced due to high operating frequency. With the adoption of reflectors, greater efficiency is obtained from the new lighting fittings.

Table 4.1 Comparison of T8 Fluorescent Lamp with Electromagnetic Ballast and T5 Fluorescent Lamp with Electronic Ballast

	Existing	Recommendation
Fixture Type	4 feet	4 feet
Lamp type	T8 Fluorescent Lamp	T5 Fluorescent Lamp
Lamp Qty. per Fixture	3	2
Predicted Lamp Power (Watt)	36.00	28.00
Ballast Type	Electromagnetic	Electronic
Ballast Qty. per Fixture	3	2
Predicted Ballast Power (Watt)	9.00	3.00
Reflector Type	N/A	Semi-specular double parabolic louver
Reflector Qty. per Fixture	N/A	2
Predicted Power per Fixture (W)	135.00	62.00
Predicted Power for 4 Fixtures (W)	540.00	248.00
Predicted Energy Saving	54.07%	
Actual Power for 4 Fixtures (W)	530.00	250.00
Actual Energy Saving	52.83%	

With the aid of power meter, the actual power ratings of the existing and the recommended lighting fittings were measured as illustrated in Figure 4.1. It was found that the predicted energy saving is very close to the actual energy saving. As a consequence, the technical data from the manufacturer is reliable and can be applied to the estimation of energy saving for a selected building in Section 4.3.6.

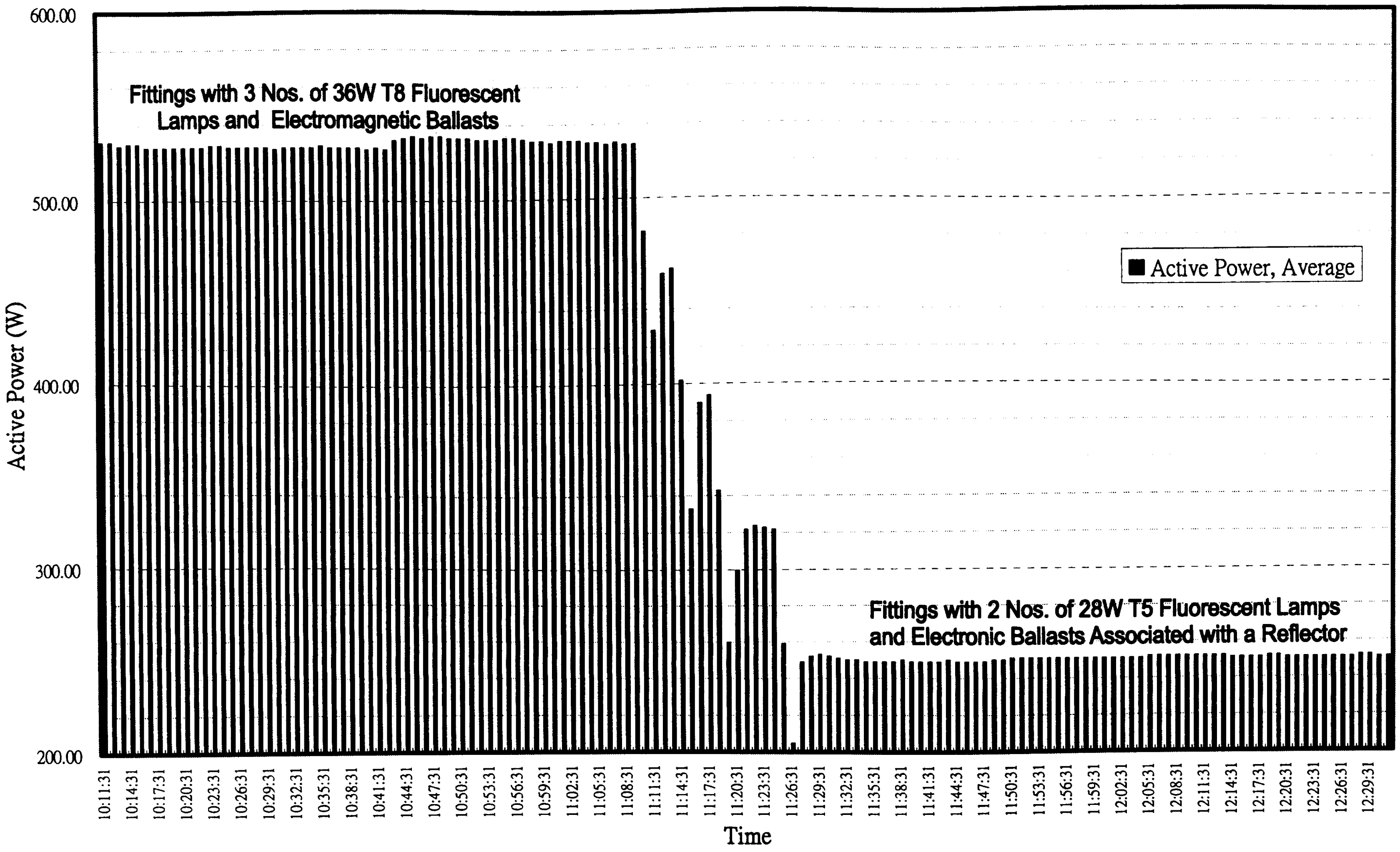


Figure 4.1 Lighting Retrofit in an Office Area with 4 Nos. of Lighting Fitting

4.2 Functional Performance

4.2.1 Interview – Supplier of C-Bus Lighting Management System

The major benefit of C-Bus lighting management system (Figure 4.2) is that it not only affords individual control for occupants as the conventional lighting system but also provides a central control for facility management operation.

Conventional toggle switches enable merely an on/off function for lighting, while specialised programmable key input units of the C-Bus system are capable to achieve various functions including: toggle switch, dimmer controller, timer or any other customised option permitted in the installation software. All of these functions can be simply programmed and controlled compactly by a single push button on the key input unit. Although the number of switches needed is thereby lessened, it is imperative to provide pertinent training for occupants to manipulate this kind of extraordinary switches. To make the individual simpler, lighting scenes or moods can be set with the press of a push button on a key input unit so that different levels of lighting such as presentation, party and master off mood can be obtained.

Other than individual control, lights can be controlled by facility management staff through computer terminal located at a central location such as building management office. FM staff can therefore control the on/off of lighting centrally. Central control can also minimise the inconvenience resulting from using individual control only. For instance, a large conference room can be divided into smaller conference rooms by moveable partitions. To control the lighting level and configuration, each smaller room has an individual lighting switch and/or dimmer. When the partitions are drawn, the conference room can be restored as one piece. However, the lighting control of this large conference room is still controlled separately by those individual lighting switches and/or dimmers. For the C-Bus system, all lighting of the conference room can be switched and dimmed simultaneously through central control or an addition push button on individual switch for master on/off control without any extra and complex wiring.

Central computer can also perform time scheduling for the lighting system to achieve energy saving. FM staff can pre-set the time setting for each defined zone based upon the office hours. As it is difficult to predict actual working period of occupants, lighting switches for individual control can override the commands given from the central computer. So occupants can still switch on the lighting they require after the office hour.

With the installation of C-Bus lighting management system, FM staff can monitor the operational status and performance of the lighting circuits. Consequently FM staff can response rapidly if there is any failure on lighting. The C-Bus software affords a user-friendly platform on which graphic images are provided for real time lighting control and monitoring. It can produce periodic and event driven report, and historical data up to one year. Furthermore, C-Bus system can connect with building management system so that FM staff can monitor all facilities including lighting on a building-wide control system.

A reconfiguration of lighting arrangement is needed in the wake of a change of spatial layout in order to cater for the new business needs of occupants. In this case both internal and external wirings of the control module have to be partially or even fully renovated. The rewiring of the low voltage control cable between the lighting control module and switches is simpler as compared with the conventional system in which the switch has to connect with the lighting fittings directly through a power cable. However, the re-assembly of the internal wiring can incur a significant premium. As a result, C-Bus system has a low flexibility to facilitate the changing space utilisation.

4.2.2 Interview – Supplier of DALI Lighting Management System

DALI which stands for Digital Addressable Lighting Interface is a communication protocol. In the market, there are mainly two types of DALI lighting management system (Figure 4.3): stand-alone system and full networked system. Stand-alone system is desirable to be applied in smaller facilities or individual space settings as it does not provide centralised control. For this study, the full networked DALI system is more suitable for the selected building.

Same as C-Bus system, DALI system also enables both individual control for end-user and centralised control for facility management staff. Addressable and programmable key input units are used for manual on/off control and dimming. Time scheduling and scene setting can also be done for particular areas or zones. Besides, DALI system enables individual control by local personal computers in the open plan office. This is because individual DALI ballast and lamp, rather than the entire lighting circuit, can be simply addressed, communicated and controlled over a single 2-wire data bus.

In the DALI system, facility management staff can also communicate with and control each and every individual ballast independently. Meanwhile, detailed information such as lamp failures, operational status and energy use can be obtained from the feedback of ballasts. Thus, the DALI system can enhance the control on maintenance and operating costs of the lighting system. For example, facility managers can attain exact information on lamp life to develop an efficient preventive maintenance schedule for lamp replacement. In addition, the system can measure energy consumption and cost per zone or tenant.

Analogue technology in lighting control is to send a signal to switch or a voltage to regulate lighting level. An analogue output (0-10V) can only command ballasts to change the lighting level based upon the control voltage. Therefore ballasts from different manufacturers may have different responses. For DALI system, it is based upon digital, 2-way communications. Digital signal simply gives the lighting level (1 to 255) required. Facility manager can give a precise command to individual ballast to obtain a specific lighting level. As ballasts from different manufacturers receive the same signal to change the lighting level at a specified rate, the lighting output for each level are consistent from one manufacturer to the next.

In the presence of light sensor, the lamp can maintain the design illuminance over the entire life of the lamp. New lamps normally possess higher output and then they will deteriorate gradually with time to their designed output. In case the lamp output is higher than the designed output, the lamp is dimmed to the required lighting level.

As the lighting management is down to the individual ballast level, the concern of DALI system is the communication to ballasts rather than the wiring of ballasts. Planning and Designing for wiring lighting fittings are no longer needed. Greater emphasis is now placed on grouping or zoning the number of lighting fittings per circuit after the wiring is installed. And changing the grouping or zoning to suit a new spatial layout is simple and can be done by reprogramming in place of rewiring. Hence, flexibility is given to facility manager to arrange the lighting layout to meet the changing workplace needs at a future time without expensive hard-wiring reconfiguration.

DALI system can perform the testing and monitoring of emergency lighting to meet statutory requirement. The centralised computer terminal can automatically check the lamp, battery and inverter while emergency lighting continues to work as normal. As a consequence, the disturbance to occupants can be minimised. More importantly, the manual testing of emergency lighting by electricians is no longer needed and the labour cost for this testing can be minimised.

Although DALI is very application-specific, having been designed and standardised to work with lighting ballasts. Building management system normally has unlimited expansion possibilities, which DALI does not have. It can allow application-specific systems to operate and communicate together. Consequently DALI system and building management system can complement each other through an interface.

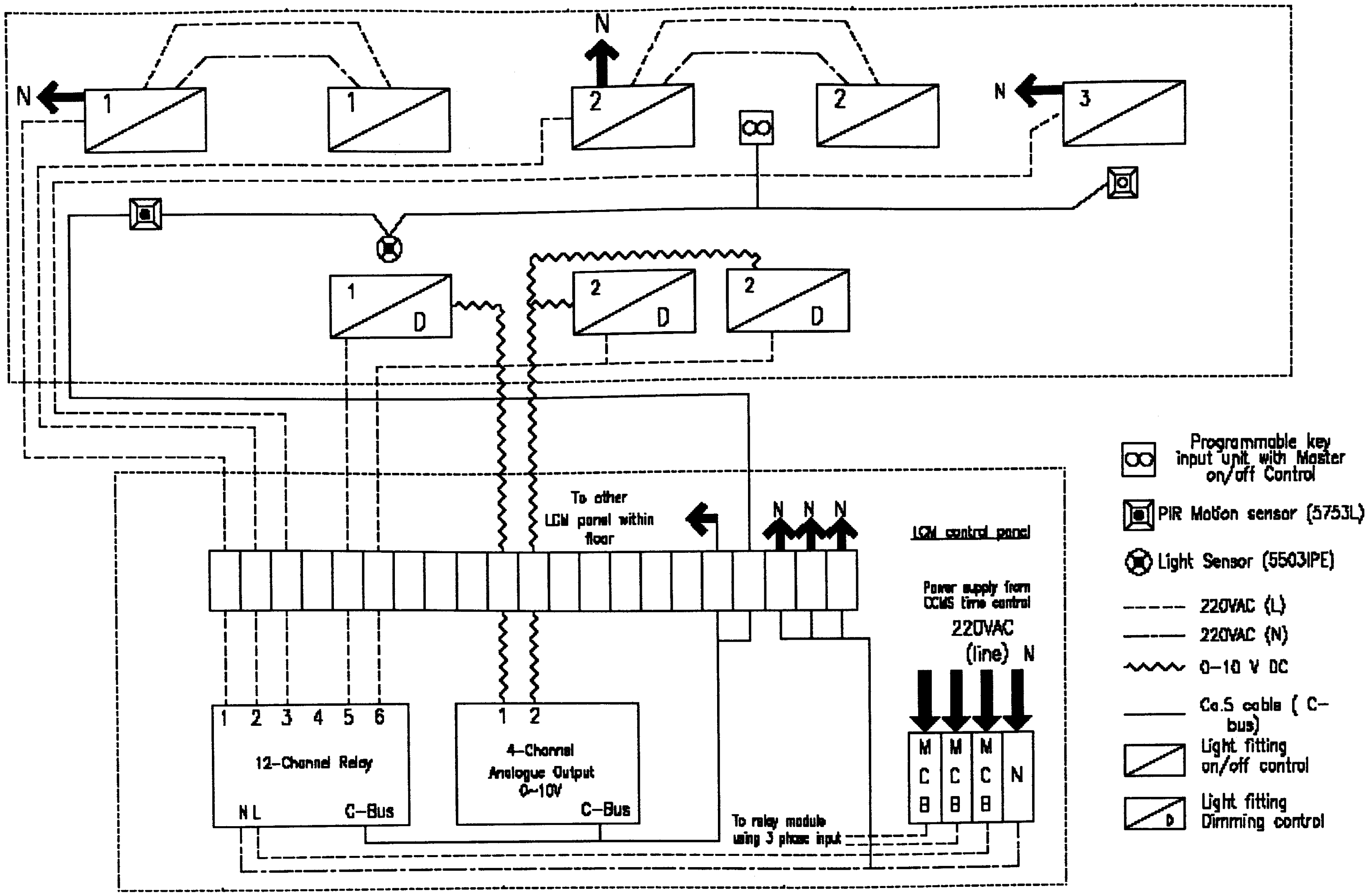


Figure 4.2 C-Bus Lighting Management System Diagram

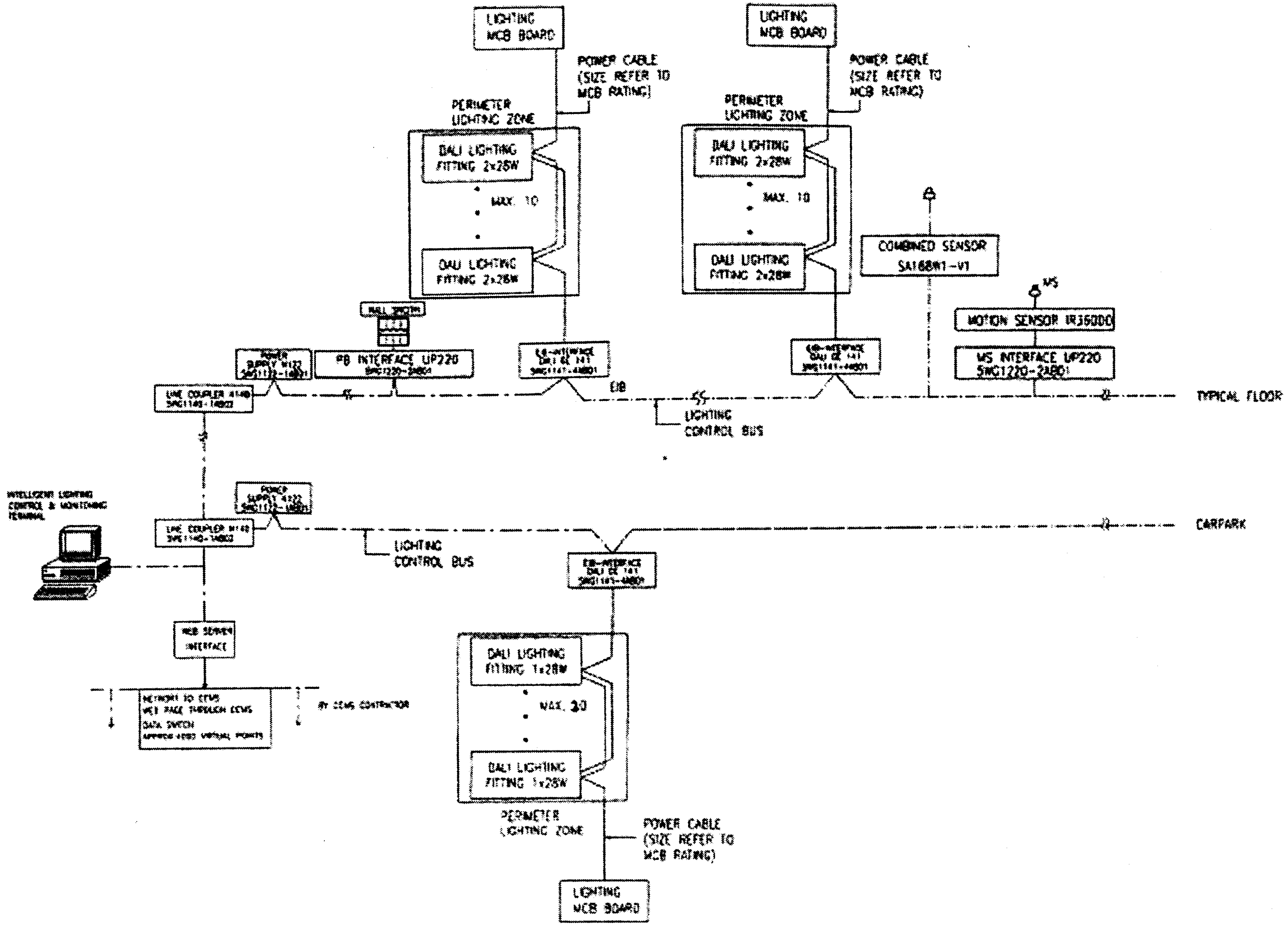


Figure 4.3 DALI Lighting Management System Diagram

4.3 Financial Performance

Not surprisingly, clients, owners or investors are unwilling to adopt an innovative lighting arrangement for offices. This is because the capital investment on any innovative lighting arrangement must be higher than the conventional one, which is using prevailing T8 fluorescent lamps and electromagnetic ballasts without any lighting control and management measures. However, other than capital investment, facility managers should also be concerned with the operating cost including operations and maintenance cost, energy cost and churn cost. They have to recommend a lighting regime which can achieve value for money within the building's life cycle to their clients.

As stated in Section 4.2, innovative lighting management system can reduce the operating cost. Although the adoption of new lighting management system inevitably incurs an additional capital investment, a tremendous saving of operating cost may be accomplished. As a consequence, the financial performance of lighting management systems would be examined in this section. The capital costs on these systems are to be explored in terms of system cost, luminaire cost and installation cost while the operating costs of different lighting arrangements are to be found from operations and maintenance costs, churn costs and energy costs. Finally, the payback periods of the lighting management systems can be estimated as compared with the existing conventional lighting system.

4.3.1 System Cost

For the two chosen lighting management systems, they are mainly composed of control modules, local lighting switches, network accessories and a software program. As illustrated in Table 4.2, high complexity and versatility of the DALI lighting management system of course result in higher expenditure on hardware equipments, especially control modules, local lighting switches and network accessories. Additionally software programming and test and commissioning of the DALI lighting management system are higher than that if the C-Bus lighting management system.

The control module of the C-Bus system comprises a 4-, 8- or 12-channel voltage free relay and a 4 channel analogue output device for dimming. All of these devices are settled in a waterproof panel in which internal wires are connected between voltage free relays and analogue output devices. Consequently additional cost has to be spent on purchasing the panels. On the other hand, the DALI system adopts all-in-one control module which offers both control and dimming functions on lighting. No panel is therefore required for internal wiring assembly.

From Table 4.2, it is found that the expenditures on local lighting switches for both lighting management system are tremendous. This is because both systems need specialised lighting switches to connect to the network and thereby communicate with the central computer. These kinds of switches are unlike the conventional flush switch. Buttons on these switches include 'learn enabled' features and can be programmed as dimmers, timers in addition to on/off toggle switches. As 36V d.c. control cable is connected to these switch in place of 220V a.c. power cable, switches for controlling normal lightings and switches for controlling emergency lightings can be put into a single switch plate. Although the unit price of local lighting switches for the lighting management systems is higher than that for the conventional system, the quantity of lighting switches required is actually lessened.

The DALI lighting management system does not have internal wiring. As a result, the total system cost of the DALI system is just a little bit higher than the C-Bus system.

Table 4.2 System Cost of Lighting Management Systems

System	C-Bus Lighting Management System	DALI Lighting Management System
Control Modules (HK$)	500,670	569,660
Local Lighting Switches (HK$)	33,295	52,530
Network Accessories (HK$)	122,060	192,630
Software Programming, Test & Commissioning (HK$)	171,675	290,910
Panel for Internal Wiring Assembly (HK$)	114,450	N/A
Total System Cost (HK$)	***942,150***	***1,105,730***

4.3.2 Luminaire Cost

Luminaires used in the C-Bus and the DALI lighting management systems are very similar. The fixture types are 1200 x 600 mm and 600 x 600 mm recessed fluorescent fittings which consist of T5 fluorescent lamps, electronic ballasts and reflectors. The luminaires have similar components except ballasts. As shown in Table 4.3, dimmable electronic ballasts are used for the C-Bus lighting system. However, specialised DALI electronic ballasts are adopted for the DALI lighting system. This is because individual ballast is required to connect the DALI network and communicate with the central computer so as to re-programme the lighting arrangement by means of software programming. As the cost of these specialised DALI electronic ballasts is nearly the double of general dimmable electronic ballast, the cost of luminaires for the DALI system is much higher than that for the C-Bus system.

Table 4.3 Luminaire Details and Cost

System	C-Bus Lighting Management System	DALI Lighting Management System
Fixture Type	1200 x 600 mm Recessed Fluorescent Fitting	1200 x 600 mm Recessed Fluorescent Fitting
Lamp Type	T5	T5
Lamp Quantity per Fixture	2	2
Lamp Power (W)	28	28
Ballast Type	Dimmable Electronic	DALI Electronic
Ballast Quantity per Fixture	2	2
Ballast Power (W)	3	3
Reflector Type	Semi-specular double parabolic louver	Semi-specular double parabolic louver
Quantity of Fixtures	2217	2217
Luminaire Cost per Fixture (HK$)	417.4	730
Luminaire Cost (HK$)	925,376	1,618,410
Fixture Type	600 x 600 mm Recessed Fluorescent Fitting	600 x 600 mm Recessed Fluorescent Fitting
Lamp Type	T5	T5
Lamp Quantity per Fixture	2	2
Lamp Power (W)	14	14
Ballast Type	Dimmable Electronic	DALI Electronic
Ballast Quantity per Fixture	2	2
Ballast Power (W)	3	3
Reflector Type	Semi-specular double parabolic louver	Semi-specular double parabolic louver
Quantity of Fixtures	169	169
Luminaire Cost per Fixture (HK$)	353	723.8
Luminaire Cost (HK$)	59,657	122,322
Total Luminaire Cost (HK$)	***985,033***	***1,740,732***

4.3.3 Installation Cost

According to the information provided by a contracting company, the installation cost of lighting management system is determined by the number of lighting point or luminaires regardless of the wiring complexity of lighting point. The average installation cost of each lighting point is HK$ 130. Thus the total installation cost of the C-Bus or DALI system is HK$ 310,180 as illustrated in Table 4.4.

Table 4.4 Installation Cost of Luminaires

System	C-Bus Lighting Management System	DALI Lighting Management System
Number of Lighting Point	2,386	2,386
Installation Cost per Lighting Point (HK$)	130	130
Total Installation Cost (HK$)	***310,180***	***310,180***

4.3.4 Operations and Maintenance Cost

The demand of maintenance or testing on lighting is infrequent except emergency lighting. Thus operations and maintenance cost comprises solely the cost for the maintenance test on emergency lighting in this section. In other words, this outlay covers the labour cost for electricians to carry out the maintenance test.

To check the back up battery of emergency lighting is healthy or not, a monthly test is needed pursuant to BS 5266-1. The DALI lighting management system can perform the maintenance test automatically so that the operations and maintenance cost can be regarded as zero. However, for the conventional lighting system and the C-Bus lighting management system, the maintenance test has to be carried out at each emergency lighting point manually.

From Table 4.5, it estimates the operations and maintenance cost of emergency lighting. There is 943 emergency lighting points in the building. Provided that each lighting point calls for 30 minutes to carry out the maintenance test and associated document work, 471.5 man-hours and 3 electricians are needed for the completion of the whole test. Consequently the annual operations and maintenance cost for the emergency lighting in this building is estimated to be HK$ 432,000.

Table 4.5 Operations and Maintenance Costs of Emergency Lighting

System	Conventional Lighting System	C-Bus Lighting Management System	DALI Lighting Management System
Number of Emergency Lighting Point	943	943	943
Average Duration to Test on Each Lighting Point (min)	30	30	0
Time Required to the Whole Test (man-hour)	471.5	471.5	0
Working Hour of Electrician per Month (hour)	176	176	0
No. of Electrician Required	3	3	0
Monthly Salary per Electrician (HK$)	12,000	12,000	0
Annual Operations & Maintenance Cost (HK$)	***432,000***	***432,000***	***0***

Note:

1. Assuming that an electrician works 8 hours a day and 22 days a month.

4.3.5 Churn Cost

In the past, the operational needs of the corporate client and end-user changed gradually with occasional turbulent change. Therefore churn cost is seldom incurred and is negligible. Today continuous and rapid change is surrounding the business. Expansion, contraction and reconfiguration of an organisation and its facilities are very common and thereby result in significant churn cost.

Benchmarking data produced by The Workplace Best Practice Group, indicates that churn rates in the UK range from 20% to 90% per annum, with the majority of businesses falling between 30% and 50% (McGregor and Then 2000). As a result, the churn rate is taken to be 40% in the study.

Table 4.6 illustrates the estimation of annual churn cost with using the conventional lighting system and the C-Bus lighting management system. The re-installation cost per lighting point is equivalent to the installation cost per lighting point. So, both systems have the same annual re-installation cost. As the C-Bus system also requires re-assembly of internal wiring inside the panel, this leads to a higher churn cost as compared with the conventional system.

The DALI lighting management system merely brings on a trivial churn cost, provided that there is no expansion or contraction. This is because the lighting arrangement including luminaires and switches can be reconfigured entirely by software programming. Even if rewiring work of a signal cable between switch and lighting controller is required, it is simple and minor. Hence the DALI system affords a trifling churn cost.

Table 4.6 Churn Costs of Lighting Management Systems

System	Conventional Lighting System	C-Bus Lighting Management System	DALI Lighting Management System
Churn Rate (%)	40	40	40
Number of Lighting Point	2,386	2,386	2,386
Re-Installation Cost per Lighting Point (HK$)	130	130	0
Re-Installation Cost for the Whole System (HK$)	310,180	310,180	0
Annual Re-installation Cost (HK$)	124,072	124,072	0
Internal Wiring Re-Assembly (HK$)	0	114,450	0
Annual Internal Wiring Re-Assembly Cost (HK$)	0	45,780	0
Annual Churn Cost (HK$)	***124,072***	***169,852***	***0***

With the adoption of a flexible lighting system, like DALI lighting management system, the churn cost can be completely eliminated and results in a significant decrease in the total operating cost. As discussed in Section 2.4, the importance of flexible working environments has been realised. A flexible lighting system not only supports a flexible working environment with lower churn cost but also causes less disruption to employees due to the rapid reconfiguration of lighting arrangements by software programming.

4.3.6 Energy Cost

Table 4.7 Energy Costs of Lighting Management Systems

System	Conventional Lighting System	C-Bus Lighting Management System	DALI Lighting Management System
Operating Hours per day	12	12	12
Operating Days per year	270	270	270
Operating Hours per year	3,240	3,240	3,240
Lamp Type	T8	T5	T5
Lamp Quantity per Fixture	3	2	2
Lamp Power (W)	36	28	28
Ballast Type	Electromagnetic	Dimmable Electronic	DALI Electronic
Ballast Quantity per Fixture	3	2	2
Ballast Power (W)	9	3	3
Total Fixture Power (kW)	0.135	0.062	0.062
Quantity of Fixtures	2217	2217	2217
Annual Energy Consumption (kWh)	969,716	445,351	445,351
Lamp Type	T8	T5	T5
Lamp Quantity per Fixture	3	2	2
Lamp Power (W)	18	14	14
Ballast Type	Electromagnetic	Dimmable Electronic	DALI Electronic
Ballast Quantity per Fixture	3	2	2
Ballast Power (W)	9	2	2
Total Fixture Power (kW)	0.081	0.032	0.032
Quantity of Fixtures	169	169	169
Annual Energy Consumption (kWh)	44,352	17,522	17,522
Total Annual Energy Consumption (kWh)	***1,014,068***	***462,873***	***462,873***

Energy Cost per kWh (HK$)	0.9	0.9	0.9
Annual Energy Cost (HK$)	***912,661***	***416,586***	***416,586***

Section 4.1 has experimentally verified that T5 fluorescent lamp and electronic ballast can reduce the energy consumption as opposed to T8 fluorescent lamp and electromagnetic ballast. And the calculation of the energy consumption of these lighting equipments is reasonable. When this calculation is applied to the lighting of the whole selected building, annual energy consumption and cost can be evaluated as shown in Table 4.7.

For both the C-Bus system and the DALI system, they are utilising energy efficient T5 fluorescent lamps and electronic ballasts instead of T8 fluorescent lamps and electromagnetic ballasts. The annual energy cost of the C-Bus or DALI system is less than a half of the annual energy cost of the conventional system.

5. Discussion

5.1 Comparisons of the Lighting Systems

In this section the results from chapter 4 are to be summarised in terms of cost, manageability and flexibility. Economics comparisons are set up for building owners and investors' interests and functional comparisons are developed for occupants and users' concerns while facility managers would benefit greatly from both.

5.1.1 Economic Comparisons

Table 5.1 Economic Comparisons of Lighting Systems

System	Conventional Lighting System	C-Bus Lighting Management System	DALI Lighting Management System
System Cost (HK$)	0	942,150	1,105,730
Luminaire Cost (HK$)	0	985,033	1,740,732
Installation Cost (HK$)	0	310,180	310,180
Capital Investment (HK$)	0	2,237,363	3,156,642
Annual O&M Cost (HK$)	432,000	432,000	0
Annual O&M Saving (HK$)	0	0	432,000
Annual Churn Cost (HK$)	124,072	169,852	0
Annual Churn Saving (HK$)	0	-45,780	124,072
Annual Energy Cost (HK$)	912,661	462,873	462,873
Annual Energy Saving (HK$)	0	449,788	449,788
Annual Cost Saving (HK$)	0	404,088	1,005,860
Simple Payback Period (yr)	***N/A***	***5.53***	***3.14***
Payback Period at 5% DR (yr)	***N/A***	***6.8***	***3.5***
Payback Period at 10% DR (yr)	***N/A***	***8.4***	***4.0***

Integrating the findings in Section 4.3, Table 5.1 is established to figure out the payback periods of the lighting management systems. Simple payback period is calculated by dividing capital investment by annual cost saving, which is compared with the existing conventional lighting system.

The simple payback periods of both proposed lighting management systems are acceptable. Although the C-Bus lighting management system requires a lower capital investment, it has a longer payback period. This is because the annual cost saving of the C-Bus system is much less than that of the DALI system. C-Bus system does not provide any savings on operations and maintenance cost and churn cost, and even results in an additional expenditure during a churn owing to the need of re-assembly of internal wiring during churn. As it still gives conspicuous saving on energy cost as compared with the conventional system, the overall saving on operating cost is desirable.

The curves of Figures 5.1, 5.2 and 5.3 demonstrate the net present value (NPV) of each system at 0%, 5% and 10% discount rates by means of discounted cash flow method so that the C-Bus and the DALI lighting management systems can be readily compared with the conventional lighting system to derive the payback periods in several circumstances. However, at the 10% discount rate, the payback period of the C-Bus system is more than twice of that of the DALI system.

Figure 5.1 Comparisons of Payback Periods at the 0% Discount Rate

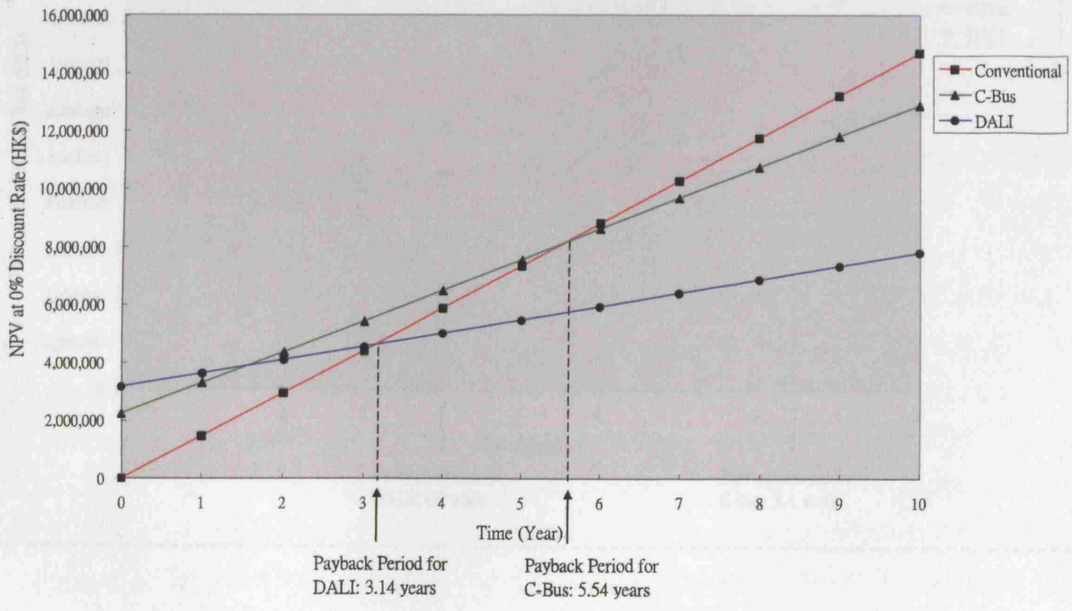


Figure 5.2 Comparisons of Payback Periods at the 5% Discount Rate

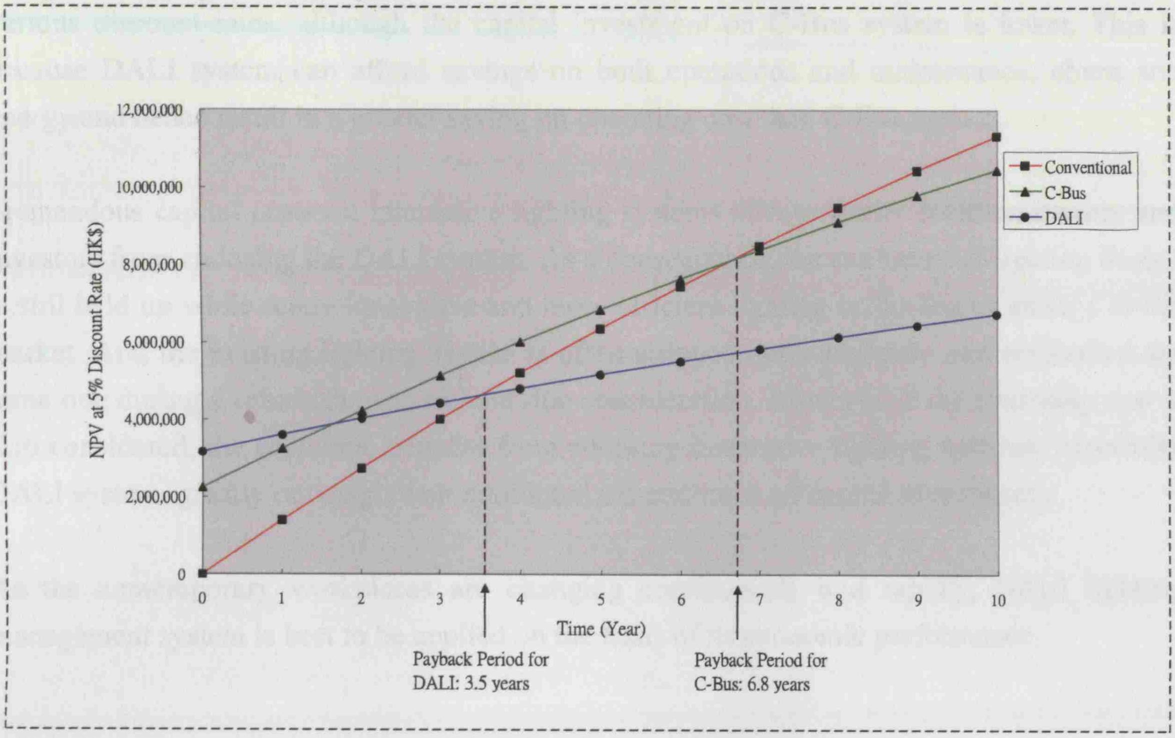
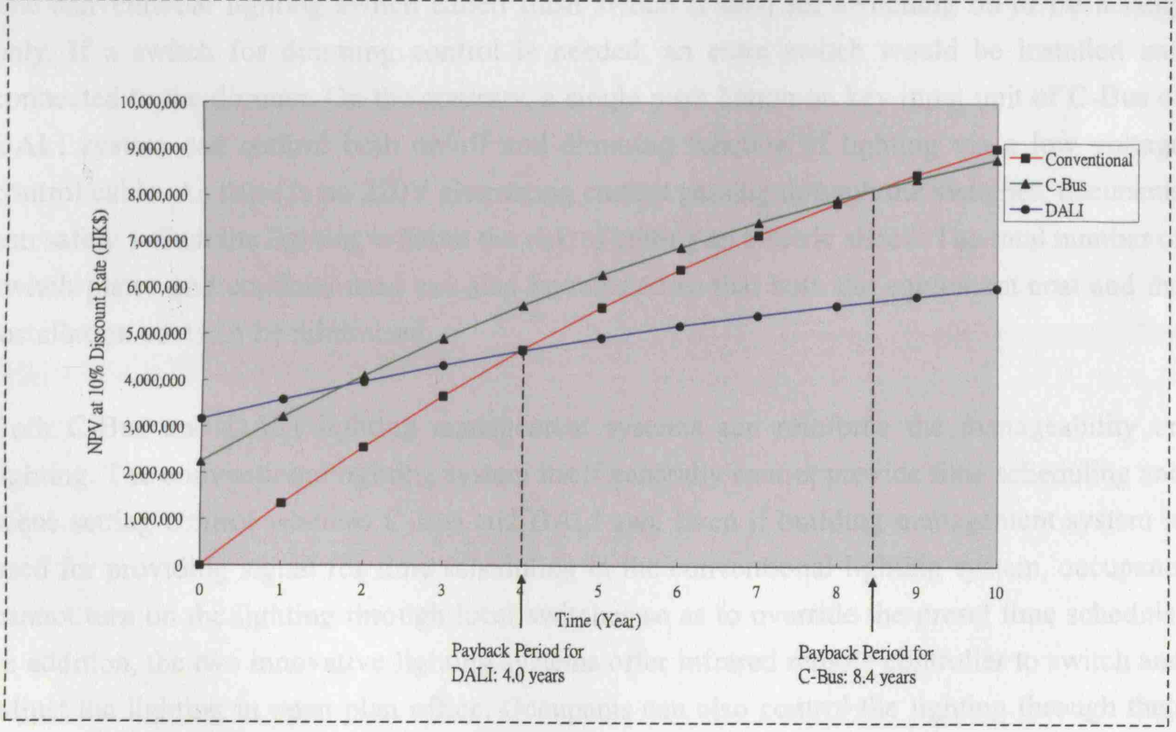


Figure 5.3 Comparisons of Payback Periods at the 10% Discount Rate



Obviously, DALI system is preferable to C-Bus system based upon their payback periods at various discount rates, although the capital investment on C-Bus system is lower. This is because DALI system can afford savings on both operations and maintenance, churn and energy and hence result in a greater saving on operating cost than C-Bus system.

Tremendous capital costs on innovative lighting systems always terrify building owners and investors from choosing the DALI system. As a consequence, the evolution of lighting design is still held up while many innovative and more efficient lighting technologies emerge in the market. And the existing lighting system is often stripped out completely and reinstalled the same one during a refurbishment without due consideration. However, if the operating cost is also considered, the economic benefits from adopting innovative lighting systems, especially DALI system, greatly outweigh their additional expenditures on capital investments.

As the contemporary workplaces are changing continuously and rapidly, DALI lighting management system is best to be applied on the basis of its economic performance.

5.1.2 Functional Comparisons

The conventional lighting switch called flush switch is used for switching on or off a lamp only. If a switch for dimming control is needed, an extra switch would be installed and connected to the dimmer. On the contrary, a single push button on key input unit of C-Bus or DALI system can control both on/off and dimming function of lighting via a low voltage control cable. As there is no 220V alternating current passing through the switches, occupants can safely switch the lighting without the risk of getting an electric shock. The total number of switch plates and conduits used can also be reduced so that both the equipment cost and the installation cost can be minimised.

Both C-Bus and DALI lighting management systems can reinforce the manageability on lighting. The conventional lighting system itself generally cannot provide time scheduling and scene setting control whereas C-Bus and DALI can. Even if building management system is used for providing signal for time scheduling in the conventional lighting system, occupants cannot turn on the lighting through local switches so as to override the preset time schedule. In addition, the two innovative lighting systems offer infrared remote controller to switch and adjust the lighting in open plan office. Occupants can also control the lighting through their personal computer in the DALI system. As a result, individual control in the innovative lighting systems is enhanced while DALI system has a higher capability for personal control. As described in Section 2.3, more personal control gives more perceived comfort for occupants and thereby assists the improvement of the lighting quality.

Other than individual control, C-Bus and DALI lighting management systems can also execute control and monitoring via central computer but the conventional lighting system cannot. For instance, facility managers can switch and dim the lighting, especially in open plan offices, through central computer on behalf of their occupant. can C-Bus can monitor the operational status for each and every lighting circuit while DALI can even monitor the operational status for each and every luminaire including lamp and ballast status, burning hours and energy consumption of each light zone. DALI system obviously provides more detailed information than C-Bus system so that facility managers could respond to any failure readily and prepare competent preventive maintenance schedules.

Additionally, DALI system can carry out automatic testing of emergency lighting, which the conventional and C-Bus systems cannot provide, through central computer in a specified period. This automatic testing is free of disturbance to occupants even if it is performed during office hours.

The frequency of workspace reconfiguration becomes higher and higher on the basis of the changing business needs. During a refurbishment, the entire lighting system is often stripped out and reinstalled the same one. With the adoption of DALI system, the reconfiguration of lighting arrangement is done by software reprogramming in place of wiring reinstallation and as a result no technician is needed to access the lighting fittings during reprogramming. Eventually, the reconfiguration of the lighting arrangement would be much less time-consuming as opposed to the conventional and C-bus systems. DALI system affords the most flexible solution for frequent changing space utilisation.

As an additional pair of control cable is required for transmitting the signal and programming, the wiring work of the innovative lighting systems is inevitably more complex. However, the wiring of C-Bus system is more complex than that of DALI system. This is because C-Bus system needs internal wiring work inside the panel. On the other hand, as the lighting can be grouped or zoned by software programming, the wiring installation of DALI system can disregard the lighting circuitry design. In other words, technicians can install the wiring in a most convenient manner for them.

Table 5.2 summarises the functional comparisons of the three lighting systems.

DALI lighting management system possesses higher degree of flexibility and manageability as opposed to other two systems. In addition to the economic considerations, DALI system is functionally best to be applied in the contemporary workplaces.

Table 5.2 Functional Comparisons of Lighting Systems

System	Conventional Lighting System	C-Bus Lighting Management System	DALI Lighting Management System
Type of Switch	Flush Switch	Key Input Unit	Key Input Unit
Dimming Control	Analogue	Analogue	Digital
Time Scheduling	No	Yes	Yes
Scene Setting	No	Yes	Yes
Wiring Complexity	Low	High	Medium
Flexibility for Changing Space Utilisation	Low	Low	High
Individual Control	Low	Medium	High
Central Control and Monitoring	Nil	Medium	High
Emergency Lighting Testing and Monitoring	No	No	Yes

5.2 Design and Management of Lighting

In reality, few designs offer strategic flexibility to the client in support their business, or operational flexibility to the facility management team (Nutt and McLennan 2000). Therefore, the contemporary lighting design is needed to improve the responsiveness of lighting to accommodate unremitting change. The emerging DALI lighting management system is a tool to improve the manageability and flexibility of lighting, and is thereby highly recommended to implement in the modern workplace for the better management of lighting.

DALI system affords operational flexibility of lighting to the facility management team as it increases the capability of lighting to respond to changing operational requirements without physical change. Managing the lighting system to meet the needs of building users, facility managers have to recognise the changing operational needs of an organisation over time and continuously customise a competent lighting arrangement. Once a change of lighting arrangement is identified, facility manager should inform the relevant technicians to reconfigure the lighting arrangement by means of reprogramming in order to cater for the needs of building users promptly at any time.

In addition, the facility management team can improve the adaptation of lighting in line with space by using DALI system if a property has been designed for adaptation. In case space needs to be subdivided into a number of zones to serve with various organisations and uses, DALI system can adapt to this change and provide adequate control and information, such as energy consumption, of lighting for each zone. As a result, DALI system not only improves manageability and flexibility of the lighting but also has a long-term viability, utility and value in the varying built environment.

The better management of lighting can enable an improvement in lighting quality as well. Lighting quality not only includes energy issue but also contains architectural, operational and maintenance, health and safety, comfort issues etc. As there are a multitude of factors that affect the lighting quality, facility managers, who have a sound management experience and knowledge, should participate in the briefing and design stages so as to establish a strategic lighting regime for the workplace.

Facility managers involving in the briefing stage can monitor and anticipate both current and future needs of users and stress the importance of a generic approach to lighting system, and as such the operational issues can become a primary concern of design. Then facility managers can search for innovative and strategic design options and choice, such as C-Bus and DALI lighting management system, in the design stage for clients' consideration. Further, facility managers have to evaluate how these new options and choice can functionally and financially benefit to building owners, investors, occupants and facility managers themselves at each stage of design decision.

5.3 Speculation for the Future

The strategic approach of facility management is directed to the management of uncertainty over time (Nutt and McLennan 2000). Hence, on one hand, a strategic approach should reduce constraints of the existing lighting system that impose on current building owners, investors and occupants, such as energy saving, personal control and central control and monitoring, in the short term future. On the other hand, it should generate and evaluate new opportunities to improve flexibility and responsiveness of the lighting system and achieve the lighting quality over the medium and longer term.

To reduce constraints and open up opportunities, facility managers should inform the stringency of manageability and flexibility to the design process and meanwhile ensure that the clients and investors recognise this essentiality. This is because the short term benefit from energy saving can be easily justified in monetary term while the long term benefits from enhanced manageability and flexibility which can contribute to individual well-being, productivity and economics is more difficult to be justified.

As the conventional lighting system is inherently inflexible, it is hard to improve its capabilities and free its limitations. It is recommended that a radical change on the existing lighting system is needed so as to reduce constraints and increase opportunities over the short and long term. The findings of this dissertation render that DALI lighting management system is the best choice in the current market. It provides a whole universe of control possibilities to improve the manageability and a programming tool to strengthen the flexibility.

Facility managers should keep on searching for any new options of lighting systems. For instance, wireless signal transmission might replace low voltage control cable in the DALI system so that the expenditure on installing wiring within the ceiling of an existing building can be eliminated and the space within the ceiling would not inhibit the adoption of DALI system due to its additional low voltage wiring.

With the lighting system of this kind, lighting system is not only a facility service to an organisation but also a valuable asset within a property. This is because the lighting system is no longer needed to be stripped out completely after property disposal in order to install a new one to cater for the next organisation and its employees.

6. Conclusion

For a long period of time, building owners and investors placed too much emphasis on cost cutting or keeping the budget as low as possible in a project. Within the context of facility management, both capital investment and operating cost of a facility should be considered together in the life cycle.

The dissertation has shown three lighting system models ranging from simple conventional lighting system to sophisticated DALI lighting management system. These systems has been compared and contrasted in terms of physical, functional and financial performances. In fact, the findings revealed that C-Bus and DALI systems with higher capital costs would not consequentially result in high operating costs and high life cycle costs. Inversely, the economic advantage of C-Bus and DALI systems will gradually arise within 3 - 6 years. It was also found that the financial performance of DALI system is much better than that of C-Bus system.

To facilitate the lighting quality, the functional performances of innovative systems are imperative other than the financial performances. A lighting system with versatile control can directly provide more personal control for occupants and the central monitoring, testing and control for facility managers, as well as indirectly improve the individual comfort and well-being and the manageability of the lighting system.

Flexibility is another important issue that a modern lighting system should provide. Any facility that is designed for the 'first-hand' users only but not to meet the diversity of client requirements is no longer suitable for the changing workplace needs. As a consequence, a generic approach should be used to design a strategic lighting system so that it can respond to changing operational requirements promptly.

To ensure building owners and investors could make a better decision to choose a lighting system, facility managers should inform the importance of manageability and flexibility on the lighting system and how it impacts on the workplace and the users during the design process. Moreover, a superior lighting system can reduce constraints and increase opportunities to an organisation and its employees over the short and long terms.

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Appendices

Discount Rate: 0%

Conventional Lighting System:

	Year	0	1	2	3	4	5	6	7	8	9	10
Capital Expenditure												
Investment Outlay of System	HK$	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Investment Outlay of Luminaire	HK$	0	0	0	0	0	0	0	0	0	0	0
Investment Outlay of Installation	HK$	0	0	0	0	0	0	0	0	0	0	0
Net Expenditure	HK$	0	0	0	0	0	0	0	0	0	0	0
Incremental cashflow												
Annual O&M Cost	HK$	0	432,000	432,000	432,000	432,000	432,000	432,000	432,000	432,000	432,000	432,000
Annual Churn Cost	HK$	0	124,072	124,072	124,072	124,072	124,072	124,072	124,072	124,072	124,072	124,072
Annual Energy Cost	HK$	0	912,661	912,661	912,661	912,661	912,661	912,661	912,661	912,661	912,661	912,661
Net Cashflow per annum	HK$	0	1,468,733	1,468,733	1,468,733	1,468,733	1,468,733	1,468,733	1,468,733	1,468,733	1,468,733	1,468,733
Cummulative Cashflow with 5% Discount Rate	HK$	0	1,468,733	2,937,466	4,406,199	5,874,932	7,343,665	8,812,398	10,281,131	11,749,864	13,218,597	14,687,330

C-Bus Lighting Management System:

	Year	0	1	2	3	4	5	6	7	8	9	10
Capital Expenditure												
Investment Outlay of System	HK$	942,150	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Investment Outlay of Luminaire	HK$	985,033	0	0	0	0	0	0	0	0	0	0
Investment Outlay of Installation	HK$	310,180	0	0	0	0	0	0	0	0	0	0
Net Expenditure	HK$	2,237,363	0	0	0	0	0	0	0	0	0	0
Incremental cashflow												
Annual O&M Cost	HK$	0	432,000	432,000	432,000	432,000	432,000	432,000	432,000	432,000	432,000	432,000
Annual Churn Cost	HK$	0	169,852	169,852	169,852	169,852	169,852	169,852	169,852	169,852	169,852	169,852
Annual Energy Cost	HK$	0	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873
Net Cashflow per annum	HK$	0	1,064,725	1,064,725	1,064,725	1,064,725	1,064,725	1,064,725	1,064,725	1,064,725	1,064,725	1,064,725
Cummulative Cashflow with 5% Discount Rate	HK$	2,237,363	3,302,088	4,366,813	5,431,538	6,496,263	7,560,988	8,625,713	9,690,438	10,755,163	11,819,888	12,884,613

DALI Lighting Management System:

	Year	0	1	2	3	4	5	6	7	8	9	10
Capital Expenditure												
Investment Outlay of System	HK$	1,105,730	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Investment Outlay of Luminaire	HK$	1,740,732	0	0	0	0	0	0	0	0	0	0
Investment Outlay of Installation	HK$	310,180	0	0	0	0	0	0	0	0	0	0
Net Expenditure	HK$	3,156,642	0	0	0	0	0	0	0	0	0	0
Incremental cashflow												
Annual O&M Cost	HK$	0	0	0	0	0	0	0	0	0	0	0
Annual Churn Cost	HK$	0	0	0	0	0	0	0	0	0	0	0
Annual Energy Cost	HK$	0	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873
Net Cashflow per annum	HK$	0	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873
Cummulative Cashflow with 5% Discount Rate	HK$	3,156,642	3,619,515	4,082,388	4,545,261	5,008,134	5,471,007	5,933,880	6,396,753	6,859,626	7,322,499	7,785,372

A.1 Financial Performance of Lighting Systems at the 0% Discount Rate

Discount Rate: 5%

Conventional Lighting System:

	Year	0	1	2	3	4	5	6	7	8	9	10
Capital Expenditure												
Investment Outlay of System	HK$	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Investment Outlay of Luminaire	HK$	0	0	0	0	0	0	0	0	0	0	0
Investment Outlay of Installation	HK$	0	0	0	0	0	0	0	0	0	0	0
Net Expenditure	HK$	0	0	0	0	0	0	0	0	0	0	0
Incremental cashflow												
Annual O&M Cost	HK$	0	432,000	432,000	432,000	432,000	432,000	432,000	432,000	432,000	432,000	432,000
Annual Churn Cost	HK$	0	124,072	124,072	124,072	124,072	124,072	124,072	124,072	124,072	124,072	124,072
Annual Energy Cost	HK$	0	912,661	912,661	912,661	912,661	912,661	912,661	912,661	912,661	912,661	912,661
Net Cashflow per annum	HK$	0	1,468,733	1,468,733	1,468,733	1,468,733	1,468,733	1,468,733	1,468,733	1,468,733	1,468,733	1,468,733
Cummulative Cashflow with 5% Discount Rate	HK$	0	1,398,793	2,730,977	3,999,724	5,208,056	6,358,845	7,454,838	8,498,638	9,492,734	10,439,492	11,341,167

C-Bus Lighting Management System:

	Year	0	1	2	3	4	5	6	7	8	9	10
Capital Expenditure												
Investment Outlay of System	HK$	942,150	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Investment Outlay of Luminaire	HK$	985,033	0	0	0	0	0	0	0	0	0	0
Investment Outlay of Installation	HK$	310,180	0	0	0	0	0	0	0	0	0	0
Net Expenditure	HK$	2,237,363	0	0	0	0	0	0	0	0	0	0
Incremental cashflow												
Annual O&M Cost	HK$	0	432,000	432,000	432,000	432,000	432,000	432,000	432,000	432,000	432,000	432,000
Annual Churn Cost	HK$	0	169,852	169,852	169,852	169,852	169,852	169,852	169,852	169,852	169,852	169,852
Annual Energy Cost	HK$	0	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873
Net Cashflow per annum	HK$	0	1,084,725	1,084,725	1,084,725	1,084,725	1,084,725	1,084,725	1,084,725	1,084,725	1,084,725	1,084,725
Cummulative Cashflow with 5% Discount Rate	HK$	2,237,363	3,251,387	4,217,124	5,136,873	6,012,825	6,847,065	7,641,579	8,398,259	9,118,907	9,805,238	10,456,867

DALI Lighting Management System:

	Year	0	1	2	3	4	5	6	7	8	9	10
Capital Expenditure												
Investment Outlay of System	HK$	1,105,730	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Investment Outlay of Luminaire	HK$	1,740,732	0	0	0	0	0	0	0	0	0	0
Investment Outlay of Installation	HK$	310,180	0	0	0	0	0	0	0	0	0	0
Net Expenditure	HK$	3,156,642	0	0	0	0	0	0	0	0	0	0
Incremental cashflow												
Annual O&M Cost	HK$	0	0	0	0	0	0	0	0	0	0	0
Annual Churn Cost	HK$	0	0	0	0	0	0	0	0	0	0	0
Annual Energy Cost	HK$	0	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873
Net Cashflow per annum	HK$	0	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873
Cummulative Cashflow with 5% Discount Rate	HK$	3,156,642	3,597,473	4,017,313	4,417,160	4,797,967	5,160,640	5,506,043	5,834,996	6,148,289	6,446,661	6,730,825

A.2 Financial Performance of Lighting Systems at the 5% Discount Rate

Discount Rate: 10%

Conventional Lighting System:

	Year	0	1	2	3	4	5	6	7	8	9	10
Capital Expenditure												
Investment Outlay of System	HK$	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Investment Outlay of Luminaire	HK$	0	0	0	0	0	0	0	0	0	0	0
Investment Outlay of Installation	HK$	0	0	0	0	0	0	0	0	0	0	0
Net Expenditure	HK$	0	0	0	0	0	0	0	0	0	0	0
Incremental cashflow												
Annual O&M Cost	HK$	0	432,000	432,000	432,000	432,000	432,000	432,000	432,000	432,000	432,000	432,000
Annual Churn Cost	HK$	0	124,072	124,072	124,072	124,072	124,072	124,072	124,072	124,072	124,072	124,072
Annual Energy Cost	HK$	0	912,661	912,661	912,661	912,661	912,661	912,661	912,661	912,661	912,661	912,661
Net Cashflow per annum	HK$	0	1,468,733	1,468,733	1,468,733	1,468,733	1,468,733	1,468,733	1,468,733	1,468,733	1,468,733	1,468,733
Cummulative Cashflow with 5% Discount Rate	HK$	0	1,335,212	2,549,041	3,652,522	4,655,686	5,567,654	6,396,716	7,150,407	7,835,582	8,458,468	9,024,728

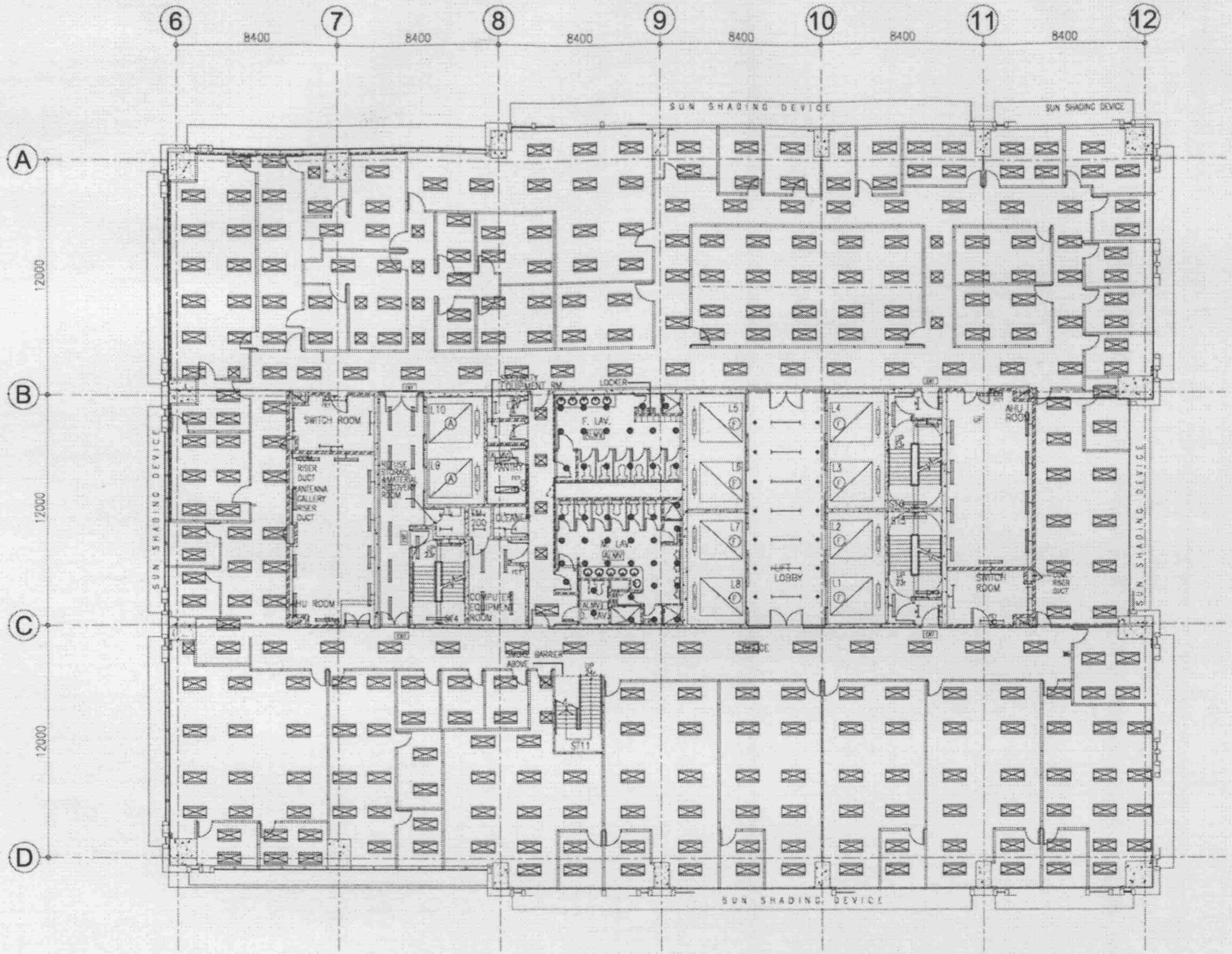
C-Bus Lighting Management System:

	Year	0	1	2	3	4	5	6	7	8	9	10
Capital Expenditure												
Investment Outlay of System	HK$	942,150	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Investment Outlay of Luminaire	HK$	985,033	0	0	0	0	0	0	0	0	0	0
Investment Outlay of Installation	HK$	310,180	0	0	0	0	0	0	0	0	0	0
Net Expenditure	HK$	2,237,363	0	0	0	0	0	0	0	0	0	0
Incremental cashflow												
Annual O&M Cost	HK$	0	432,000	432,000	432,000	432,000	432,000	432,000	432,000	432,000	432,000	432,000
Annual Churn Cost	HK$	0	169,852	169,852	169,852	169,852	169,852	169,852	169,852	169,852	169,852	169,852
Annual Energy Cost	HK$	0	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873
Net Cashflow per annum	HK$	0	1,064,725	1,064,725	1,064,725	1,064,725	1,064,725	1,064,725	1,064,725	1,064,725	1,064,725	1,064,725
Cummulative Cashflow with 5% Discount Rate	HK$	2,237,363	3,205,295	4,085,233	4,885,176	5,612,396	6,273,506	6,874,518	7,420,890	7,917,592	8,369,140	8,779,637

DALI Lighting Management System:

	Year	0	1	2	3	4	5	6	7	8	9	10
Capital Expenditure												
Investment Outlay of System	HK$	1,105,730	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Investment Outlay of Luminaire	HK$	1,740,732	0	0	0	0	0	0	0	0	0	0
Investment Outlay of Installation	HK$	310,180	0	0	0	0	0	0	0	0	0	0
Net Expenditure	HK$	3,156,642	0	0	0	0	0	0	0	0	0	0
Incremental cashflow												
Annual O&M Cost	HK$	0	0	0	0	0	0	0	0	0	0	0
Annual Churn Cost	HK$	0	0	0	0	0	0	0	0	0	0	0
Annual Energy Cost	HK$	0	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873
Net Cashflow per annum	HK$	0	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873	462,873
Cummulative Cashflow with 5% Discount Rate	HK$	3,156,642	3,577,436	3,959,975	4,307,739	4,623,887	4,911,295	5,172,575	5,410,102	5,626,035	5,822,339	6,000,796

A.3 Financial Performance of Lighting Systems at the 10% Discount Rate



B.1 Layout Diagram of Typical Floor